IN-SERVICE CHEMISTRY TEACHERS' REFLECTIONS ON AND EXPERIENCES WITH SUPERVISED LABORATORY INSTRUCTION IN ETHIOPIA

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ABSTRACT

This qualitative study reports on 12 in-service teachers' reflections on and experiences with supervised laboratory instruction (SLI) based on a two-day professional development workshop. Three main themes emerged from thematic analysis of the interview transcripts: (1) SLI is an attractive teaching method, (2) SLI is challenging to implement in the classroom and (3) teachers need support to teach SLI. Attractive features of SLI included pre-laboratory activities, reflective group discussions, and scaffolding that could help them accomplish difficult laboratory tasks. However, teachers felt limited by an overloaded curriculum, little time, and a lack of lab facilities, self-confidence, and experimental experience. To implement SLI in their own classrooms, the teachers expressed the need to receive support from university staff through regular in-service laboratory training and inspirational scientific discourses. Furthermore, they emphasized the importance of access to SLI-adapted teaching materials and qualified laboratory assistants. Overall, teachers found SLI quite beneficial to their laboratory teaching in high school chemistry education. *[African Journal of Chemical Education—AJCE 12(2), July 2022]*

INTRODUCTION

Teaching science without laboratory activities—engaging tasks that learners perform by manipulating equipment and materials in a laboratory or another environment to observe and understand the natural world—is almost unimaginable. Indeed, laboratory instruction has been an integral part of science curricula at various levels for over a century [1-2]. The benefits of engaging students in laboratory activities include the potential to develop conceptual knowledge, enhanced understanding of the complexities and ambiguities of science, problem-solving skills and practical skills, an increased interest in science, and teamwork skills [1, 3-4]. Laboratory activities could potentially also enhance positive social relationships among students [5].

The use of laboratory activities in chemistry is less common in developing countries such as Ethiopia—despite the call for laboratory-based instruction in the Ethiopian science curriculum [4, 6]. The main reasons for this are a shortage of laboratory space and facilities, lack of time, few trained technicians, fear of chemical hazards, poor preparation of teachers, lack of confidence, absence of quality curriculum materials, overloaded curricula and large class sizes, and lack of student-centered teaching methods [4, 7-8]. Indeed, the so-called Ethiopian Education Development Roadmap (2018–30) initiative, launched by the Ethiopian Ministry of Education [9, p. 23–26], argues that previous efforts to improve STEM (Science, Technology, Engineering & Mathematics) teaching have failed due to an exaggerated emphasis on school buildings and facilities, such as instructional satellite televisions, over learning outcomes as well as the use of uninspired curriculum materials that are disconnected from the world of work. The 2018 roadmap recommends, among other things, that the high school science curriculum foster practical skills, scientific inquiry skills, and innovative and critical thinking skills, all of which might be developed as part of well-planned laboratory activities. A remarkable annual real GDP growth (6.1% in 2019/20) has indeed made it feasible to invest in science education at the secondary school level in the country and at the regional level [10]. To this end, the Ethiopian government has implemented a so-called 70:30 policy through which 70% of the enrolled students would be in STEM subjects [11].

The overarching goal of the project to which this study belongs is to help Ethiopian chemistry teachers implement meaningful laboratory instruction in their classrooms. For this purpose, we have developed a laboratory instruction pedagogy (introduced below), applied it to selected chemical experiments, and tested it on teachers who attended a professional development workshop. By training teachers in this pedagogy and analyzing their reflections and experiences in learning from, and practicing it, we aimed to contribute to the understanding of how laboratory instruction can be taught in an Ethiopian context.

Professional development for laboratory teaching and learning

Well-designed professional development (PD) programs are considered to be crucial to transforming schools and improving students' academic achievements [12-13]. To promote the quality of school learning, however, teachers' PD experiences must result in effective teaching practice [14]. This could be achieved by training teachers in conceptual understanding and practical work and by establishing a culture of shared responsibility to support students' learning—like a professional learning community [15].

However, a change in active learning instructional strategies takes time and requires material resources, such as well-developed curriculum materials; it might also involve school incentives, such as reduced teaching loads or financial benefits [16-17]. Teachers may also have difficulties translating new insights into their school settings [13]. For teachers in African countries, their lack of training in laboratory experimentation constitutes an additional challenge in implementing active learning practical laboratory work in their classrooms [4, 8]. [18], however, revealed that when teachers take time to try out active learning pedagogies in which they can learn about and try out experiments, there is a high chance of changing their traditional teaching practice.

The workshop that we designed for this study was organized as one such PD activity in which teachers could get practical experience both in doing laboratory experiments in the classroom and in practicing a new instructional pedagogy and discussing it and sharing experiences in groups of peers. To this end, based on research on factors that could contribute to learning through laboratory instruction, we developed a pedagogy hereafter referred to as supervised laboratory instruction (SLI).

Supervised laboratory instruction (SLI) and meaningful learning

SLI is a learner-centered laboratory instructional pedagogy which emphasizes learning through social interaction in groups and for which sufficient scaffolding [19-20] to actively engage learners in hands-on and minds-on activities [21] and promote learning is considered pivotal [22]. To further benefit students' learning in the laboratory, on the recommendation of [23], pre-laboratory activities have been included as well.

In SLI, like in inquiry-based teaching, the teacher takes the role of facilitator, who assists the students to process the information and coach their actions [24]. Teachers' scaffolding help focus learners' attention toward the learning outcomes, simplify the learning activities, model and demonstrate, and prompt ongoing evaluation and assessment of learning [19-20, 23]. In sum, the following three main features characterize SLI pedagogy: *pre-laboratory activities* to allow the learners to prepare well, *teachers' scaffolding* during and after the laboratory activities, and *reflective group discussions* with peers to enhance learning (during and after the laboratory activities). The framework for operationalizing these aspects is presented in the "Workshop and experiments" section below.

When selecting experiments, the following features were emphasized: In order to foster meaningful learning experiences among teachers and students, we looked for so-called *context-based* laboratory activities in which the chemistry was applied to a "real-world situation" [25, p. 53]. For example, the experiments included topics from everyday life such as hard water analysis and polymer properties in diapers. Also, engineering design was demonstrated through the construction of a Lego colorimeter [26]. To make our SLI more feasible in Ethiopian schools, we were interested in experiments that made use of *low-cost and homemade materials and equipment*. Among the low-cost materials we included is a small-scale chemistry equipment, which reduces waste and the use of costly consumables and is made from plastic rather than breakable glassware [27]. Furthermore, the materials used are from the students' everyday life and are free of so-called black boxing (i.e., instruments whose content and principles are sealed and hidden from the learner) [28] to make the principles behind possible to grasp.

Research Questions

To understand to which extent and how the Ethiopian teachers found the SLI pedagogy and the selected experiments to be useful in their classrooms and what experiences they had from using the method during the workshop, we asked the following research questions (RQ):

1. Which features of the SLI did the teachers find readily applicable for their own adaptation of the method in their classrooms?
2. What challenges did the participating teachers foresee in implementing SLI in their classrooms? We also looked at the kind of support they needed to implement the SLI method in their classrooms.

RESEARCH CONTEXT AND METHODOLOGY

This study targeted Ethiopian in-service chemistry teachers who taught in grade 12 classrooms. In the national high school education structure, grade 12 constitutes the last year of the second cycle of senior high school education, at the end of which the students sit the National Higher Education Entrance Certificate Examination. Grade 12 science education is reckoned to be pivotal in implementing the 70:30 policy mentioned above.

Before starting the current study, an informal discussion with school rectors, teachers, and students in the region where the study would be conducted revealed a shortage of laboratory space and facilities in the part of Ethiopia where this study took place. Since large numbers of students (roughly 25% of all students in Ethiopia, see [29], are enrolled in this region), teachers expressed the need to have qualified technical assistants to assist them in their laboratory courses.

Other challenges mentioned in the informal discussions included the expectation of teaching an overloaded curriculum prepared by the government, the decline in students' and teachers' interest in science, and the teachers' lack of knowledge, skills, and confidence to engage in practical experiments—as noted above [4, 9]. The teachers reported that they either demonstrated chemistry experiments before a crowd of over 70 students or simply offered theoretical lectures.

Workshop and experiments

The SLI workshop for teachers was conducted in November 2019 and lasted for two days, about 14 hours in total, so that teachers could be able to participate on the weekend, to avoid collision with their own classroom teaching. Five potentially low-cost (i.e., paper-based galvanic cell, electrolysis apparatus, homemade Lego colorimeter, and disposable diapers) and context-based experiments (i.e., water quality in the hard water experiment and soil nutrients' leaching analysis in the disposable diapers experiment) available from the library of chemical experiments published in the *Journal of Chemical Education* [27, 30-33] were selected, adopted to SLI pedagogy and grade 12 Ethiopian curriculum, and laboratory manuals developed. The SLI-based laboratory manuals were offered to the participants one week before starting the workshop. The grade 12 chemistry topics utilized in the SLI workshop were solutions, acid-base equilibria, electrochemistry, and polymers. At the beginning of the workshop, an hour lecture was offered to the participants on how SLI could be used to support students' learning while doing science. The role of pre-laboratory activities, teachers' scaffolding, and reflective group discussions in enhancing practical laboratory teaching-learning processes in the SLI pedagogy were elaborated on and exemplified and the selected experiments' relevance to the high-school chemistry curriculum was discussed.

The methodological approach employed a PD framework with three phases, as described by [34], and used in laboratory instruction by [35]: forethought phase, performance phase, and self-reflection phase. In *the forethought phase,* the participants actively engaged in pre-laboratory activities (i.e., pre-laboratory quizzes and discussion), in which the researchers provided support by asking, for example, “What is the function of radiation in photometer?” to help students understand the principles of the colorimeter, in the experiment where a small-scale Lego colorimeter was used with a light-emitting diode [32]. The pre-laboratory activities were meant to ensure that the teachers were prepared for the laboratory learning and to help them develop conceptual knowledge, as well as cultivate the interests, motivation, and intellectual confidence necessary for their laboratory experiences [23].

In *the performance phase*, once teachers obtained a brief orientation about the safety issues and the basics of the experiments and laboratory activities, they conducted the experiments in small groups (three to five participants in each group), while the teacher-researcher guided and facilitated the laboratory teaching-learning process by asking questions to help them complete the tasks. For example, teachers were assigned to find out how the unknown concentration of copper sulphate ($CuSO_4$) was determined in the Lego colorimeter experiment using hands-on lab activities (e.g., manipulating the Lego colorimeter, preparing solutions), and minds-on activities (e.g., calculating absorbance and concentration, reflecting on how to use the Beer-Lambert’s law, drawing a calibration curve). In the hardness of water experiment scaffolding activities included asking teachers “Why should the complexometric titration be adjusted at a pH of 6-8?” to guide the teachers’ inquiry process.

In the *third phase, self-reflection*, the teacher-researcher led discussion forums to allow the teachers to reflect on their laboratory experiences; this was an avenue toward greater collaboration and a professional learning community. For example, the teacher-researcher initiated group discussions by posing the question "How could you identify the origin of coffee samples in Ethiopia?" to help teachers recollect what they had undertaken in the colorimeter experiment.

Each of the experiments took approximately two and a half hours, out of which about 20 minutes were allocated to pre-laboratory activities; about 90 minutes were dedicated to the experiment itself and 40 minutes for the post-review discussion forums.

Data and informants

Sixteen high school chemistry teachers (two females and fourteen males) from six different schools in Ethiopia participated in the workshop. Purposive sampling was employed to select participants: Teachers who were found to be hardworking (by their school rectors), who had previously taken part in any laboratory-based training, and whose residence was within 50 miles radius from the first author's base was invited to participate. Seven of the teachers who participated held master's degrees in chemistry and taught grade 11–12 students, while nine of the teachers held bachelor's degrees and normally taught students in grades 9–10, sometimes in grades 11–12. All had followed a pre-service teacher education program with chemistry as their major subject and physics and mathematics as minors. Twelve of the informants had also followed a one-year post graduate diploma in teaching (PGDT) program. Furthermore, all participants regularly attended government-endorsed in-service school-based PD courses on subject-specific teaching methods and "recipe-style" [36] laboratory practices. The teachers had between 9 and 36 years of high school chemistry teaching experience.

Twelve of the sixteen teachers involved in the study were selected for semi-structured focus group interviews. Generally, group interviews were favored over individual interviews because they can be considered more natural settings in which participants can express their viewpoints while discussing them with peers, and therefore the interviews can provide data that might not be accessible otherwise [37]. Also, group interviews are cost-efficient compared to individual interviews. More specifically, focus group interviews were chosen to obtain an in-depth understanding of the experiences of a purposely selected group of the workshop participants. In this case, to avoid statements about the potential of laboratory work in general we were particularly interested in the opinions and experiences of teachers who were experienced in doing chemical experiments prior to the SLI workshop, and who also had demonstrated that they did not mind speaking openly in groups. To make conversation easy and comfortable, the twelve selected teachers were grouped with participants they knew well. Each focus group (FG1, FG2, FG3) consisted of three to five participants.

The focus group interviews were conducted by the first author in the laboratory room of one high school within two days after completing the workshop. Semi-structured interview guide and probing follow up questions were used to elicit sufficient information. The first author moderated the focus-group discussions, balancing between firm steering and keeping the discussion open, in an open-minded and non-judgmental way to avoid researcher's bias. The four planned interview questions that were specifically aimed at gathering data relevant to the research questions for this study were 1) Which aspects of the training did you find helpful and readily applicable in your school context? 2) What support do your students need to learn chemistry through SLI? 3) Did you face any challenges, or can you think of any potential challenges in implementing SLI in the classroom? and 4) What materials (resources) do you need to practice SLI to increase the interest of high school students? We also asked what the participants learnt from the SLI method, and whether or not they thought the method would be motivating for their students.

Each interview lasted between 60 and 100 minutes. The interview data were audio-recorded and stored confidentially. They were first transcribed verbatim in Amharic and then translated into English, as well as checked by an Amharic-English bilingual colleague, who also acted as an external reviewer who checked the questions for researcher's bias. That the participants were able to use their native language in the workshop and interviews instead of English, which is commonly used in teaching, might have reduced the language barriers that could make informants uncomfortable and prevent researchers from capturing participants' views. All participants who agreed to take part in the study signed an informed consent letter. The data collection was approved by the Norwegian Center for Research Data (NSD).

Data analysis

This study employed a qualitative research design that used a multi-phase thematic analysis [38] which included the following phases: 1) Familiarizing with the data through repeated reading of interview transcripts, 2) thorough (inductive) coding working bottom-up from the data while paying attention to features of potential relevance to the RQs, 3) grouping of codes as a first step toward the development of themes, 4) critical examination of candidate themes, and further development and refining of themes and sub-themes in a recursive process going back and forth between codes and themes until valid and coherent themes addressing the RQs had been developed. Included in this process was the analytic and iterative process of writing the theme descriptions, which involved the selection of extracts, editing, further analysis, and re-organization of the data. Finally, 5) both authors were involved in the coding and theme and sub-theme development through regular video conferences and face-to-face meetings. This systematic approach was critical to establishing the reliability of the codes and themes, while phase 4-5 was especially important for the validity of the study. Overall, the steps taken to increase the trustworthiness of the study include thick descriptions (transparency), checking of interview questions with respect to researchers' bias as well as to linguistic precision by an external reviewer, purposive sampling, moderate facilitation, data saturation, systematic procedures for coding and theme-development involving negotiation between the authors, and continuous discussions on interpretations of the data. Three final themes were developed, which captured three essential aspects of SLI as the informants expressed it: (1) SLI is an attractive teaching method; (2) SLI is challenging to implement in the classroom; and (3) teachers need support to teach SLI. For clarity and reading ability purposes, the selected codes that sort under each theme are italicized under each description in the Results section.

RESULTS

Theme 1: SLI is an attractive teaching method

Teachers found the SLI laboratory workshop to be interesting and useful for their own teaching. One aspect of SLI that teachers strongly appreciated was the use of *pre-laboratory activities* that would make them well prepared to conduct laboratory work and include it in their own teaching. For example, John (FG2) said the following:

> The pre-laboratory quizzes are useful for asking myself critical questions like "What am I going to do now? What should I get now? What prior knowledge should I come up with? What knowledge and skills should I be expected to add along the way?" It serves as a means to construct new knowledge, not just as the end of the story, so to speak.

Similarly, Michael (FG3) expressed that he "recognized [that] the pre-laboratory questions are helpful in stimulating students' thinking at the early stage of the experiment." These statements exemplify the views among teachers that the pre-laboratory questions allowed them to think about what they were going to do in the lab and helped them capture the essence of the laboratory activities beforehand. However, some of the participants found it difficult to conduct pre-laboratory activities if they did not have enough background knowledge on the topic in question. As Amen's (FG3) expressed, for example, the lack of prior knowledge "is an obstacle that couldn't make me complacent with the workshop." However, challenging could also mean helpful, as Kibru (FG1) said: "Pre-lab questions were challenging for me. But the questions necessitate our critical thinking and actually I like this challenge—for it offer me an opportunity to scrutinize concepts as deeply as possible."

The participants also appreciated that they were offered support (*scaffolding*). Teachers were of the opinion that students would be able to learn science better if they were given scaffolding that could help them to accomplish difficult laboratory tasks, just as the teachers had been given during the workshop. For example, Lidya (FG1) stated: "…after [participating in] SLI, with the help of researchers' scaffolding, I came to know that polymers…contains an aggregate of monomer units joined in a strong covalent bonding." This example indicates potential for learning chemistry concepts through scaffolded, or supervised, instruction. John (FG2) further demonstrated what such support would mean using an Amharic proverb: "*Kebero siyayut yamir siyizut yadenagir*" ("A drum looks beautiful only when we see it, but it requires a skill to actually play it oneself"), meaning that scaffolding students' learning in the laboratory is a difficult task which requires certain skills, different from the skills needed to offer lectures and "recipe-like" laboratory activities.

The participants also appreciated the *reflective group discussions*. Kibru (FG1), for example, believed "[group discussions] fine-tune the difficulties in grasping chemistry concepts" and John (FG2) said, "It [group discussion] enlightens and help you recall what you have done in the experiment: 'What did I know?' What knowledge did I share with colleagues? What knowledge should others get from me?'" This indicates that the group discussions provided the teachers with opportunities to reflect and evaluate their own and others' ideas and laboratory experiences, which might help to develop their cognitive and metacognitive thinking skills (and their students').

Teachers also thought that the selected experiments were well suited to connect chemical knowledge with day-to-day life experiences (*context-based teaching approach*). For example, John (FG2) said: "When you contextualize the lesson with what you get in your surroundings, you will become more motivated to discover more…." An explicit connection, the teachers reasoned, might help students develop scientific literacy. Amen (FG3) stated: "I think this method [SLI] is very useful to teach students meaningfully by relating what they have learned in the lecture with real concrete experiences. No doubt this will promote their chemical literacy." To the teachers, contextualizing chemical concepts with what students might encounter daily was important to develop their skills to navigate the socio-scientific issues in general and the lesson of interest in particular.

The participants also appreciated the use of simple, *low-cost, and homemade materials and equipment*, which made it easy to teach laboratory courses in a risk-free learning environment. For example, Murad (FG3) noted: "The important features of the workshop for which I was very interested are: It uses easily available materials; it is safe; and free of any hazards."

In summary, the teachers found SLI to be a cost-effective and pedagogically feasible method for providing meaningful laboratory experiences. In particular, the pre-laboratory activities and reflective group discussions offered participants with opportunities to actively engage in practical laboratory teaching and learning. However, the teachers found that the level of complexity of the laboratory activities should be designed carefully, and sufficient scaffolding be provided to encourage learners to do science on their own. Furthermore, the participants found features such as context-based learning activities and the use of low-cost and homemade materials in the selected experiments to be helpful for the implementation of laboratory instruction in their own classrooms.

Theme 2: SLI is challenging to implement in the classroom

While SLI seems to have contributed to teachers' interest in science laboratory teaching and learning and to have helped the teachers develop their laboratory experiences, the Ethiopian teachers in our study felt *limited by constraints,* such as ambitious curriculum, shortage of curriculum materials, time, and class size. For example, John (FG2) elegantly expressed this point when asked what possible challenges would prevent him from implementing SLI for teaching practical chemistry courses in high schools:

> Our education system is like people who build houses for rent but are more obsessed with the money than with worrying about the service they have to give to the tenants, so to speak… What prevents us from doing SLI in our classroom are the time constraint and the large class sizes that are not manageable. The fact that the textbooks are too voluminous to finish at the right time also makes it [SLI] unthinkable.

Evidently, John (FG2) holds the view that the Ethiopian government has paid much attention to access to education but less to the quality of education. This viewpoint aligns well with the Ministry of Education report [9], which states that less focus has been given to students' learning outcomes as compared to building schools and establishing lab facilities. Similarly, Taha (FG1) said that "high school chemistry textbooks contain a large amount of information that the teacher is expected to teach," which requires a lot of time.

Teachers also stated that a *lack of sufficient experimental training and experience* hindered them in implementing SLI in their own classrooms. For example, John (FG2) explained that:

"[previously], I did not get sufficient practical laboratory experience, as the possibilities to conduct experiments are very few. [In addition,] … what we have done [before] is not a motivating kind of practical work. Needless to say, I was striving to get to know the names of the equipment, let alone assisting my students in getting relevant laboratory experiences."

Also, little attention had been given to experiments during the teachers' previous training (although some courses had been offered on "recipe-style" experiments). Because of an emphasis on theoretical training, the teachers felt that they lacked the ability to articulate abstract chemistry concepts to their students (i.e., to associate the lesson with appropriate tangible, concrete practical examples and to support students in obtaining meaningful in-depth learning). Tedros (FG3), for example, explained how the lack of training in applying theoretical chemistry to new situations even had consequences for his own understanding of chemistry, as he experienced with the diaper experiment:

> My prior understanding about diapers, for example, was just knowing about their liquid absorbing ability, nothing else. I did not know that diapers contain polymer molecules, nor did I know the idea behind what makes polymers superabsorbent in diapers.

Clearly, Tedros did not know that diapers are comprised of polymers, nor did he know the chemistry of diapers and other related areas where polymers could be applied. Consequently, since he was personally not aware of the connections between polymer chemistry and diapers, he would not have been able to implement such real-life contexts as part of laboratory instruction in his own classroom. As John (FG2) put it, traditional teaching methods "…are far-fetched in addressing the [chemistry] concepts…."

Another challenge that teachers in all groups regarded as an obstacle to implementing SLI in their classrooms is the *lack of lab facilities*. Based on her own teaching experience, Laura (FG1) said the following: "[We] quite often ignore many experiments in our school thinking that the equipment and chemicals are expensive." Other teachers, too, shared Laura's description of the lack of equipment (e.g., a digital balance), which prevented them from conducting experiments in their classrooms. As Lidya (FG1) said, "[Y]ou will realize how embarrassed you feel standing before your students when what you have taught is not integrated with real practical experiences." This was a sentiment echoed by Kibru (FG1): "I am afraid [that I will not be able] to allow my students to do practical experiments." The statements from these three teachers illustrate how hard it might be to conduct experiments regularly due to the lack of laboratory facilities. However, teachers were inspired by the selection of experiments in the workshop and aspired to search for low-cost and homemade materials that could be suitable for their high school chemistry experiments. Laura regarded it as "a mistake to ignore experiments" and was determined to include low-cost materials in her laboratory teaching after the SLI workshop. Kibru was eager to apply what he had learned in the SLI workshop:

> I came to recognize that we should not wait for the school to buy such and such chemicals and equipment; instead, I began searching for locally available materials to replace expensive chemicals with something cheaper.

Furthermore, participants showed that their students' *negative attitudes toward science* might prevent them from implementing SLI to their classrooms. For example, Kibru (FG1) thought that "some of the social problems existing in the country, such as unemployment and political chaos and instability," have reduced his students' motivation for learning science. Murad (FG3) found it problematic that students believe "…that chemistry experiments are complex, time consuming, and need only expensive chemicals and equipment." *Little faith in the use of low-cost experiments* was also a common attitude among teachers in the workshop. For example, Tedros (FG3) said: "We have a mindset that chemistry is something that requires a well-furnished laboratory." Kibru (FG1) also stated that he "had never believed in that the low-cost [and small-scale] titration kit would help to determine the hardness of water." Attitudes of students and teachers alike were therefore perceived as a challenge in implementing SLI in chemistry classrooms.

Despite the many positive aspects of SLI, many teachers found SLI to be challenging to adapt in their own classrooms. Specifically, they were concerned about how constraints, such as curriculum overloads, little time, and lack of lab facilities, could impede adapting SLI in high school laboratories. The teachers also felt that their lack of sufficient experimental training and experience alienated them from science, and that the negative attitudes toward science among students and teachers alike made it difficult to implement SLI in the teachers' own teaching practices.

Theme 3: Teachers need support to teach SLI

Three sub-themes emerged from this main theme. The first sub-theme, "to learn the SLI method," provides insight into the kind of support that teachers said they need from researchers when they were trained on how to apply the SLI method. "To motivate students' science learning," the second sub-theme, describes the support that teachers need to motivate their students to actively take part in SLI instruction, and the third sub-theme, "to make SLI sustainable," arose from several participants' interest in obtaining support that would help them implement the method on a permanent basis in their own classrooms.

To learn the method. Teachers recognized that PD takes time, and some teachers were overwhelmed with their laboratory experiences from the workshop. Particularly, these teachers reiterated that *getting regular laboratory training is imperative* for understanding the SLI method well. For example, Tedros (FG3) said, "Two days are too short to grasp this [SLI] method…had we had enough time to discuss what other options might be possibly used, we could have benefitted more from it…." Michael (FG2) further described that the two-day workshop was not enough time to learn the method: "Had it been given in a relaxed way, I would have extinguished many of my misconceptions."

Similarly, teachers thought that if they had the opportunity for *sharing experiences with university staff through seminars and research projects*, they could enrich their chemical knowledge and experiences with the SLI method. For example, Michael (FG2) reiterated that participating in such discussion forums with university staff might help to "grasp chemical concepts very well" and, as John (FG2) expressed it, "to share experiences … about how to prepare a standard lesson plan." Michael's and John's comments can serve as examples of the views among teachers that researcher-led discussion forums might be useful for developing teachers' content and pedagogical content knowledge. It seems that the scientific discourses they were exposed to as part of the workshop opened teachers' eyes to the possibilities of peer collaboration initiated by researchers—for example, preparing lesson plans jointly and discussing post-laboratory questions, and reflecting upon their laboratory experiences to enhance their conceptual understanding.

To motivate students' science learning. Participating teachers also expressed the need for researchers to *arrange practical tutorials* for the teachers while in training; if the teachers have more hands-on experience, this will help to develop their students' motivation and scientific practices. For example, John (FG2) said: "I guess, teachers could stir up their students' motivation for learning laboratory courses when they obtain sufficient tutorials from researchers." Teachers even felt the need to *get motivational support from researchers both in and out of the classroom* to motivate students' science learning. For example, Amen (FG3) described the need to take his students to university laboratories to increase their desire to learn science in the future:

> [Quite] often they [students] also want to visit laboratories in universities, as this will help them to be more aspired to pursue chemistry with great effort in the future. For instance, it is nice if you [researchers] demonstrate how the centrifuge device works, since they do not find it in their high school laboratory.

This exemplifies the view among participating teachers that the high school students' interactions with the university laboratory learning environment might aspire them to pursue science studies, such as SLI. John (FG2) further explained it as follows:

> We need you [university staff members] to aspire to and motivate our students through these [SLI] experiments. Those who have gained a lot of experience and practical laboratory skills from overseas…should bring locally available and easy-to-make equipment to our schools to impress our students.

Evidently, John held the view that experienced researchers could intrinsically motivate students by conducting low-cost experiments (exactly as what they have done in the workshop) in students' schools, since it might help capture students' interest in learning science.

To make SLI sustainable. Teachers reflected on what they thought were important for making the SLI method sustainable in their own classrooms. Firstly, they thought that *adapted SLI material resources should be made available*. As a first step, Yirga (FG3) expressed a dire need to get the SLI teaching resources available in the teaching laboratories: "It is worth requesting that all the laboratory teaching materials that we have used during SLI [workshop] should be supplied to high schools' laboratories." Further to this, John, for example, said that "SLI design must take into consideration the large content and the scope of high school chemistry textbooks." John's concern was that teachers should not be unnecessarily burdened with activities that require much effort and time to complete (i.e., both the ambitious curriculum and the preparations needed for doing practical experiments in the laboratory classrooms were demanding for the teachers). Thus, John suggested that SLI should cover a reasonable number of experiments that should be available to teachers, which could be done within the allowed time frame. Also, the scope of the SLI lab activities should be in line with the existing curriculum materials.

Another support needs that teacher deemed important for making SLI sustainable in the classroom was the need to get *qualified lab assistants*. For example, Adam (FG2) said, "There should be a way that can reduce teachers' burden as they both offer the lectures and takes the role of a laboratory assistant." In addition, teachers indicated that the adaptation of SLI to their own teaching would be more feasible if *students learned about SLI in lower secondary school* (grades 9–10) instead of first learning about this method in upper secondary schools (grades 11–12). For example, Amen (FG3) said: "SLI training should be offered as a basic level starting from grades nine to ten." This is because, as Laura (FG1) explained, "students can develop their chemical knowledge and increase interest in laboratory practices at the early stage [of their schooling]."

In summary, teachers were in favor of implementing SLI training on a permanent basis through a wedded collaboration with university staff to better learn the laboratory teaching method, and to become inspired. Furthermore, they expressed the need for regular in-service laboratory training. To make SLI sustainable in high school teaching laboratories, the teachers desired to obtain ready-made SLI-adapted resource materials that were in line with the curriculum, qualified lab assistants, and begin SLI at early schooling.

DISCUSSION

RQ1: Which features of SLI did the teachers find readily applicable for their own adaptation of the method in their classroom?

Laboratory-based PD opportunities play a critical role in promoting teachers' abilities in and attitudes towards translating new pedagogical interventions, such as SLI, into their teaching practices [18]. In the present study, too, participants highlighted that the SLI laboratory workshop was useful for adapting the method in their own laboratory teaching. The features the teachers emphasized are italicized below.

Participant teachers found *pre-laboratory quizzes and discussions* beneficial to their understanding of chemical concepts and laboratory processes, as well as a way of stimulating curiosity about the laboratory beforehand, which are in line with findings by e.g., [23, 39]. It appears that the pre-laboratory activities made the teachers in our workshop perform well in the execution of the laboratory activities as it provided them with the leverage to delve into thoughtful engagement in the theoretical and practical aspects of the laboratory. The opportunity to prepare for the laboratory activities seems to have minimized the potential cognitive load that might otherwise have been created in the complex laboratory learning environment, as pointed out by [23]. That teachers obtained information about the laboratory in advance also appears to have increased their motivation and reduced negative feelings about laboratory instruction, in line with what [39] have found. However, some teachers reported about their lack of competence in performing the pre-laboratory tasks and hands-on SLI-lab activities. A similar finding was reported by [40]: The pre-service teachers showed lack of competence in preparing chemical solutions because they had limited understanding of the relevant chemical concepts, and also because they had not acquired the necessary practical laboratory skills.

The participants also described that conscious engagement in scientific “talks” and “actions” (i.e., to think and act upon lab activities, used by [41] *scaffolded by the teacher-researcher* offered them the chance to gain some laboratory learning experiences. This finding aligns with the results reported by [41] on the effect of scaffolding on students' observation skills when doing laboratory activities, which consequently led to increased learning. According to [19], scaffolding should be done to improve science learning by having active teacher–student and peer interactions, as well as by integrating learners' thinking into actions. Similarly, [1] who made meta-analysis suggested that laboratory instruction that provides students with sufficient time and opportunities for prompting questions, reflection, and feedback about their ideas could result in enhanced conceptual understanding and metacognitive skills. This is consistent with what the participants said *reflective group discussions* had done for them: it helped them to gain collaborative group work habits and improved their cognition and metacognition skills.

RQ2: What challenges did the participating teachers foresee in implementing SLI in their classrooms?

The present study has pointed to some constraints that might impede teachers from implementing SLI-type laboratory instruction. Teachers who participated in our workshop felt that *lack of quality curricular materials, little time and overloaded textbooks* in Ethiopia were important hinders for the adaptation of SLI in their classrooms. Also, teachers reported that they had *little confidence in their own ability* to teach and design student-centred laboratory activities in their school context. The participants were experienced teachers, but they reported that they did not have enough background in chemistry content to use their day-to-day life experiences, nor did they possess the experimental skills needed to design chemistry laboratory courses and give laboratory instruction. This may be because participants had been largely exposed to teacher-centered laboratory instructional practices in their teaching as well as during their training. *Lack of theoretical and practical training* might have prevented participants from learning SLI and from implementing the method in their classroom. [1] Asserted the following:

> Many preservice and in-service courses in science and in science teaching and learning provide very limited direct experience, if any, through which the teachers can develop the skills needed to organize and facilitate meaningful, practical learning experiences for students in the school science laboratory (p. 45).

This implies that sufficient theoretical and laboratory training are important factors for teachers when they are implementing new laboratory strategies in their own classrooms.

Another challenge that participants believed significantly hindered the implementation of SLI in their classrooms was the *lack of lab facilities*. As evident in the statements of in-service teachers' shortage of basic lab facilities forced them to revert to traditional teacher-centered instruction in their schools. This observation is at odds with what the [9, p.25] report indicated—namely, that initiatives such as "school improvement packages" have been introduced to facilitate the science teaching-learning process. In our experience, the increasing size of high schools is partly to blame for the lack of facilities; in such circumstances it might be difficult to establish the necessary spaces for learning. Indeed, the lack of lab facilities seems to be a common problem in teaching chemistry in African high schools and elsewhere (e.g., [8, 42-43]). Nonetheless, earmarked laboratory expenses per se cannot guarantee that teachers will be successful in teaching laboratory practices; instead, the instructor-driven "scaffolding and structure of the laboratory activities determine, if any, of the positive learning outcomes associated with laboratory activities occur" [9, 17, p. 136].

Students' negative attitudes to science, which reduces their motivation to learn science, was another challenge that participants perceived would impede them from implementing SLI in their own laboratory classrooms. [44] Recommended that the design of laboratory teaching strategies should consider how such a laboratory program would create a positive learning environment and boost students' attitudes and motivation for learning. This is in keeping with what SLI participants described concerning how hands-on SLI lab activities and the support structure characteristic for the pedagogy had increased their motivation for learning through SLI. Teachers demonstrated such a viewpoint when they indicated that they wanted to replace traditional school experiments with SLI by identifying low-cost materials, equipment, and chemicals for their own teaching, and by instructing students by providing support in the form of pre-laboratory activities, group learning and post-laboratory reflections.

Teachers need support to teach SLI in their own classrooms

Changes in teachers' classroom teaching practices, attitudes, and beliefs, as well as students' learning outcomes, are a long process [12], and thus participants wanted to acquire additional laboratory training from the researchers to develop the necessary competences to teach SLI in their classrooms. The participants highlighted the *need to engage in seminars, SLI-based research projects, and discussion forums*, as well as to *take part in regular laboratory training and tutorials with researchers*. Previous research where pre-service and in-service physics teachers discussed how to plan practical work, suggests that discussing challenges with instructors and peers might help them be better prepared for facing those challenges in their own practice [42]. Similarly, teachers who participated in our workshop indicated that the reflective group discussion would be a good way to develop their laboratory experiences in the preparation of lesson plans, while improving their conceptual understanding through collaborative learning. The fact that the participants did not have previous experience with SLI-type instruction makes this approach demanding.

Teachers suggested that *adapting SLI material resources, acquiring qualified high school lab assistants, and introducing SLI to lower secondary schools* would help implement SLI in upper secondary classrooms. Considering the teachers' own report about lack of chemistry knowledge and practical experience, it would be difficult for them to design and develop hands-on SLI laboratory activities and manuals on their own. Lab assistants can help them prepare solutions and facilitate the experiments. To master SLI at higher levels where the need for chemistry competence is high, teachers could start by practicing the method in the lower grades.

Limitations to the study

Teachers were interviewed only once. A longitudinal study in which teachers are followed over a few years could provide more in-depth insight into their views about SLI and the challenges in implementing it in their classroom. Although the interview data were rich, and data saturation was reached, the absence of metacognition from the participants' teaching culture [45] might have limited their ability to reflect on their views on the SLI workshop. Moreover, since the SLI workshop was perhaps new and unique to the participants, they might have responded in favor of this method because of its "novelty effect" [46]. Nevertheless, the teachers' reflections, as reported in this study, could provide significant information on how high school teachers could implement well-planned laboratory instruction such as SLI in their own school contexts. Thus, this research not only confirms existing studies but also serves as a meaningful basis for advancing research on teachers' scientific practices and designing and implementing teacher PD programs, thereby discouraging the taken-for-granted traditional laboratory teaching strategies in particular and the lecture method in general at different levels of science education.

CONCLUSIONS AND IMPLICATIONS

Our study suggests that SLI has the potential to create a conducive laboratory learning environment and provide teachers with collaborative learning opportunities and skills. Therefore, SLI might be useful in developing teachers' agency—that is, providing them with more opportunities to autonomously make choices, engage in independent action, and take responsibility for students' science learning based on their own teaching practices. The implementation of SLI can help to overcome existing challenges Ethiopian teachers face related to laboratory instruction. This study also suggests how to incorporate at-home, inexpensive, safe, and relevant student-centered, hands-on and minds-on laboratory activities in high school science curriculum to promote students' engagement and learning. The application of pre-laboratory activities, teachers' scaffolding and reflective group discussions in the low-cost and small-scale as well context-based chemistry experiments might well equip teachers with diversified teaching-learning practices, thereby encouraging teachers to design and implement more experimental work in chemistry in Ethiopian high schools and elsewhere.

To ensure effective implementation, we recommend that Ethiopian high school teachers and stakeholders such as school rectors, science educators, and policymakers, meet to discuss how to facilitate the use of student-centered, well-planned laboratory instruction, establish basic laboratory facilities at rural as well as urban schools, and offer a PD program on such laboratory instruction for pre-service and in-service teachers on a regular basis. Finally, to better understand the in-service teachers' views on SLI, longitudinal PD programs—along with investigating the effect of SLI on students' science laboratory learning—should be provided at different levels of science education.

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REFERENCES

1. Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. Science Education, 88(1), 28–54.
2. Reid, N., & Shah, I. (2007). The role of laboratory work in university chemistry. Chemistry Education Research and Practice, 8(2), 172–185.
3. Lee, M. H., Liang, J. C., Wu, Y. T., Chiou, G. L., Hsu, C. Y., Wang, C. Y., ... & Tsai, C. C. (2020). High school students' conceptions of science laboratory learning, perceptions of the science laboratory environment, and academic self-efficacy in science learning. International Journal of Science and Mathematics Education, 18(1), 1–18.
4. Tesfamariam, G., Lykknes, A., & Kvittingen, L. (2014). In: I. Eilks, S. Markic & B. Ralle (Eds.), *Science education research and education for sustainable development,* Chapter in anthology. Germany: Shaker Aachen.
5. Hofstein, A., & Lunetta, V. N. (1982). The role of the laboratory in science teaching: Neglected aspects of research. Review of Educational Research, 52(2), 201–217.
6. Joshi, R., &Verspoor, A. (2013). *Secondary education in Ethiopia: Supporting growth and transformation*. Washington, D.C.: The World Bank
7. Westbrook J, Durrani N, Brown R, Orr D, Pryor J, Boddy J, Salvi F (2013) Pedagogy, curriculum, teaching practices and teacher education in developing countries. Final report. Education Rigorous Literature Review. Department for International Development. http://eppi.ioe.ac.uk/
8. Cossa, E. F. R., & Uamusse, A. A. (2015). Effects of an in-service program on biology and chemistry teachers' perception of the role of laboratory work. Procedia-Social and Behavioral Sciences, 167, 152–160.
9. MoE (2018). Ethiopian education development roadmap (2018-30): An integrated executive summary (draft), Addis Ababa, Ethiopia: Ministry of Education, Education Strategy Center.
10. World Bank (2019). The World Bank in Ethiopia. Retrieved 20 May 2021 from www.worldbank.org/en/country/ethiopia/overview.
11. Belay, S., Atnafu, M., Michael, K., & Ermias, M. A. (2016). *Strategic policy for national science, technology and mathematics education*. Addis Ababa, Ethiopia: Ministry of Education.

12. Guskey, T. R. (2002). Professional development and teacher change. Teachers and Teaching, 8(3), 381–391.
13. Osman, D. J., & Warner, J. R. (2020). Measuring teacher motivation: The missing link between professional development and practice. Teaching and Teacher Education, 92, 1–12.
14. Krasnoff, B. (2014). *Professional development*. Education Northwest: The Northwest Comprehensive Center (NWCC).
15. Åhman, N., Gunnarsson, G., &Edfors, I. (2015). In-service science teacher professional development. NorDiNa: Nordic Studies in Science Education, 11(2), 207–219.
16. Brownell, S. E., & Tanner, K. D. (2012). Barriers to faculty pedagogical change: Lack of training, time, incentives, and… tensions with professional identity? Cell Biology Education Research—Life Sciences Education, 11(4), 339–346.
17. Boesdorfer, S. B., & Livermore, R. A. (2018). Secondary school chemistry teacher's current use of laboratory activities and the impact of expense on their laboratory choices. *Chemistry* Education Research and Practice, 19(1), 135–148.
18. Hayes, K. N., Inouye, C., Bae, C. L., &Toven-Lindsey, B. (2021). How facilitating K–12 professional development shapes science faculty's instructional change. Science Education, 105(1), 99–126.
19. Lin, T. C., Hsu, Y. S., Lin, S. S., Changlai, M. L., Yang, K. Y., & Lai, T. L. (2012). A review of empirical evidence on scaffolding for science education. International Journal of Science and Mathematics Education, 10(2), 437–455.
20. Yuriev, E., Naidu, S., Schembri, L. S., & Short, J. L. (2017). Scaffolding the development of problem-solving skills in chemistry: guiding novice students out of dead ends and false starts. Chemistry Education Research and Practice, 18(3), 486–504.
21. Ateş, Ö., &Eryilmaz, A. (2011). Effectiveness of hands-on and minds-on activities on students' achievement and attitudes towards physics. In *Asia-Pacific Forum on Science Learning and Teaching*, 12(1):1–22. The Education University of Hong Kong, Department of Science and Environmental Studies.
22. Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. International Journal of Science Education, 30(14), 1945–1969.
23. Agustian, H. Y., &Seery, M. K. (2017). Reasserting the role of pre-laboratory activities in chemistry education: A proposed framework for their design. Chemistry Education Research and Practice, 18(4), 518–532.
24. Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. Journal of Science Teacher Education, 13(1), 1–12.

25. King, D. (2012). New perspectives on context-based chemistry education: Using a dialectical sociocultural approach to view teaching and learning. Studies in Science Education, 48(1), 51–87.
26. Huri, N. H. D., & Karpudewan, M. (2019). Evaluating the effectiveness of Integrated STEM-lab activities in improving secondary school students' understanding of electrolysis. Chemistry Education Research and Practice, 20(3), 495-508.
27. Kakisako, M., Nishikawa, K., Nakano, M., Harada, K. S., Tatsuoka, T., & Koga, N. (2016). Stepwise inquiry into hard water in a high school chemistry laboratory. Journal of Chemical Education, 93(11), 1923–1928.
28. O'Donoghue, J. (2019). Simplified low-cost colorimetry for education and public engagement. Journal of Chemical Education, 96(6), 1136–1142.
29. MoE (2020). Education statistics annual abstract September 2019-March 2020. Addis Ababa, Ethiopia: Ministry of Education, Education Management Information System (EMIS) and ICT Directorate
30. Eggen, P. O., & Kvittingen, L. (2004). A small-scale and low-cost apparatus for the electrolysis of water. Journal of Chemical Education, 81(9), 1337–1338.
31. Criswell, B. (2006). A diaper a day and what's going on with gaviscon?: two lab activities focusing on chemical bonding concepts. Journal of Chemical Education, 83(4), 574.
32. Asheim, J., Kvittingen, E. V., Kvittingen, L., &Verley, R. (2014). A simple, small-scale Lego colorimeter with a light-emitting diode (LED) used as detector. Journal of Chemical Education, 91(7), 1037–1039.
33. Chatmontree, A., Chairam, S., Supasorn, S., Amatatongchai, M., Jarujamrus, P., Tamuang, S., &Somsook, E. (2015). Student fabrication and use of simple, low-cost, paper-based galvanic cells to investigate electrochemistry. Journal of Chemical Education, 92(6), 1044–1048.
34. Zimmermann, B. J. (2002). Becoming a self-regulated learner: An overview. Theory into Practice, 41(2), 64–70.
35. Schmidt-McCormack, J. A., Muniz, M. N., Keuter, E. C., Shaw, S. K., & Cole, R. S. (2017). Design and implementation of instructional videos for upper-division undergraduate laboratory courses. Chemistry Education Research and Practice, 18(4), 749–762.
36. Domin, S.D. (1999). A review of laboratory instruction styles. Journal of Chemical Education, 76(4), 543–547.
37. Dilshad, R. M., & Latif, M. I. (2013). Focus group interview as a tool for qualitative research: An analysis. Pakistan Journal of Social Sciences (PJSS), 33(1), 191-198.
38. Clarke, V. & Braun, V. (2014). Thematic Analysis. In T. Teo (ed.), *Encyclopedia of Critical Psychology* (pp. 1947-1952). New York: Springer. DOI 10.1007/978-1-4614-5583-7.

39. Spagnoli, D., Wong, L., Maisey, S., & Clemons, T. D. (2017). Prepare, do, review: A model used to reduce the negative feelings towards laboratory classes in an introductory chemistry undergraduate unit. Chemistry Education Research and Practice, 18(1), 26–44.
40. Karataş, F. Ö. (2016). Pre-service chemistry teachers' competencies in the laboratory: a cross-grade study in solution preparation. Chemistry Education Research and Practice, 17(1), 100-110.
41. Högström, P., Ottander, C., &Benckert, S. (2010). Lab work and learning in secondary school chemistry: The importance of teacher and student interaction. Research in Science Education, 40(4), 505–523.
42. Nivalainen, V., Asikainen, M. A., Sormunen, K., &Hirvonen, P. E. (2010). Preservice and inservice teachers' challenges in the planning of practical work in physics. Journal of Science Teacher Education, 21(4), 393–409.
43. Yalcin-Celik, A., Kadayifci, H., Uner, S., & Turan-Oluk, N. (2017). Challenges faced by pre-service chemistry teachers teaching in a laboratory and their solution proposals. European Journal of Teacher Education, 40(2), 210–230.
44. Chua, K. E., & Karpudewan, M. (2017). The role of motivation and perceptions about science laboratory environment on lower secondary students' attitude towards science. Asia-Pacific Forum on Science Learning and Teaching, 18(2), 1–16.
45. Heyes, C., Bang, D., Shea, N., Frith, C. D., & Fleming, S. M. (2020). Knowing ourselves together: The cultural origins of metacognition. Trends in Cognitive Sciences, 24(5), 349–362.
46. Bindis, M. (2020). "I love science": Opinions of secondary school females toward science and science careers. International Journal of Science and Mathematics Education, 18, 1655–1671.