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Supporting the Teacher Identity of Pre-Service Science Teachers through Working at a Non-Formal STEM Learning Laboratory

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Abstract: This qualitative case study aims to examine the role of a non-formal STEM (science, technology, engineering, and mathematics) learning laboratory in supporting the development of teacher identity among pre-service science teachers. With teacher identity impacting the educational responsiveness and resilience of a teacher, it is important to support the professional identity of STEM educators if we are to enhance the quality of STEM education. Data collection occurred in three stages between 2017 and 2024. Qualitative content analysis through an inductive category formation was used for data analysis. The intercoder reliability was checked (Cohen's kappa 0.802). Results suggest that non-formal STEM learning environments can enhance pre-service teachers' professional learning and identity by allowing the autonomous practical application of theory in an authentic collaborative laboratory environment and by strengthening their self-efficacy through positive teaching experiences. Participants reported that such versatile experiences are generally not available during their formal university education. This study offers suggestions for STEM teacher education and insights into ongoing research dialogues about the role of non-formal learning in supporting the learning and identity of STEM teachers.

Keywords: continuous professional development; non-formal learning; pre-service science teachers; STEM; teacher identity

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1. Introduction

This research aims to examine the role of a non-formal STEM (science, technology, engineering, and mathematics) learning laboratory in supporting the development of teacher identity among pre-service science teachers working as instructors in the environment. Amidst a global emphasis on STEM education, it is increasingly important to strengthen the professional identity of STEM educators. Teacher identity—constituted by educational beliefs, attitudes, and behavior that define an individual as a teacher—is the foundation on which teachers' classroom decisions and actions reside [1–3]. Furthermore, teachers' perceptions of their own teacher identity influence their responsiveness to educational innovations such as STEM education and their resilience against pedagogical challenges [4–6].

Providing pre-service teachers with practical teaching opportunities is essential for developing their teacher identity. Several theoretical frameworks and pedagogic approaches that regard learning as a social and constructive process support incorporating practicums or internships into teacher education programs, as they offer authentic experiences and place pre-service teachers within professional communities. For instance, situated learning theory [7] emphasizes that individuals gain expertise and form identities as they actively engage in the sociocultural practices of a community [7–9]. Similarly, work-integrated learning, which involves students, educational institutions, and external partners, provides versatile, authentic experiences that integrate theory and practice within the curriculum [10]. This can enhance career readiness, transferable skills, resilience, and self-efficacy among pre-service teachers [11,12]. However, teacher identity is dynamic and multidimensional

and can vary depending on the educational moment and context [1,4,8]. Consequently, a teacher might perceive themselves differently when teaching chemistry compared to teaching STEM education. The research on teacher identity formation within the context of STEM education remains inconclusive [8]. Moreover, practicums are typically organized in formal school settings. This study focuses on supporting teacher identity in non-formal STEM learning environments.

Non-formal learning environments, which exist outside the traditional school context yet maintain an organized and goal-directed structure, offer a distinctive intersection of formal rigidity and informal freedom [13,14]. This unique position makes them potential settings for providing diverse opportunities for gaining teaching experiences and professional learning that influence teacher identity [1,3,15]. In addition, non-formal STEM learning laboratories are apt for modeling interdisciplinary learning, inquiry, design, and problem-solving—practices central to STEM education [16–19]. They offer teacher education a potential solution to fix the reported gap between science teacher education programs and STEM requirements [6,20].

Previous studies on non-formal learning environments have shown that positive experiences in these authentic environments can promote professional learning, self-reflection, and teacher identity exploration [15,21,22]. Regardless, research has not indicated a comprehensive understanding of the possibilities of non-formal learning environments for science and STEM teachers' professional learning or the development of STEM teacher identity, especially for long-term non-formal activities. Our research not only contributes to this research discussion but also aims to provide valuable insights for STEM teacher educators.

This case study utilized qualitative content analysis to examine data gathered from online questionnaires and interviews with pre-service science teachers and chemistry students working as instructors at a non-formal STEM learning laboratory. This study aims to understand how working in such environments can shape the STEM teacher identity of pre-service teachers. Data collection occurred between 2017 and 2024 at the Chemistry Lab Gadolin located at the University of Helsinki's Department of Chemistry.

2. Theoretical Framework

2.1. Teacher Identity in STEM Education

A teacher's professional identity is a complex, dynamic, and overarching concept, which consists of sub-identities that define the individual as a teacher [1]. It encompasses a range of educational beliefs, attitudes, and values and a sense of agency and self-awareness [1–3,8], and is evolving in an ongoing process where educational contexts, personal conceptions and behavior, and relationships within the professional community interact and influence each other [1–3].

Teacher identity includes teachers' self-efficacy—teachers' beliefs in their capabilities in given educational situations [23,24]—and is intertwined with their personal pedagogical content knowledge (pPCK): their unique understanding of teaching, informed by beliefs, prior teaching experiences, educational background, and interactions in the professional community [25]. Self-efficacy beliefs are context-specific judgments [23]. Consequently, they may vary across different teaching situations. Although more research is needed to fully understand STEM teachers' self-efficacy, previous studies provide some insights. Prior experiences, along with vicarious experiences, verbal persuasion, and emotional and physiological states, are key sources of self-efficacy [23]. Haatainen et al. [5] highlighted self-efficacy as a key factor explaining science teachers' perceptions of and their lack of confidence in implementing interdisciplinary science education, as well as their need for support. However, teachers lack experience and training with integrated approaches such as STEM or STEAM [26,27] and could, therefore, have lower self-efficacy beliefs in STEM education. We know that teachers with lower efficacy tend to adopt a custodial orientation, viewing student motivation pessimistically and relying on strict regulations and extrinsic inducements to control classroom behavior [23,28]. Therefore, offering pre-service teachers diverse training opportunities to carry out interdisciplinary STEM education can positively

affect their self-efficacy in STEM education. This can influence teachers' willingness to engage and implement STEM education in future [5,17,26].

Beside the personal, teacher identity is influenced by socially and culturally prescribed professional characteristics, educational contexts, and attitudes [1,8]. STEM education, as stated in many educational policies and curricula, requires teachers to have multidisciplinary knowledge across the STEM disciplines and new context- and inquiry-based pedagogical practices, which help facilitate student-centered, collaborative, and integrated STEM learning experiences with their pupils [6,16,29]. While there are growing numbers of STEM-focused schools opening, science and mathematics education are still disciplinary-based, and it is the subject teachers who often are responsible for STEM education. When learning these STEM education attributes and engaging in a new and different educational experience, subject teachers start to develop new identities, STEM teacher identities [6]. The educational change can cause experienced teachers to feel conflicted about their professional identity, similarly to what pre-service teacher students can experience when constructing their teacher identities during teacher education [1]. Therefore, it is important to support teachers in this learning process, as it can affect teachers' willingness to engage in STEM education [4–6]. Despite the progress made, there is still a significant need for further research on science teachers' professional identity associated with recent reforms, including STEM education [8].

2.2. Supporting Pre-Service Teachers' Teacher Identity in Non-Formal STEM Learning Environment

Learning environments define how and where learning takes place. These environments can be categorized into three types, formal, non-formal, and informal, each possessing distinctive attributes related to learning and influenced by factors such as physical location, motivation, interest, social context, and assessment [13,30]. Formal learning typically occurs within an educational institution, such as a school, where learning is teacher-led, follows a strict curriculum, and is subject to evaluation [13,14]. Informal learning, on the other hand, applies to situations in everyday life that come about spontaneously [13], for example, while watching social media or conversing with family. Non-formal learning is situated between formal and informal, occurring in a planned but highly adaptable manner, in various environments and situations [13,30,31]. Examples include museums, science centers, and field trips to the Chemistry Lab Gadolin. Despite existing outside the traditional school context, non-formal learning environments maintain an organized and goal-directed structure. Learning in these environments is structured and often led or supported by a teacher or an authority figure [13,14,31–33].

The benefits of non-formal learning environments for school students have been widely studied [34–36], and, in many countries, these environments have emerged to provide additional value to formal science education [14,35]. As teachers create opportunities for their students to engage in non-formal learning environments, they themselves are also exposed to learning opportunities within these environments. A recent study by Martín-García and Dies Álvarez [15] highlights how in-service teachers gain spontaneous learning experiences through participation in long-term non-formal science activities and how these experiences contributed to teachers' preparedness to teach science and enhanced their professional knowledge across various domains. Similarly, in a STEM education context, Aslam et al. [22] delved into teachers' perspectives on out-of-school STEM activities, focusing on, among other things, the impact of STEM engagement on their professional development. Findings indicated that participation in STEM outreach activities contributes to teachers' sense of identity as STEM professionals by facilitating interactions with leading scientists and exposure to cutting-edge research [22].

Similarly, working in non-formal STEM learning environments, such as the Chemistry Lab Gadolin, can present pre-service teachers with unique opportunities to hone their skills, develop their pPCK, and reinforce their STEM teacher identity. In a study conducted by Tang et al. [37], non-formal learning within higher education significantly influenced the

professional competence of pre-service teachers. By participating in practical experiences, engaging in professional dialogues with practitioners, and observing teaching methods, pre-service teachers acquire a profound grasp of pedagogical content, general teaching principles, and contextual factors [37]. For pre-service teachers, the work as a Gadolin instructor can be defined as work-integrated learning that can support teacher-identity-related aspects such as self-efficacy [11,12] Similarly, it fits the co-teaching model described by Dubek and Doyle-Jones [38] that suggests co-teaching—including collaboration in planning, instructing, and reflecting—in teacher education programs as a more effective alternative to traditional teacher practicum models. Research has indicated similar collaborative teacher education and professional development programs with a focus on STEM knowledge and interdisciplinary teaching approaches can be effective [20,22,26].

Non-formal learning can be organized in various manners and environments. Even though some research has been conducted on the benefits of these experiences for pre- and in-service teachers, there are still gaps in the literature [39]. Research has not conclusively shown how non-formal STEM learning laboratories can support pre- and in-service teachers' professional learning or STEM teacher identity.

3. Methodology

This qualitative case study focuses on pre-service science teachers and chemistry students working as instructors at the Chemistry Lab Gadolin situated in the University of Helsinki's Department of Chemistry. The overarching aim is to explore the possibilities of non-formal learning environments in supporting the development of teacher identity through the following research questions:

1. How does working as an instructor in a non-formal learning laboratory support pre-service science teachers' professional identity?
2. How does working as an instructor in a non-formal learning laboratory support professional learning?
3. What recurring elements of work are perceived as professionally relevant by the students working as instructors in a non-formal learning environment?

The focus is on students' perceptions, as a teacher's professional identity is essentially an individual perception, a sense of self that defines him or her as a teacher. A case study is a suitable method for qualitative educational research with a small amount of participants, when focusing on an authentic environment and seeking to understand the perception of individual actors [40]. Furthermore, the choice of a case study is justified when understanding the context is essential for the issue being studied [41], as is the case in this study.

3.1. Research Context

The Chemistry Lab Gadolin is a non-formal, free-of-charge LUMA learning laboratory that serves diverse learning communities, from pre-schools to secondary and vocational schools. LUMA, originally an abbreviation from the Finnish words for natural sciences and mathematics, now encompasses technology and an interdisciplinary approach to these fields, aligning with the STEM concept. The Chemistry Lab Gadolin specializes in chemistry education, which is enlivened through interdisciplinary themes such as sustainability and energy, connecting learning to everyday experiences, societal questions, vocational issues, and modern technology. The main form of activity is a hands-on study visit. Annually, approximately 200 study visits are organized, engaging around 4000 children and youths, and over 400 teachers. Having operated for 15 years, the Chemistry Lab Gadolin stands as the oldest LUMA (STEM) learning environment within the LUMA Centre Finland—a science education network of Finnish universities aiming at inspiring children and youths to get involved with and study STEM fields. The Chemistry Lab Gadolin employs a full-time coordinator to manage daily activities and about ten part-time instructors. It is a part of the Faculty of Science's outreach program, chemistry teacher education, and science education research, facilitating collaboration with learning communities, teacher

educators, and researchers. In Finland, teacher education is a master's degree program that is traditionally comprised of subject matter studies and one-year pedagogical studies that include a practicum in schools [42]. The collaborative work-integrated model described in this study is not a common practice in Finnish teacher education.

The position of a Gadolin instructor is a part-time, short-term job held by university students majoring in either chemistry or chemistry education. The students work alongside their university studies. The work does not start immediately at the beginning of the studies, and, towards the end of their studies, students start applying for teaching positions in schools. Therefore, the career length of a Gadolin instructor on average is a couple of years. In contrast to working as an assistant in a university laboratory course, Gadolin instructors lead laboratory work for children and youths instead of peers, which entails a more diverse range of responsibilities. Instructors at the Chemistry Lab Gadolin are tasked with a range of duties that extend beyond leading study visits. These responsibilities include planning educational sessions, guiding visitors, creating learning materials, liaising with visiting educators, and upholding laboratory standards through cleaning, maintaining equipment, and managing waste. Instructors at Gadolin also contribute to the development of new experimental tasks, working in teams to foster an atmosphere of peer support and collective innovation.

In preparation for their instructional roles, new instructors receive extensive training that covers laboratory practices, safety protocols, and the pedagogical approaches employed by Gadolin. To acquire practical experience, they are mandated to observe a minimum of three study visits conducted by experienced instructors and to engage in reflective learning processes. Furthermore, prior to independently facilitating any experiment included in study visits, an instructor must test the experimental work, particularly for sessions they are leading for the first time, with peer collaboration being a recommended practice.

3.2. Data Collection

The qualitative data were collected through online questionnaires conducted in three different timeframes between 2017 and 2024, with over two years between data collection rounds to minimize the possibility of having same student instructors participating twice. Participation was voluntary and designed to maintain anonymity; hence, demographic-related questions were excluded. In total, 21 student instructors participated in this study. The participants per data collection round can be seen in Table 1.

Table 1. Data collection: methods and participants per data collection round and the related research questions (RQ).

Data	Participants	Data Collection Method	RQ
1 (2017)	9	Questionnaire with open-ended questions	1–3
2 (2021)	5	Questionnaire with open-ended questions	1, 2
3 (2024)	7	Questionnaire with open-ended questions	1–3
4 (2024)	3 [1]	Semi-constructed interviews	1–3

Note: [1] Three out of the seven participants of Data 3.

The questionnaires were distributed via email to all student instructors working at the Chemistry Lab Gadolin at the time of data collection and included open-ended questions focusing on what pre-service teachers had learned while working as an instructor and how Gadolin could support their learning better. In the third data collection round, permission for a follow-up interview was asked, and three out of seven participants (Data 3) gave their permission. The aim of the interviews (Data 4) was to dig deeper into the work of an instructor and what elements of work pre-service teachers perceive as most supportive or beneficial for their future profession and for their teacher identity.

3.3. Data Analysis

Qualitative content analysis was used for analysis of the data. The procedure followed an inductive category formation [43] in which two researchers augmented the categories while working through the data. Clear semantic elements that answered the research questions were coded. The coded units could be single words, for example, for word-list types of answers in questionnaires or larger text fragments such as sentences or paragraphs. Coding examples are shared in Table 2. The intra- and intercoder reliability was checked during the collaborative category forming process. The category system was revised until a coder agreement of over 95% was achieved.

Table 2. Coding examples.

Example	Source	Text Passage	Coding	Category
1	Questionnaire: What have you learned through your work at Gadolin?	Calmness, organization, time management, and pedagogical skills. [ID3-06]	"calmness, organization and time management" refers to more general occupational skills and personal qualities	Job skills
			"pedagogical skills"	Pedagogical expertise
2	Questionnaire: What have you learned through your work at Gadolin?	Fed my own creativity to further develop work instructions and create new inspiring learning materials; at work, subject boundaries are crossed and students are encouraged to create links between the things they learn. [ID1-02]	Highlights transfer of knowledge, interdisciplinarity and creativity that refer to abilities enabling richer and more versatile teaching.	Versatility in education
3	Interview: Describe your work in detail.	Well, when a feasible experiment has been obtained, it is not enough, then the [learning] materials are created around it. That is, some pre-material that can be done by the visiting students and teachers in school, and some post-material for teachers, if they so wish, they can continue with the topic in the school. If you can find a scientific text that is reasonably understandable, it could be quite nice especially for high school students. [ID3-02]	A step-by-step description of designing a new hand-on experiment for a study visit. It is not linked to teacher identity by the participant, nor does it highlight what the participant has learned.	not coded

Finally, 50% of the material with the category system was given to a third coder to check the intercoder reliability with Cohen's kappa. The coder agreements was discussed, and, thereafter, the value of kappa was 0.802, indicating over 90% coder accuracy with six categories [44].

4. Results and Discussion

The results are presented here along with discussion. First, the results relating to RQ1 and RQ2 and then RQ3.

4.1. Supporting Professional Learning and the Development of Teacher Identity (RQ1 and RQ2)

Students' perceptions on how working as an instructor supports their teacher identity and professional learning are presented in Table 3, with frequencies per category occurrence within the material. The two categories that stood out and were mentioned in some form by all students were Pedagogical expertise and Scientific knowledge and practices. This is not

surprising, as the focus here is pre-service teachers' professional learning and their teacher identity, and the work is situated in a STEM learning laboratory focused on chemistry. However, this does not make the results arbitrary, and a closer look at students' perceptions reveals a richer picture of the various skills and knowledge learned and the effect of the learning and working experiences on their teacher identity.

Table 3. Perceptions on how working as a Gadolin instructor supports teacher identity and professional learning. Categories, frequencies per case, and examples.

Category	Freq.	Freq. (%)	Examples
Pedagogical expertise	44	28.2	"it [Gadolin] has enabled the growth of one's own pedagogical abilities and at the same time given the opportunity to guide different groups and plan the visits" [ID2-04] "I have developed tremendously as a teacher thanks to Gadolin" [ID1-09] "I have developed my skills to guide [students'] laboratory work" [ID1-01] "I have learned to guide and plan inquiry-based working" [ID3-02]
Scientific knowledge and practices	39	25.0	"most important I have strengthened my chemistry" [ID1-04] "Enhanced expertise in laboratory" [ID3-05] "[I have] learned how waste should be sorted in the laboratory and how chemicals should be stored." [ID1-03] "I have learned more when doing general introductions and talking about the kinds of professions that chemists are needed for. I have used collaboration companies as examples" [ID1-02]
Self-efficacy and motivation	23	14.7	"Working at Gadolin has strengthened my 'teacher self': I have gained a lot of confidence as a teacher and have already found my teaching style that suits me; I have been able to grow as a teacher" [ID1-04] "Self-confidence: Sometimes in Gadolin one has had to learn to adjust tools, student groups and schedules so much that I feel I can cope with almost any problem related to experimental learning in the future" [ID1-07] "I have gained confidence in being a teacher and positive teaching experiences. These have strengthened the desire to act as a teacher and [my] self-efficacy" [ID2-03]
Job skills	23	14.7	"Liability, self-reliance" [ID3-02] "Calmness, organization, time management" [ID3-06] "[My] readiness and work routine has developed" [ID1-05] "Through the science video projects, my skills in the use of social media have evolved" [ID3-03]
Differentiation and taking students into account	15	9.6	"The learning of and interactions among children and adolescents of different ages and backgrounds" [ID1-01] "Critical thinking about which way of working works with which age group" [ID3-07] "Differentiation: to apply the work instruction to a more appropriate group of students: to learn to take better account of the wishes and needs of each group and to design a learning visit appropriate to their level" [ID1-02]
Versatility in education	12	7.7	"The work has also brought more creativity to teaching through, among other things, the planning of science clubs and implementation and development of work instructions" [ID2-05] "Now I have several ready-made teaching plans and entities to use in school" [ID1-07] "[Work at Gadolin] taught me to use cross-curricular learning modules naturally in other teaching as well, and I have learned to bring out the links between things, topics and subjects in a holistic and inspiring way" [ID1-02]

The Pedagogical expertise category includes a range of skills related to pPCK, with either a focus on science and chemistry education or general statements such as "pedagogical skills". Students reported increases in their general teaching proficiency and abilities to plan

and design teaching sessions and guide students' learning, particularly with experimental hands-on activities and inquiry-based learning, which are seen important by researchers and teachers for STEM education [16,18–20,45].

The Scientific knowledge and practices category encompasses various aspects, including, among others, learning scientific concepts or theories, comprehending the nature and relevance of science, and developing diverse laboratory skills. It delves into how Gadolin instructors learn about and engage with science, particularly chemistry. For instance, instructors emphasized the importance of gaining a deeper understanding of chemistry, proficiency in chemical handling techniques, developing waste management skills, and honing scientific practices (i.e., problem-solving, inquiry, reasoning, and critical thinking).

The acquisition of these scientific knowledge and practices extends beyond science education; it also benefits STEM education. Kelley and Knowles [16] have proposed focusing on disciplinary practices (i.e., scientific inquiry, technological literacy, mathematical thinking, and engineering design) to achieve what they call situated STEM learning. Similarly, Roehrig et al. [19] advocate for STEM education that emphasizes disciplinary practices and provides insights into STEM careers. The latter, or, more precisely, how working in Gadolin has fostered students' appreciation for the significance of chemistry in society and the career opportunities, was noted in seven cases under this category. Moreover, it is something that few students expressed interest in learning more about in the future, for example through collaboration with researchers and companies.

The Self-efficacy and motivation category pertains to students' beliefs, trust, or confidence in their abilities to effectively perform their role as educators. It encompasses notions about their confidence in managing classroom dynamics, engaging students, adapting appropriate teaching methods, and adapting to diverse learning needs. This confidence in their abilities appears to enhance students' motivation to pursue teaching as a profession. A notion that teachers' higher self-efficacy for integrated STEM education can increase job satisfaction and motivation to teach STEM has been reported in earlier studies [5,39,46]. Motivation in this category can refer to desire to work as a teacher or a sense of teaching being a natural fit for oneself, contributing to a teacher's sense of identity. It is not about acquiring teaching skills (which are coded under pedagogical expertise) but rather about the feeling and identity associated with teaching.

In addition, this category was coupled with professional learning and working experiences that students reported as enhancing their self-efficacy and motivation:

> "Being an instructor has heightened my expectations for my teaching. I feel more "skillful", so I expect my teaching to be of higher quality as well". [ID3-02]

> "[Organizing] science clubs and science birthdays, has been rewarding. It's great to see children and young people getting excited about science! Working at Gadolin has reinforced my desire to become a teacher through these positive experiences". [ID2-05]

> "Without Gadolin instructor experience, incorporating lab work into teaching in the future would probably be much more challenging, but now doing experiments in teaching does not cause any uncertainty". [ID1-08]

The Job skills category encompasses references that highlight the learning and practice of skills essential for success in the modern workplace. This includes various organizational skills such as time- and self-management, organizing, collaboration, and communication skills, interpreted broadly to encompass all aspects of communication, including public speaking, use of communication technologies, and planning and executing social media posts. Additionally, this category includes mentions of the acquisition of personality traits that are generally considered beneficial in the workplace, such as patience, composure, and systematic thinking.

The last two categories, Differentiation and taking students into account and Versatility in education, are closely linked to pedagogical expertise; however, as they were frequently and clearly highlighted in the material, they were given a category of their own. The former

(Differentiation and taking students into account) encompasses comments that refer to the ability to tailor instruction and accommodate various types of learners. Differentiation is interpreted broadly here, including task differentiation and the ability to assess students' levels or understanding, enabling adaptation or differentiation of instruction as needed. The students mentioned differentiation or taking students into account as instructional strategies to achieve learning objectives or support students' motivation.

The Versatility in education category includes cases that highlight, for example, the integration of science education into everyday life or interdisciplinary approaches, as well as the skills necessary for implementing such approaches. Students noted creating connections between concepts and considering or choosing an appropriate everyday life context for education, which are relevant aspects of STEM education [19,26,45]. Additionally, this category encompasses mentions of acquiring new teaching materials and ideas as well as descriptions of teachers' ability to creatively plan and teach, such as developing new materials or implementing teaching methods flexibly, not solely relying on textbooks but incorporating new ideas and diverse perspectives.

4.2. Professional Relevance of Work as an Instructor at the LUMA (STEM) Learning Laboratory Gadolin (RQ3)

The role of instructors in leading study visits emerged as a crucial factor for their professional development. Participants reported acquiring practical experience in group management, skill in communicating scientific concepts, and increased confidence in both subject knowledge and self-efficacy. Moreover, the students cherished the opportunity to create innovative educational workshops and experiments, which enhanced their grasp of the material and enabled them to apply theoretical knowledge to scientific practices. Two examples from the interview transcripts highlight these aspects.

> "I would say that practical work as study visit instructor has been the most valuable [element], because you learn how to guide a group, what kind of things are good to take into consideration and how to explain things. One also gets a certainty that okay, what I can and dare to do, what is safe to do with the students and how to implement it to make it work. There isn't much of this if you are not working at Gadolin, so you don't get a lot of such practical experience of experimental work or doing demonstrations, because there is very little of these things in studies otherwise".

> "And, of course, the development work is another valuable element. Of course, as a teacher there is no or very little time for preparation. If you start the developing work from zero, it would be laborious work, and for the teacher I don't see this as being the most realistic option. But if you find some [experimental] works that are somewhat right, then with a little editing you can make them suitable for you. And you know how to design it to fit it better to your teaching. One gains that kind of flexible thinking and understanding on how to apply these and find these [works]. . . " [ID3-02]

> "We actually just talked about this yesterday with [name], we both realized that there has been a lot of practical learning in Gadolin which one has not really figured out during the laboratory courses or lectures out there. For example, just take the handling of liquid nitrogen. So, we have teaching labs, and yeah, we use liquid nitrogen there, but it's been used once and then you think that it's really dangerous; or it is really dangerous, but you thought about its dangerousness quite differently than for example now. And this thing [chromatography machine], yes, we knew the theory of a gas chromatography, but we didn't really know how to use the machine in practice. This learning of little practical things I regard really useful, for just about any assignments in chemistry you can get in. And here we have such a wide range of different tasks and you get to try them out by yourself much more freely and so you learn a lot of this kind of general practical chemistry work. It's like useful everywhere". [ID3-06]

Furthermore, students valued the autonomy granted to them as instructors at the Gadolin learning laboratory; particularly, they appreciated the freedom to work in a genuine laboratory setting and autonomy in the design and development of diverse experimental works and teaching materials, which contrasts with the structured and more restrictive nature of their university laboratory courses or the practicum in pedagogical studies. This is elaborated by the narration of student [ID3-03]:

> "Maybe the kind of general opportunity to work in the lab quite freely. First of all, all the experimental works that we have and use for guiding [study visit], they all have basic laboratory working methods, they have now become really familiar to me. Particularly now, when designing and developing experimental works or when doing science videos, one is free to define the kind of chemistry one does, the kind of methods etc. one uses; One kind of gets to practice the concrete practical work and the lab becomes familiar as an environment. If, on the other hand, you compare with those who attend only the laboratory courses that are part of the [university] education, there are a lot of them sure, but they are always really short periods of time, so one kind of gets a little nervous every time one goes back to the teaching laboratory. In that sense, I'm even in a privileged position, as I constantly get to go to the laboratory". [ID3-03]

The collaborative nature of working at Gadolin was cited unanimously as both a motivational and an educational asset. Co-working fostered a strong team dynamic, provided a support structure for individual initiatives, and facilitated peer learning. This synergistic climate is exemplified by the following participant description:

> "We currently have a very nice team and a good working environment, which of course boosts all of this and makes it easier to do work and offers sufficient support for all of these work things. While there is freedom to do it, there is no need to do it alone, it is perhaps one additional positive side that supports the development". [ID3-03]

The collaboration with companies was regarded as relevant to a lesser extent. The results suggest that the societal relevance of chemistry and the vocational possibilities for STEM careers become apparent to the students primarily through collaborations with companies. Although, for students, the current collaboration with corporate partners did not surface as an impactful element for their own professional learning, it presents an underutilized resource that the students themselves seemed to recognize as valuable. For example, "The Gadolin as a workplace could offer more collaborative opportunities with partners for the students working as instructors, thereby generating more diverse pool of career possibilities" [ID1-01].

5. Conclusions

The results suggest that non-formal STEM learning environments like the Chemistry Lab Gadolin support pre-service teachers' professional identity by enhancing self-efficacy through providing positive teaching experiences, which are a prerequisite for enhancing self-efficacy [5,23,24]. Students reported that working as an instructor increased their self-efficacy and self-confidence, especially for laboratory work, guiding experiments, and inquiry-based teaching. Working in a laboratory is an essential scientific practice that should be included in STEM education [16,20], and inquiry-based learning, along with other student-centered approaches, such as project-based learning, are considered essential approaches for STEM education [20,26]. Furthermore, students reported having a deeper or broader understanding of teaching sciences, such as knowledge about chemistry and its relevance in society, scientific knowledge practices, inquiry-based learning, and differentiation. Being aware of recent trends in research and teaching is considered important for STEM teachers [6]. This kind of teachers' unique understanding of teaching, pPCK, is informed by beliefs, experiences, educational background, and interactions [25] and therefore is closely linked to teacher identity.

The key elements contributing to professional learning and teacher identity in this study were autonomy in the workplace and the opportunity to engage in the creation of diversified experimental educational material that can be interpreted to be part of career readiness. For example, student instructors perceived practical work in an authentic learning laboratory, including extended investigations, experiments, personal autonomy, and possibilities for co-working and peer feedback, professionally relevant; these features are associated with enhanced interest and motivation for learning [47,48]. Similarly, collaborative working, students' engagement, inquiry, and authentic experiences are essential featured to be taken into account in STEM education [18,19,26,45]. While learning these features and gaining new STEM-related educational experiences, the student instructors start to develop their STEM teacher identities [6].

An equally important facet of the Gadolin experience was the supportive and collaborative spirit among peers. The collaboration possibilities with researchers and companies were also present, even though it seems their full potential is not utilized. This directly addresses a key challenge in STEM education—the importance of cooperative learning and collaboration with other educators and partners and teachers' need for support in actualizing this [5,17,45].

Based on these results, offering pre-service teachers' opportunities to practice and work in similar non-formal STEM learning environments offers a dual benefit to pre-service STEM teachers. It enhances their professional learning and identity by allowing a practical application of theory and by strengthening their self-efficacy through impactful teaching experiences. Furthermore, students reported that such experiences are generally not available during their formal university education, where course and practicum constraints do not afford the same level of autonomy and possibilities for extended practice. These findings contribute to the existing research on the benefits of work-integrated learning in teacher education [11,12], especially in the context of a non-formal STEM learning environment. One option for the future could be forming and strengthening the partnership between teacher education and non-formal learning environments, not just using non-formal learning environments as places to visit or do a short practicum but integrating this into teacher education courses. The Chemistry Lab Gadolin is a part of the same institution as chemistry teacher education, which offers synergy and flexibility for both partners. If possible, teacher education institutions could use a similar model for work-integrated learning, as it seems to mitigate some of the challenges reported by Jackson [10], such as institutions' reputational risk.

As this is a small case study in the context of a single STEM learning laboratory focused on chemistry, the results are not generalizable, and we call for further research to explore these possibilities across diverse contexts. Nevertheless, the insights garnered from this study offer a valuable contribution to ongoing dialogues about work-integrated learning in science and STEM teacher education and the role of non-formal STEM learning environments in supporting STEM teacher identity and, thereby, the quality of STEM education.

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