education sciences

MDPI

Article

Examining the Effects of Supervised Laboratory Instruction on Students' Motivation and Their Understanding of Chemistry

Mirtachew T. Ali [1,2,*], Annette Lykknes [1] and Dawit T. Tiruneh [3]

[1] Department of Teacher Education, NTNU–Norwegian University of Science and Technology, N-7491 Trondheim, Norway; annette.lykknes@ntnu.no
[2] Department of Chemistry, Bahir Dar University, Bahir Dar P.O. Box 79, Ethiopia
[3] REAL Centre, Faculty of Education, University of Cambridge, Cambridge CB2 8PQ, UK; dtt24@cam.ac.uk
* Correspondence: mirtachew.t.ali@ntnu.no

Abstract: This paper examines the impact of supervised laboratory instruction (SLI) on grade 12 students' understanding of acid–base and solution chemistry topics in the context of Ethiopian secondary schools. A mixed-methods research design was employed, with a purposive sampling of 160 secondary students from six schools in Northwest Ethiopia. The students were divided into two groups: an experimental group (n = 76) and a control group (n = 84). The experimental group attended sessions that were designed based on self-regulated learning (SRL) strategies with SLI, and the control group attended regular instruction designed by the course teacher. Both quantitative and qualitative data were collected to explore the impacts of the experimental and control lessons on improving students' conceptual understanding and motivation. Descriptive and inferential statistics (for the quantitative data)and reflexive thematic analysis(for the qualitative data)were employed to analyse the data. The findings showed that the SLI-SRL teaching approach for the experimental group resulted in a significantly higher conceptual understanding of the selected chemistry topics than the regular instruction for the control group. In addition, participants from the experimental group indicated that the SLI approach enhanced their motivation towards chemistry. These findings suggest that improving high-school students' motivation and their conceptual understanding of chemistry requires paying attention to the lesson design.

Keywords: chemistry education; supervised laboratory instruction; acid–basechemistry; solution chemistry; conceptual understanding; Ethiopia

Citation: Ali, M.T.; Lykknes, A.; Tiruneh, D.T. Examining the Effects of Supervised Laboratory Instruction on Students' Motivation and Their Understanding of Chemistry. *Educ. Sci.* **2023**, *13*, 798. https://doi.org/10.3390/educsci13080798

Academic Editor: James Albright

Received: 25 June 2023
Revised: 27 July 2023
Accepted: 1 August 2023
Published: 3 August 2023

1. Introduction

Recent high-school science teaching practices in low-income countries, such as Ethiopia, show that there is a lack of effective instructional strategies that actively engage students in meaningful scientific learning activities and acquire sufficient opportunities to collaborate with their peers [1]. Ethiopian chemistry teachers' laboratory teaching practices, for example, are largely restricted by the lack of laboratory spaces and facilities, large class sizes, overloaded curricula, insufficient experimental practices, students' lack of interest and motivation in learning chemistry and the absence of qualified lab assistants [1,2].

Within the Ethiopian education sector, grade 12, in which this study takes place, is the final year of senior high-school education. At the end of this school year, students sit for the national higher education entrance certificate examination to join a university program. Therefore, equipping students with sound knowledge and practical skills in chemistry is helpful for their university transition in particular, and for future scientific endeavours in general. In the present study, we examine the effects of a carefully designed supervised laboratory instruction (SLI) program based on Zimmerman's [3] three-phase cyclical learning model—forethought, performance and self-reflection (see below)—aimed at improving grade 12 students' conceptual understanding of the topics of acids–bases and solutions. In this study context, SLI refers to learner-centred laboratory instructional pedagogy that emphasizes learning via social interaction in groups, for which sufficient scaffolding to actively engage learners in hands-on and minds-on activities and promote learning is considered pivotal. SLI can also be described as an enquiry-inspired teaching method in which teachers play the role of facilitators and assist students in processing information and coaching their actions [4].

To this end, two selected experiments were used to embed the learning of a chemical concept into a meaningful context for the students and served as an avenue to improve their conceptual understanding. Following the recommendations by Asheim et al. [5] and to make SLI more feasible and motivating for the students, small-scale, low-cost and easy-to-make equipment and materials from students' everyday lives were used. Teaching chemistry through the SLI model has previously been attempted on Ethiopian in-service teachers [6]. The SLI approach was found to be a rich method for facilitating meaningful laboratory learning among high-school teachers. Teachers who participated in the SLI professional development (PD) training workshop reported that the method helped them enrich their scientific knowledge, as well as self-reflect and evaluate their own and their peers' learning and develop collaborative teaching–learning practices.

In this study, we look at whether and how the implementation of SLI in grade 12 chemistry improved students' conceptual understanding and motivation in acid–base and solution chemistry. The topics of acid–base and solution chemistry were purposely selected for this study because (1) most students are familiar with these topics, although with limited conceptual understanding [7]; (2) some acid-base and solution chemistry is necessary to understand the phenomena encountered in daily-life practices [8]; and (3) a deep understanding of acid–base and solution chemistry is more likely to support the learning of advanced chemistry topics, such as chemical kinetics, chemical equilibrium, acid–base equilibrium and electrochemistry [9,10].

In this study, the implementation of SLI-SRL laboratory activities (with small-scale, low-cost, and homemade equipment and materials) was considered important for many reasons. First, it serves as a platform for conducting laboratory activities in teaching laboratories with underprivileged laboratory teaching–learning contexts. Second, SLI-SRL might provide opportunities for an active and reflective laboratory learning environment. Conducting group discussions, participating in hands-on laboratory activities, encouraging students to make connections between science and their day-to-day life experiences, and helping students' development of self-evaluating abilities during their own learning processes are helpful to encourage students to become agents in the laboratory instructional process. Third, this study might offer science teachers the opportunity to effectively design laboratory lessons that guide and support students' meaningful learning by carefully embedding explicit SRL strategies into SLI.

The main purpose of this study is to examine the effectiveness of SLI on grade 12 students' conceptual understanding of acid–base and solution chemistry and on their motivation to learn chemistry. Additionally, students' experiences with SLI and challenges related to their learning from SLI are examined. This research is guided by the following research questions:

(1) What is the effect of an SLI teaching approach in improving grade 12 students' conceptual understandingofacid–base and solution chemistry topics?
(2) What aspects of SLI do the students find motivating and useful for their chemistry learning and which aspects do they find challenging?

2. Theoretical Background and Framework

2.1. Theoretical Background

Students studying chemistry (and teachers alike) face considerable difficulties in understanding chemical concepts properly. Learning difficulties related to acid–base and solution chemistry are prevalent in the extant literature. Barke et al. [11] summarised commonly held alternative conceptions among students, which included the idea that acids are “aggressive”, that only acids (not bases) can be defined by the Brønsted definition, that “pH values are different for acids and acidic solutions” (p. 177), and they reported that students have been reported to confuse acid–base neutrality for electrical neutrality. Likewise, Hoe and Ramanathan [12] found that Singaporean grade 9 students failed to build a firm understanding of the properties of acids and bases, strengths of acids and bases, pH, neutralization, indicators and sub-microscopic view of acids and bases. Sheppard [13] also indicated that acid–base concepts applied tounderstanding titration processes posed many challenges to 16 American grade 10–11 high-school students. The author reported, for example, that only one student was able to explain the differences between pH 3 and 5, representing a hundred-folddifference in the H^+ ion concentration.

Ebenezer and Erickson [14] examined high-school students’ understanding of the solubility concept. Students found it difficult to distinguish between the terms dissolving and melting. The problems related to explaining solution chemistry concepts at the macroscopic and submicroscopic levels were also found. By examining junior and senior high-school students’ conceptual understanding of, for example, the “conductivity of solutions”, Çalik [15] concluded that students have difficulties in comprehending the investigated concepts. Pınarbasi and Canpolat [16] also showed that Turkish undergraduate students had problems grasping chemistry concepts, and a large proportion of the students did not apply their chemical knowledge to real-life settings. Özden [17] reported that pre-service teachers failed to clearly articulate the relationship between solubility and temperature and how the boiling point of a solution is affected by the presence of dissolved substances.

An instructional remedy, which has been widely discussed since the 1970s, is to apply well-designed instructions that could make learners dissatisfied with their prior conceptsand acquirenew concepts, therebypromoting conceptual change [18]. Good results have been reported in subjects, including chemistry [19,20], but conceptual change as an instructional strategy has also been criticised for only considering individual cognitive processes and ignoring other individual processes (e.g., motivation and epistemological beliefs) and social factors, including the role of peers in learning processes [21]. Indeed, in order for conceptual change to occur via social interactions, “carefully thought-out scaffolding of scientific discourse” is reckoned to be important [18] (p. 67). Overall, students’ misconceptions seem to be largely resistant to change, persistent and difficult to remove even when using innovative instructional interventions [22,23].

Practical work, or laboratory instruction, is generally considered an important part of science teaching and might be referred to as a canon of science teaching, often taken for granted as an efficient and motivational way of teaching science concepts. However, both its learning effects and impact on students’ motivation for science have been challenged [24–26]. Indeed, Abrahams and Reiss [26] concluded that practical work was not effective in promoting science concept learning per se. They recommended carefully planned and explicit practical lessons in which hands-on activities were combined with a minds-on approach. Likewise, Agustian and Seery [27] contended that the use of well-designed chemistry pre-laboratory tasks could bring about a robust conceptual understanding and increased efficiency in performing laboratory activities. The use of higher-order thinking skills, minds-on laboratory activities [28] and enquiry-type laboratory work [29] have also been shown to provide high-school students with an enhanced understanding of acid–base concepts and develop positive attitudes towards chemistry learning in comparison to teacher-centred instruction. Priyambodo et al. [30] highlighted the role of collaborative learning in improving the motivation for learning acid-base chemistry among senior high-school students. Consequently, our SLI teaching was designed with pre-laboratory activities, minds-on laboratory activities and group reflections. Furthermore, our SLI was guided by the theory of self-regulated learning (SRL).

2.2. Theoretical Framework and the Design of SLI Teaching

This study employs self-regulated learning (SRL) as a foundational theoretical framework. Zimmerman [3] (p. 65) describes SRL as “the self-directive process by which learners transform their mental abilities into academic skills”. SRL has also been referred to as an active learning process in which learners proactively perform tasks to optimize their learning goals [31] and involves key self-regulatory process skills, such as goal setting, flexible use of learning strategies, self-monitoring, planning, efficient use of time, self-evaluation, self-motivation, appropriate help-seeking and attention control [3,32]. In school contexts, such skills have been found to enhance success in problem solving, academic achievement, intrinsic motivation and task interest [33,34]. For example, Labuhn et al. [35] examined the connection between self-regulatory learning interventions and the acquisition of a conceptual understanding of the "nutrition" content among 199 grade 7 German students. Their results showed that students' knowledge of subsequent instructional units was enhanced by the preceding intervention. Cleary et al. [36], who investigated the effect of a self-regulation empowerment program (SREP) on the conceptual understanding of U.S. biology 9th-grade urban high-school students, also reported that students who were taught through the SREP intervention improved their conceptual understanding and showed greater use of adaptive self-regulation strategies (i.e., environmental structuring and seeking help). SRL has also been considered suitable for effective teaching in science (laboratory) classrooms [37].

We designed an SLI program aimed at guiding learners towards cognitive and motivational engagement in learning tasks, inspired by Zimmerman's [3] SRL model. Zimmerman's [3] model involves three cyclical learning phases—forethought, performance and self-reflection—which can enhance students' self-generated thoughts and actions before, during and after engaging in learning tasks. In the developed SLI-based laboratory activities, learners were provided with sufficient opportunities to proactively monitor, regulate and control their thoughts to enable them to navigate their learning experiences and to help them promote their acquisition of knowledge and practical skills [3]. The forethought phase in Zimmerman's model involves goal setting (for example, defining the expected and attainable outcomes of laboratory learning) and strategic planning of tasks (e.g., selecting appropriate learning methods that suit the intended tasks and environmental contexts), as well as outcome expectations (beliefs about the ultimate products of the work) and learning goal orientation (identifying the purpose of the learning activity) to prepare for the work ahead [3,32,38]. The performance phase refers to the learning processes that occur during the implementation of, in this case, a laboratory session and involves self-control mechanisms, such as attention focusing and task strategies, along with self-observation and self-experimentation. In the third phase of Zimmerman's model, the self-reflection phase, learners not only engage in self-evaluation (one form of self-judgment) of their laboratory experiences pertinent to SLI-based laboratory activities but also engage in self-reaction in a way that reflects on their feelings of self-satisfaction and positively affects their performance in science laboratory learning. Self-reflection refers to thetime taken to stop, think and evaluate oneself and to systematically communicate with one's own learning experiences [3,39].

Zimmerman's [3] model appeared to be dependent on the learners' use of cyclical forethought, performance and self-reflection phases, thereby developing their self-initiative, perseverance and adaptive skills [40]. For example, Zimmerman and Moylan [38] indicated that students' goal-setting during the performance phase may affect the standard that they will employ to self-evaluate during the self-reflection phase. Zimmerman and Moylan [38] also claimed that students who acquired strong learning goal orientations had a greater chance of enacting strategic planning in the forethought phase and displaying superior self-reflection processes. It isworth noting that both forms of students' self-reactions are dependent on their self-judgments during the self-reflection phase, which influences the forethought phase's processes in cyclical learning while embarking on further efforts to acquire proficiency [38]. The striking feature of the self-reflection phase lies in the use of students' reflections to help them adapt their planning, strategy, time management and self-monitoring to plan for the next tasks [3]. According to Zimmerman and Moylan [38], "one of the purposes of the three-phase model of self-regulation was to identify specific metacognitive processes and motivational sources and to explain their cyclical interrelation during ongoing efforts to learn in real contexts (p. 13)".

Gericke et al. [41] argued that designing laboratory activities that focus on students' abilities to pose questions and plan investigations, along with offering sufficient teachers' guidance throughout the teaching—learning process, would make a worthwhile contribution to improving students' (self-regulated) learning. These ideas also align well with Abraham and Reiss's [26] recommendation of carefully planned and explicit practical lessons to increase the learning outcome of practical activities. In SLI-SRL, as part of the forethought phase, great attention was paid to establishing a plan for laboratory tasks and pre-laboratory discussions to support students' acquisition of sound conceptual knowledge and independent learning skills, as well as to increase their interest in learning chemistry [27,42]. Questions such as "Do the laboratory tasks build on a task you have done before?" and "How much time do you think the tasks will take?" were part of the laboratory planning. The examples of pre-laboratory discussion questions in SLI were "What is the function of radiation in the determination of unknown concentration using Lego colorimeter?" and "How does hardness of water occur?". Teachers' follow-up questions included the following: "What do you think the roles of chemical weathering of rocks in increasing the hardness of nearby water sources?" and "How do the chemical reactions occur during the chemical weathering of rocks?" Pre-laboratory activities are included in SLI because they are (1) beneficial to students' learning in the laboratory, (2) they can be embedded into the overall laboratory learning process, (3) they focus on the whole task, drawing learners' attention to overall strategy and approaches, (4) they focus on supportive information and (5) they address the affective domain [27]. The pre-laboratory activities were meant to ensure that the students were prepared for the intellectual confidence necessary for their laboratory experiences [27]. Task strategies in the performance phase include asking students the following questions: "Why should the complexometric titration be adjusted at a pH of 6–8?" and "What observation techniques and tests do you think are helpful to identify the different water samples (i.e., distilled, bottled and tap water)?" Also, allowing students sufficient time to conduct laboratory activities isconsidered important to provide them with authentic laboratory experiences, thus adding to their practical skills and understanding of scientific work [43,44].

Tosum up, the following three central factors characterize the SLI-SRL pedagogy: pre-laboratory activities to allow learners to prepare well, teachers' scaffolding during and after laboratory activities, and reflective group discussions with peers to enhance learning (during and after laboratory activities).

Based on these findings, we have introduced an SLI instruction that makes use of SRL strategies as a tool to enhance students' motivation and their conceptual understanding of acids and bases, as well as solution chemistry.

3. Method

3.1. Research Design

A mixed-method research design was employed in this study. The quantitative method involved a quasi-experimental design with a pre-test–post-test non-equivalent control group. The pre- and post-tests were aimed at understanding whether or how laboratory instructional approaches (either the SLI or regular teaching methods) improved grade 12 students' conceptual understanding of acid–base and solution chemistry topics, which serves to answer the first research question of this study. The qualitative method involved utilizing semi-structured focus group (FG) interviews and classroom observation notes to answer the secondresearch question. In this way, we captured students' experiences with SLI and the features of SLI that they found to be useful and challenging.

3.1.1. Participants and Setting

This study took place in six public senior high schools in Northwest Ethiopia. Grade 12 students had comparable academic backgrounds, with similar environmental surroundings at school and in the local community. Six schools were selected purposely using the following criteria: schools that were located around a 50 miles radius from the first author's base, weekly course schedules that were suitable for the research work, and schools where permission was granted to conduct the study. From the six selected schools, four were randomly assigned to the experimental schools. The remaining two schools were assigned as controls. An invitation to participate in the study was first sent out to all the students in the experimental and control schools. From the experimental schools, we randomly selected 76 students (girls = 34; boys = 42) among the students who agreed to participate. We selected a proportional number of students per school: school 1 = 20; school 2 = 23; school 3 = 14; school 4 = 19. A total of 76 students were assigned tothe experimental group (EG). From the two control schools, we randomly selected 84 students (girls = 37; boys = 47) among the students who provided consent, and they were assigned to the control group (CG). We selected 42 students from each control school because the overall grade 12 student population was the same in each school. The grade 12 chemistry teachers in both the experimental and control schools were comparable: similar years of teaching experience and equivalent qualifications (master's degree in chemistry). One teacher was selected from each experimental school and control school to implement the lessons. The participants for the focus group interviews were recruited (and selected) following a purposive sampling approach: (1) students who agreed to participate in the FG interview, (2) students who were able to provide "information-rich" discussions throughout the intervention, assuming that they would have the potential to maximize comprehension of the laboratory experiences regarding SLI, and (3) students who had sufficient time to participate in the interview. A total of 41 students (16 girls and 25 boys) who volunteered were selected.

3.1.2. Experimental Group Teachers' Training

The four teachers who taught the EG participated in a previous SLI professional development workshop as part of this project. The teachers who taught the control group did not receive SLI-based training as part of this project. Teachers who taught the EG were also provided with SLI-adapted laboratory manuals.

In the workshop training, the teachers conducted five potentially low-cost and relevant chemistry experiments as a means of learning from and practicing a new pedagogical intervention for its effective implementation in their own classrooms. Two experiments—unknown concentration determination using a homemade Lego colorimeter and the hardness of water—were selected for this study. The experiments created an avenue for shared responsibility among teachers, similar to that of a professional community of learners. Furthermore, the workshop included training on active teaching–learning skills related to how pre-laboratory activities, teachers' scaffolding, and reflective group discussions could be applied in high-school science teaching laboratories.

3.2. Interventions

The interventions of the two SLI-adapted experiments for the EG and teaching the same topics for CG through a regular instructional approach were implemented for nearly four weeks: one week for collecting informed consent and administering the pre-test, two weeks for implementation and one week for conducting the post-test. The content for the lessons in both the experimental and control sessions was based on the same national chemistry curriculum developed by the Ethiopian Ministry of Education, which aimed at teaching acid–base equilibrium and solution topics from the grade 12 syllabus. For the purpose of this study, concepts such as types of solutions, ways of expressing concentrations of solutions and solution preparations, pH, acid–base, complexometric titrations and acid–base indicators were selected.

3.2.1. Intervention for the EGs

As noted, the interventions of SLI involved SRL processes, as identified by Zimmerman [3]. For this purpose, two SLI-adapted laboratory activities, namely the hardness of water test adapted from Kakisako et al. [45] (to teach acid–base chemistry topics) and unknown concentration determination of Cu $(NO_3)_2$ solution (from Asheim et al. [5]) to teach solution chemistry topics were used in the EG as active learning materials.

The experimental sessions were carried out with 14 to23 students in each EG classroom. The students worked in groups of three to five students. A typical laboratory session for the EG lasted for two and a half hours, which involved student discussion of pre-laboratory questions for 30 min, conduction of the actual experiment for 80 min and evaluation and self-reflection on their own and peers' laboratory activities and discussion of post-laboratory exercises for about 40 min. The EG teachers led the discussions by providing support to students' learning throughout the teaching–learning process.

Students were supported in setting their goals and planning strategies by helping them increase their abilities to ask themselves questions such as "How will I structure the given laboratory tasks?", "What immediate checkpoints and sub-goals do I have to better understand the given tasks?", "Will I need to search for additional resources from the library and seek out support from my peers and teachers?" and "Given my learning needs, when should I get started on the given tasks?" Teachers who taught the experimental group (EG) students also helped them set expectations for the outcomes and mapped out effective learning strategies that suited their set goals. For example, students were asked guiding questions, including "Given the amount of time you have available and your strengths and weaknesses, and your current attitudes towards SLI, what kind of outcomes would you wish to attain?"

3.2.2. Intervention for the CGs

The CG students attended lessons on the same topics and for the same duration as the EG students, but the lessons were designed by a regular chemistry teacher. A typical CG session lasted for nearly two and a half hours and involved the teacher defining and elaborating on the solution and acid–base concepts verbally, sometimes by writing on the blackboard with the help of their notes and sometimes dictating short notes to the students. Few, if any, practical activities were conducted. Each teacher solved some multiple-choice questions related to acid–base and solution chemistry concepts in the classroom that they thought could prepare students for the coming nationwide university entrance examination. While the students solved problems, the teacher walked around the classroom with limited one-to-one support. The teacher sometimes provided the students with take-home assignments.

In general, the instruction in the CG was largely based on direct instruction where the teacher dictated the facts and concepts of solutions and acids–bases in chemistry. A summary of the contents of the CG and EG interventions is shown in Table 1.

3.3. Hardness of Water Experiment

The hardness of water test experiment was conducted during the first week. The purpose of the hardness of the water test was to develop students' comprehension of the fundamental principles of complexometric titration. Students' frequent contact and usage of water on a daily basis made an important resource for introducing the relevance of chemistry learning to their daily lives, such as understanding environmental issues [46].

Before coming to the actual lab sessions, students were required to draw a flow chart that represented the whole laboratory task approach so that they could set their learning goals and devise strategies to accomplish the laboratory activities. In the forethought phase, students were required to gain a sound understanding of the hard water concept and the basics of acids–bases and properties and chemical reactions of aqueous solutions through pre-laboratory activities and group discussions performed prior to starting the actual experiment. These activities included the use of three models that help to define acids–bases: (1) the Arrhenius model (a substance that produces H^+/OH^- ions in aqueous solution), (2) the Brønsted–Lowry model (proton [H^+] donor/acceptor) and (3) the Lewis model (the transfer of electron pair [s]). The Lewis model has some more advantages in understanding the main characteristics of the molecules and ions that exhibit acidicand basic behaviours. For example, to guide students towards a better understanding of the chemical and physical properties of hard water, cations that act as Lewis acids, such as Al^{3+}, were discussed to further broaden the range of substances that can be considered acids, such as Ca^{2+} and Mg^{2+} ions, since cations have empty orbitals that allow them to act as Lewis acids.

Table 1. Summary of the control and experimental group interventions.

Types of Instruction (Groups)	Main Features of the Intervention	Supplementary Features of the Intervention	Teaching—Learning Strategies
Regular teaching method (CG)	Lectures Asking and answering questions Take-home assignments	• Targeting nation-wide multiple-choice exams • Little, if any, demonstration activities • Limited one-to-one support during the lecture	• Defining and elaborating abstract chemical concepts • Dictating notes/copying notes from the blackboard • Asking oral questions
SLI (EG)	Pre-laboratory activities Teachers' scaffolding Reflective group discussions	• Small-scale, low-cost, and homemade materials and equipment • Introduction of relevance into chemistry experimentation with the inclusion of daily life experiences • Interactive lab activities adapted from published articles as active learning materials	• Forethought phase • Performance phase • Self-reflection phase

In the performance phase, students performed the experiment in small groups on the established water quality analysis tests, namely the dissolution of Ca^{2+} and Mg^{2+} ions and the pH of water samples collected from three different water sample sources (i.e., bottled, tap and distilled water). The teachers led the reflective small-group discussions and provided guidance and support to help the students develop firm knowledge about acid–base concepts and to enrich their skills about how an acid–base type complexometric titration could be applied to quantify the hardness of water.

The hardness of the water was determined using a small-scale Total Hardness Test Kit (HC874663, Darmstadt, Germany), which uses a titration method. The teacher demonstrated core concepts such as titration, equivalence point, the acid–base characterization of metal ions and EDTA and metal indicator, Eriochrome Black T (BT), along with a demonstration of the titrimetric determination process with titration pipette using a test kit for modeling students' learning. This was aimed at enabling students to acquire the basic experimental principles of acid–base type complexometric titration at large.

In the self-reflection phase, students were provided with invaluable insights into conducting multidirectional conversations that involved back-and-forth movement between the acid–base chemistry concepts and solution chemistry and contextual issues to make the experiment relevant to students' real lives. For example, in the discussion forum, reflective group discussions dealt with concepts such as the physicochemical properties of soaps and how mild heartburn can be relieved when someone swallows his/her saliva repeatedly. After the students debated about these chemical phenomena, the teacher, for example, provided a hint that an acid–base neutralization reaction was responsible for the decrease in heartburn since saliva contains the bicarbonate ion (HCO_3^-), which acts as a base and, when swallowed, neutralizes some of the acids in the oesophagus.

Students discussed the quality of water and the methods used to soften water through exhaustive discussions based on their synthesis of the collected data. Briefly, students were assigned to reflect on their laboratory experiences and conduct post-laboratory activities that focused on navigating the acceptable concentrations of Ca^{2+} and Mg^{2+} ions and pH values for the suitable use of water for drinking based on reference values reported by the World Health Organization [47]. In addition, the teachers led reflective group discussions with respect to the impacts of hard water–whether the effectiveness of soaps and detergents was reduced by causing decreased lathering–and the effects related to residue and build-up formed in water pipelines and washing machines. These activities were considered important for enhancing students' ecological knowledge of the effects of an increased concentration of metal ions in water on the healthy lifestyle of a community.

3.4. Unknown Concentration Determination of Cu (II) Solution Experiment

In the second week of the second experiment, the unknown concentration determination of copper nitrate solutions was implemented in four sessions (i.e., one session in each experimental school using similar assignments and procedures to the hardness of the water experiment). We aimed to equip students with a deep-level understanding of the types of solutions and preparations of solutions, characterizing solutions by considering their capacity to dissolve in a solute and the effects of ion-dipole interactions in the solution formation process. As a means of providing an opportunity to deeply understand the concept of the solution–formation process, which is affected by energy and entropy, teachers brought up a "Card game analogy" to make the entropy concept even more understandable to the students: a deck of new playing cards becomes mixed up after it has been shuffled a few times in the same way as solute and solvent molecules mix to form a solution, thereby increasing randomness or disorder.

The students also studied molarity and ways of preparing solutions to prepare them for quantitative enquiry. To emphasize the usefulness of chemical analysis and quantification in everyday life, students were allowed to determine unknown concentrations of a Cu (II) solution with the help of the teacher's guidance and support. In doing so, students also learned about the fundamental concepts related to Beer–Lambert's law using a low-cost, small-scale and homemade Lego colorimeter with light-emitting diodes as the light source and detector (light-voltage sensor). The Lego bricks provided an accurate and robust alignment of the light source and detector while still being flexible. In the performance phase, the colorimeter presented an opportunity for students to explore basic concepts, such as transmittance, absorbance and determination of unknown concentration after making a calibration curve. During the enquiry process, the teachers assisted students by providing directive questions that scaffolded their learning, such as "How is a green laser pointer similar in function and working principles to a radiation source"?

Although the laboratory activities of the second experiment were mainly concerned with the unknown concentration determination of the Cu $(NO_3)_2$ solution, in the self-reflection phase, students were also allowed to undergo reflective group discussionsthat-would enable them to acquire knowledge about thedetermination of the concentration of salicylic acid in shampoos that are used for washing face [48]. The determination of caffeine concentration in coffee beans was also brought up as a strategy to identify the origin of coffee samples in Ethiopia [49] as a 'need-to-take-action' activity. In this case, students were provided with supporting materials before they came to the laboratory session. In addition, students were given opportunities to explore the working principles of the colorimeter in the identification of unknown concentrations intuitively utilizing simplified laboratory activities. Since the topic was somehow advanced, great care was taken to keep the experiment within the level of the students' comprehension.

In summary, the acid–base concepts learned in the hardness of the water experiment were inseparably connected to the solution concepts studied in the unknown concentration determination of the Cu (II) experiment.

3.5. Data Collection

The data were collected between January and March 2020. In order to answer the research questions, rich data were collected using a three-tier multiple-choice Chemistry Concept Test (CCT), semi-structured FG interviews and classroom observations. While both the EG and CG students completed pre- and post-tests of the CCT, additional data were collected from the EG using FG discussions and classroom observation notes to document the students' experiences with SLI as a method. Classroom observation data were also obtained from the CG students' teaching–learning processes to understand the classroom practices in relation to the questions the teacher asked, the collaboration between the students on various classroom assignments, the feedback the teacher provided to the students, and the overall student–student and teacher–student interactions.

3.5.1. Chemistry Concept Test (CCT)

The CCT consisted of twelve items, with three-tier multiple-choice questions andfour alternative options, whichwere adapted from previously prepared tests in the literature and further developed by the authors. In the development of the test, the authors employed a modified version of the method applied for three-tier test preparation aimed at diagnosing primary teachers' understanding of the ecological footprint by Liampa et al. [50] (see also Cetin-Dindar&Geban [51] for three-tier acid–base test development). The purpose of the CCT was to measure the CG and EG students' understanding of the concepts of acids and bases and solutions in chemistry and to identify their misconceptions (see Appendix A for the CCT questions). The test aimed to cover an acid–base equilibria unit, during which the concepts of pH (item #1), titrations (item #2), acids and bases (item #5) and indicators (item #8) are investigated, and a solution chemistry unit that considered concepts of properties, preparations and formation processes of solutions (items#3, #6 and #7), concentration (item #4) and as the application of knowledge of acid–base and solution chemistry to articulate real-life issues (item #9). The CCT employed in this study comprised nine questions in total after the item analysis was completed.

In the first phase of the development process, the conceptual definitions of acid–base and solution chemistry concepts were investigated in the literature, and then the response or content tier questions were developed. In the second phase, the students' ability to explain was judged by developing the reason or explanation tier, and their overall performance was assessed using the confidence tier for correctly answering the two tiers. In the first- and second-tier questions, one correct answer and three distractors were developed by considering students' misconceptions about the acid–base and solution chemistry concepts in the literature and based on the authors' own teaching experience in high schools. In the third phase, the prepared CCT was checked for its format and content validity by two experienced university chemistry instructors and one science educator. Furthermore, two EG teachers and two CG teachers reviewed the instrument to check whether it was applicable to the lesson of interest. The content validity of the three-tier test was checked in such a way that experienced teachers and science educators evaluated the test in terms of appropriateness to grade 12 students' conceptual understanding, misconceptions, and the list of objectives to be achieved after lab sessions and regular instruction. Based on their analysis, constructive feedback, such as revisiting the depth of students' understanding and eliminating ambiguous statements to enhance the clarity of language was obtained and the test was improved. Finally, the test was piloted with 25 grade 12 students from other high schools who did not participate in the study, and some modifications were made to the test items after the pilot test.

Students who correctly answered the response tier and reason tier and showed their confidence by choosing "Yes" for correctly answering the response and reason tiers were assigned a score of "1"; otherwise, combinations were assigned "0". The total test scores consisted of 12 points. The students took the pre- and post-tests face-to-face, which lasted about 45 min. Test items were kept at a minimum to avoid cognitive fatigue and lack of response to the test items.

To check the difficulty level of the test and determine how well it discriminated between high achievers and low achievers, an item analysis was conducted. The item difficulty index that was obtained after excluding three items that were not found to be within the acceptable range in terms of item difficulty and item discrimination indices was between 23% and 72%. This result indicated that the test items were neither too easy nor too difficult. In addition to the item difficulty levels, the item discrimination indicesrangedfrom 0.41 to 0.54, which was within the acceptable range, as indicated by Khairani and Shamsuddin [52]. The KR-20 (Kuder–Richardson Formula 20) reliability coefficients of the pre-CCT and post-CCT were 0.87 and 0.79, respectively. The reliability coefficients across the items ranged from 0.62 to 0.93. This shows that both the administered test scores were internally consistent. The CCT test is provided in Appendix A.

3.5.2. Semi-Structured Focus Group Interviews

The aim of the semi-structured FG interviews was to explore in depth the students' experiences with SLI, the features that motivated them the most and the challenges related to this instructional approach. It was decided to use focus group (FG) interviews because they can create a more natural setting for participants to sufficiently discuss the topics under investigation in groups and, therefore, can offer inevitable opportunities for researchers to gather rich data that might not otherwise be accessible [53]. In addition, FG interviews are cost-efficient, as opposed to individual interviews. Eleven FG interviews, which consisted of three to four participants in each group, were carried out for a total of 41 students (16 girls and 25 boys). FG interviewees who knew each other very well were assigned to their respective groups to allow them to provide "shared experiences and enjoy a comfort and familiarity which facilitates discussion or [even increase in their] ability to challenge each other comfortably" [54] (p. 293).

The FG interviews were conducted face-to-face by the first author in a quiet laboratory classroom of each experimental school within three days after completing the intervention and lasted between 25 and 45 min (the majority lasted 35 min), depending on the size of the participants involved in the FGs and the schedule of the schools. The first author conducted the interviews using active mediation/facilitation of the discussion groups in an open-minded, flexible and non-judgmental way, during which a balance between firm steering and interactive open discussions was maintained aimed at soliciting in-depth data from the participants' views. The first author also reflected on the remarks made by the interviewees to further elicit the relevant phenomena under investigation. The first author prioritized a more flexible and fluid approach to FG interviewing, which facilitated the interaction and co-construction of meaning between the author and the interviewees. To this end, the first author employed semi-structured FG interview questions and probing follow-up questions, such as "Can you tell me a bit more about the benefits of the SLI approach?", to elicit sufficient information. The semi-structured interview questions are given in Appendix B.

The Intervention and interviews were originally conducted in the Amharic language, and the audio-recorded interview data were transcribed verbatim. The transcribed transcripts were first translated into English by the first author, and then an Amharic-English bilingual professor checked the appropriateness of the translation. In order for the researcher to capture rich data from the students' views and to make participants comfortable, the interviews and interventions were conducted using the participants' mother tongue instead of English, which is used as a common language in teaching and learning at high schools. The interview recordings were kept confidential so that no one other than the authors could access them and were deleted after the recordings were fully transcribed. Pseudonyms were used for the transcripts and further analysis.

3.5.3. Classroom Observations

Classroom observation notes were maintained throughout the intervention period for both groups. The first author observed the sessions and took observation notes on students' classroom activities (questions from the teacher, note-taking by students, questions and discussions in groups of peers and teacher–student or student–student interactions). Specifically, notes were taken on the potential challenges related to learning from the method that came to mind while observing.

3.6. Data Analysis

Descriptive and inferential statistics were used for the quantitative data. Visual inspection of histograms for the pre-test and post-test CCT scores showed that there were no potential outliers (see Figure 1). Tests of assumptions for normality were also conducted by examining the standardized CCT scores for the pretest and posttest. Shapiro–Wilk's test indicated that the CCT scores were normally distributed for both the pre-test (p = 0.38) and post-test (p = 0.60).

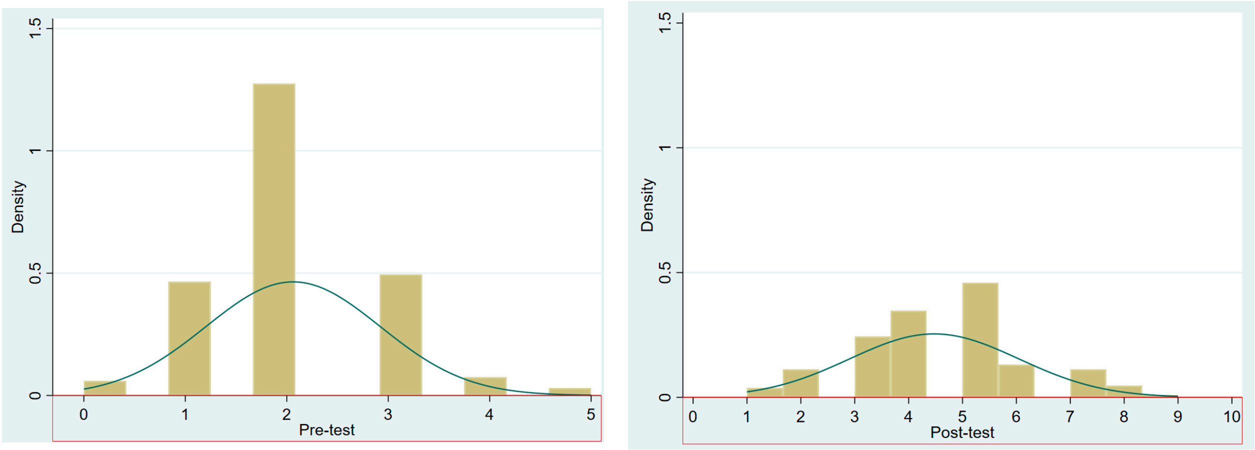

Figure 1. Histograms for pre-test and post-test CCT scores.

The interview transcripts were analysed using a reflexive thematic analysis (RTA) framework [55–57]. We utilized Braun et al.'s [55] multiphase RTA approach: (1) Data were familiarized with, and familiarization notes were written through reading and rereading the transcripts thoroughly in relation to the research questions. (2) The generation of initial codes, which involved focusing attention on systematically and rigorously making sense of meaning through an inductive coding approach working bottom-up from the data, was carried out. (3) Initial themes were generated, during which the back-and-forth analytical work of the earlier phases was performed to gain patterns of shared meaning. The first author performed the initial coding, which was reviewed, discussed and refined by the second author.

During this process, some codes were changed and some were moved between the code groups and themes. For example, the code "SLI is a motivating method to learn with" was moved from theme 2 to theme 1, and the code "SLI facilitates the development of laboratory skills" replaced the code "SLI allows to do hands-on laboratory activities" in theme 2 to better capture the essence of the informants' statements. The themes were then repeatedly checked until coherent themes that could offer an insightful story about the data in relation to the research questions were produced and agreed upon. (4) A review of potential themes was carried out to ensure that each candidate theme functioned as a fruitful interpretation of the data and offered opportunities for the provision of information that addressed the study's research questions. Finally, (5) defining and naming themes was performed by openly examining the themes and codes to make further revisions to the themes' names, content and structure, as well as to check whether the analytic narrative clearly utilized meaningful data extracts. A key approach to this phase includes a thorough and reiterative discussion among authors with the aim of checking (and double-checking) the themes against the whole dataset and noticing the apparent changes in the order in which the themes are placed, which would help establish a meaningful flow for the qualitative findings. During this process, for example, we refined theme 1 from "SLI enhances students' enjoyment in and learning of chemistry" to "SLI increases students' motivation for learning chemistry" and defined it as theme 1 instead of 2 in the original suggestion. The final codes and themes identified and developed from the qualitative analyses are presented in Table 2.

Table 2. Themes and codes for students' views on SLI.

Themes	Codes	Sample Excerpt
SLI increases students' motivation for learning chemistry	SLI is a motivating method to learn with	SLI is an essential and motivational instruction, which could redress the problems of the lecture method (Abdi, FG6).
	SLI encourages chemistry learning	SLI has helped me develop a sense of responsibility for what I should learn about chemistry in the laboratory (Lucas, FG4).
	SLI is an enjoyable teaching method	I found it [SLI] enjoyable to learn with (Husnia, FG7).
	SLI inspired me to study chemistry further	SLI further increased my motivation towards the pursuit of heading to chemistry-related careers (Linda, FG1).
SLI is a multifaceted learner-centred laboratory instruction	SLI makes chemistry more relevant	. . .it [SLI] has helped me identify what really exists in the daily-life practices and to find myself immersed in the process of systematic investigations (Brian, FG9).
	SLI facilitates the development of laboratory skills	I have learned how to practically prepare solutions, which is quite different from solution on paper (Habib, FG6).
	SLI encourages collaborative learning through reflective group discussions	SLI allows me to ask questions, reflect on lab tasks, and to discuss with my peers (Tore, FG1).
	SLI is a learner-centred laboratory instruction	I participated in lab activities that provide opportunities for collecting data while actively experimenting and to understand behind-the-scenes of the experiments (Nasir, FG2).
Laboratory learning through SLI is a demanding process	SLI is difficult without technical staff and sufficient laboratory equipment and consumables SLI takes much time It is difficult to comprehend the SLI teaching–learning materials	A shortage of laboratory materials and lack of laboratory technicians who could relentlessly guide students' chemistry learning. . .was seriously a real concern (Selam, FG8) The students may get bored with spending much time in the laboratory until they ensure the lab activities they are assigned to perform are thoroughly examined (Abi, FG3) We failed to understand the nature of SLI teaching–learning materials, and hence we were terrified and anxious about the delicacy of the apparatus and the equipment (Habib, FG6)

3.7. Ethical Issues

Permission to carry out the data collection and research was sought through formal letters to the school administrators. The way the collected data would be stored and the protection of subjects' sensitive and identifying information were reviewed and approved by the Norwegian Centre for Research Data. All the participating students, teachers and school directors signed a letter of consent. Students and teachers were informed about the processing of data and that no person-identifying information would be retained. Furthermore, they were given the opportunity to opt out of the study at any time.

4. Results

4.1. Quantitative Results of the Three-Tier CCT

Pre-Test–Post-Test Improvement on Conceptual Understanding

Our first research question focused on the effect of SLI on students' understanding of acid–base and solution chemistry topics. We hypothesized that students in the experimental group who attended lessons designed based on the SLI approach would significantly outperform those in the control group on conceptual understanding of acid–base and solution chemistry. The pre-test and post-test mean scores for the experimental and control groups are shown in Table 3. An independent sample t test was conducted to compare the pre-test CCT scores of the control and experimental groups. The mean score difference (0.11) was not statistically significant: $t(158) = 0.78$, $p = 0.78$. However, we found a significant difference in the post-test CCT scores between the control and experimental groups: $t(158) = 10.01$, $p < 0.001$). On average, students in the experimental group scored two more points in the post-test CCT items than those in the control group. We furtherexamined the specific CCT items that students answered correctly in both the pre-testand post-test.

Table 3. Descriptive statistics for pre- and post-test CCT scores, by gender and school.

Group	Mean (SD) Pre-Test	Mean (SD) Post-Test	Differences in Mean (Post-Test–Pre-Test)	T-Statistics
Control ($n = 84$)	2.01 (0.91)	3.55 (1.17)	1.54 ***	9.51
Girls ($n = 37$)	2.00 (0.88)	3.57 (1.19)	1.57 ***	6.43
Boys ($n = 47$)	2.02 (0.94)	3.53 (1.16)	1.51 ***	6.93
School C1 ($n = 42$)	2.07 (1.02)	3.79 (1.00)	1.72 ***	7.77
School C2 ($n = 42$)	1.95 (0.79)	3.31 (1.29)	1.36 ***	5.84
Experimental ($n = 76$)	2.12 (0.80)	5.50 (1.30)	3.38 ***	19.30
Girls ($n = 34$)	2.12 (0.81)	5.38 (1.44)	3.26 ***	11.56
Boys ($n = 42$)	2.12 (0.80)	5.60 (1.19)	3.48 ***	15.69
School E1 ($n = 20$)	2.55 (0.62)	5.45 (1.05)	2.90 ***	8.95
School E2 ($n = 23$)	2.26 (0.62)	5.39 (1.03)	3.13 ***	12.47
School E3 ($n = 14$)	1.71 (0.61)	5.43 (1.74)	3.72 ***	7.53
School E4 ($n = 19$)	1.79 (0.63)	5.74 (1.52)	3.95 ***	10.45
Mean differences: mean (experimental)—mean (control)	0.11	1.95 ***		

Note. t test scores for differences in mean are significant at *** $p < 0.001$; SD = standard deviation; maximum expected score for either the pre- or post-testwas 9 points.

On average, there was a significant improvement in CCT scores between the pre-test and post-test for students in both the control and experimental groups. As shown in Table 3, we also found that both female and male students in the control and experimental groups showed significant pre-test and post-test improvements in their CCT scores. The gain in CCT scoresover time was also statistically significant across all six schools. However, the magnitude of the gain in the CCT average score at the post-test by students in the experimental group (3.38) was larger than those students in the control group (1.54). With regard togender, we found no significant difference in post-test CCT scores between boys and girls ($p = 0.48$). This suggested that boys and girls benefited equally from the intervention.

To examine whether the statistically significant differences in the post-test CCT scores could be maintained after accounting for the pre-test CCT score, we conducted an analysis of covariance (ANCOVA). We found that the mean CCT post-test score for the experimental group was significantly higher than that of the control group: $F(1157) = 99.5$, $p < 0.001$, adjusted R-squared = 0.41. The findings suggested that after controlling for pre-test CCT scores, the SLI teaching approach accounted for approximately 41 percent of the variance in post-test CCT scores between the experimental and control group students. It should also be noted that students' pre-test CCT scores significantly predicted the post-test CCT scores: $F(1157) = 4.84$, $p < 0.05$.

4.2. Qualitative Results

After the intervention, the students' experiences with SLI were investigated using semi-structured FG interviews. In addition, classroom observations were used for corroborating the interviewdata and answer the research questions of the study. The qualitative analysis involving inductive coding and thematic analysis resulted in three main themes: (1) SLI increases students' motivation for learning chemistry; (2) SLI is a multifaceted learner-centred laboratory instruction; and (3) laboratory learning through SLI is a demanding process.

4.2.1. SLI Increases Students' Motivation for Learning Chemistry

Almost all student respondents reiterated that SLI was a motivating and enjoyable learning method. For example, Smith (FG1) stated: "I have become motivated and interested in doing hands-on practical experiments [after SLI]". Ahmad (FG8), too, echoed his positive sentiment: "SLI has encouraged me to take self-initiative and responsibility for understanding chemical concepts, which increased my motivation and curiosity to study chemistry in-depth". Classroom observations supported the above interview results.

> *"...studentsrecollected what they had previously learnt in their biology lessons about the function of epithelial cells on the stomach wall in producing the bicarbonate-rich mucus, which, as they pointed out, was responsible to neutralize the gastric acid. The students seemed to be motivated in the lesson".* (*Author 1, notes [20 March 2020]*)

Jonas (FG3) further elaborated this as follows: "I found SLI motivational; it is particularly inspirational for science subjects to translate theory into practice, to solve problems, so this type of instruction needs to be bolstered to improve the chemistry pedagogy". Teaser (FG9) elegantly described what SLI is all about using an Amharic proverb: "*Yemiadegtijakegemeduyastawukal*", which literally means 'a calf who would grow well is easily identified by its effort to escape from a tied rope in a cage', meaning that SLI can serve as an effective student-centred instruction method that might lead to the abandoning of the taken-for-granted regular teaching approach.

Many student respondents further thought that SLI was critical for their own encouragement in learning chemistry. For example, Siraj (FG5) said, "SLI had invigorated me to learn chemistry in the laboratory learning environment".

Some participants also pointed to the effect of SLI in encouraging in-depth chemistry learning. Kim (FG10), for example, stated that she found a way to better grasp abstract chemical concepts after conducting SLI experiments: "It has helped me contemplate and recollect what I was taught through SLI-based lab activities. This notion is similar to image created from watching films and is better than reading books". Likewise, Latifa (FG7) was of the opinion that SLI had enhanced her understanding of the chemical concepts: "Evaluating my previous little experience, I am now regrettably disappointed, but now I have learned chemical concepts in a better way, so SLI was inspirational".

Some students expressed that SLI was an interesting and enjoyable method for learning chemistry. For example, Jonas (FG3) described it as "enjoyable and the lessons I got from it [SLI] will be easy to understand as I learned by doing, so I am happy with it". Pre-laboratory activities sparked an interest in learning chemistry, according to some of the students. For example, Johannes (FG11) stated: "I loved pre-laboratory quizzes since they are important to pave the way to step forward and minimize the time needed to do the experiments". Author 1 also noted an enjoyable atmosphere in the classroom when the students worked on pre-laboratory activities.

Furthermore, some students expressed that the SLI method made them enthusiastic about pursuing chemistry and related Science, Technology, Engineering, and Mathematics (STEM) careers in the future. For example, Habib (FG6) commented, "It [SLI] has made me anticipate about my future career, such as forensic science examinations". Kim (FG10) mentioned: "As chemistry is applicable in our daily lives, I realized that we need to like chemistry like our bread. We are longing for another topic to come and do practical laboratory work as [SLI] helped us to be researchers".

In summary, students found that SLI-based laboratory activities offered them the opportunity to comprehend and transfer their chemistry knowledge and skills in new contexts. The statements from the students also suggest that the SLI laboratory teaching–learning method activated them in the laboratory work in an enjoyable manner, which in turn increased their intrinsic and extrinsic motivation towards chemistry and STEM career investigations.

4.2.2. SLI Is a Multifaceted Learner-Centred Laboratory Instruction

Many respondents expressed that they thought that SLI-based experiments made chemistry more relevant, for example, by bringing theory from the classrooms to real-life contexts. Brian (FG9) said that "…it [SLI] has helped me identify what really exists in the daily life practices". Mina (FG2) noted, "It also helps us apply what we have been taught theoretically to different circumstances that we encountered in our environment". Author 1 noted the excitement that followed when one student came to realize the chemistry behind a well-known flavor:

> *"Students had reflected on a nice smelling musk that is produced by an African civet in the discussion forum and one student asked an interesting question: 'You guys, do you think that after doing the unknown concentration of Cu (II) experiment we can manage to determine the concentration of the chemical components in the musk of a civet, I mean in the near future? It is awesome! I appreciate the role that chemistry can play in understanding the natural world'".* (*Author 1, [19 March 2020]*)

Liyu (FG5) extended her comment pertinent to the very essence of chemistry by stating, "I have also learned that chemistry is everything, everywhere, and is for everyone". This might suggest that the relevance of chemistry to their lives was undercommunicated in their earlier education and that they found the application of theory through the use of relevant and SLI-based experiments enlightening.

The opportunity to develop laboratory skills was also appreciated by students. For example, Brian (FG9) expressed that SLI can "spark curiosity and laboratory skills". Habib (FG6) also described that he had "learnt how to practically prepare solutions, which is quite different from solution on paper" and Johannes (FG11) expressed, "I also developed my skills to measure chemicals, manipulate equipment and properly handle them". Classroom observations highlighted that the EG students became good at manipulating the volumetric flask for preparing standard solutions.

Another important feature of SLI that some students emphasised was the extensive use of reflective group discussions, which they felt were encouraged by collaborative learning. For example, Tore (FG1) stated: "…SLI allowed me to ask questions, freely reflect on lab tasks, and discuss with my peers". Indeed, the first author observed that the students in the EG asked relevant questions and engaged in interactive and reflective group discussions with their peers and teachers. For example, one student asked the teacher "whether the bottled water and tap water pass in different water treatment processes or not". These findings suggest that students had increased their ability to ask relevant scientific questions; for example in this case, they were curious about if the physicochemical treatment processes used to maintain the quality of tap and bottled water were the same to gain an understanding about which type of water is safer to drink compared to the other.

TheSLI is a learner-centred laboratory instruction that was useful for actively involving the students in the laboratory teaching–learning process, which was highlighted by many students. They expressed that SLI would be helpful in improving their chemical knowledge and performance in practical-related process skills. For example, Nasir (FG2) indicated that SLI provided him with opportunities to participate in "lab activities that provide opportunities for collecting data while actively experimenting, and to understand behind-the-scenes of the experiments". Seifu (FG5), too, reiterated that "[l] earning science by doing makes the lesson meaningful and easy to remember". Several students also reiterated the potential positive impact of SLI on implementing student-centred laboratory instruction, as Siraj's (FG5) response, for example, echoed: "SLI makes chemistry learning always memorable because we practically learnt by doing, showing, mixing or testing".

In summary, students stressed that SLI was a student-centred laboratory instructional approach that was considered to be beneficial by some students for improving individual and social laboratory learning skills, creating enhanced motivation for experimental learning and incorporating typical real-life examples as a means of developing their scientific knowledge.

4.2.3. Laboratory Learning through SLI Is a Demanding Process

Despite the good experiences with the SLI method, some students found it challenging as well, thereby making it difficult to adopt it in their laboratory learning contexts. Some respondents reiterated that there was a lack of skilled manpower and laboratory facilities in their schools, which would impede their learning. For example, Brian (FG9) revealed that the "lack of capacity of schools in furnishing materials that are necessary for laboratory experiments was a big challenge". Selam (FG8) mentioned that she had previously encountered "a shortage of laboratory materials and lack of laboratory technicians who could relentlessly guide students' chemistry learning". Students' reflections imply that practical teaching and learning would be more feasible when there isa sufficient supply of laboratory facilities and skilled manpower.

Many respondents expressed that SLI takes a lot of time. For example, Abi (FG3) stated: "The students may get bored with spending much time in the laboratory until they ensure the lab activities they are assigned to perform are thoroughly examined". However, a few participants also showed the need for additional time to better practice SLI. An exemplary quote obtained from the reflection of Hiwot (FG3) can serve as an example: "We need to save our regular classes and I suggest the [SLI] training should be held in extended time to yield the training beyond rhetoric". As was apparent in the classroom observations, "students were also happy to take much time to discuss with the teachers and their peers alike, but time limited them to go further".

Some respondents felt that it was difficult to comprehend the SLI teaching–learning materials. For example, Amanda (FG2) noted that she was "unable to comprehend the teaching and learning materials introduced during SLI properly, and it was difficult to imagine that I didn't know all the apparatus and equipment employed in SLI". Likewise, some students found that the introduction of pre-laboratory activities was a completely new experience and was, therefore, challenging. For example, Hagera (FG10) said, "We were terrified due to the lack of experience when we struggled to answer the challenging pre-laboratory questions as we have never had the same experience [before]".

Habib (FG6) also felt that he was "terrified and anxious" due to his new experience with SLI: "We failed to know the nature of materials, and hence we were terrified and anxious about the delicacy of the apparatus and the equipment". Ikhlas (FG1) said, ". . .failure to measure volume accurately due to lack of experience may make us lose hope". This is in clear contrast to the results noted before in classroom observations by the first author, in which several participants felt confident in manipulating volumetric flasks to prepare standard solutions. This contradiction may be explained by her relatively decreased self-efficacy beliefs in performing practical tasks successfully.

In summary, students expressed that SLI is a difficult laboratory learning method that takes time. In addition, the obstacles in terms of fulfilling skilled manpower and laboratory facilities were highlighted by the students as important indicators of the impediments to learning chemistry effectively from this method.

5. Discussion

5.1. The Effect of SLI on Students' Conceptual Understanding of Chemistry (RQ1)

Both the t test and ANCOVA results indicated that the students who attended the SLI sessions acquired a better understanding of acid–base and solution chemistry concepts than the students who attended the regular chemistry instruction. This finding is consistent with the results of previous studies by Demircioğlu et al. [22] and Damanhuri et al. [58] onhigh-school students;Karslı-Baydere et al. [59] on pre-service science teachers; and Baydere [60] on primary school students. It is likely that the instructional activities in the SLI sessions resulted in significant pre-test–post-test improvement in students' conceptual understanding of acid–base and solution chemistry. The EG students were offered different learning approaches and strategies (where great attention was given to pre-laboratory activities, teachers' scaffolding and reflective group discussions) in an active learning environment, such as the Prepare, Do, Review model suggested by Spagnoli et al. [61]. Based on our observations of the actual lessons, we noticed that the students in the CG were minimally engaged in the instructional activities. This may have led to a shallow understanding of the chemical concepts discussed in the demonstration of regular laboratory sessions. The opportunities provided for the EG students to actively engage in purposely designed instructional activities may have facilitated an in-depth understanding of chemical concepts. Observations from the classrooms suggest that EG students exhibited a solid understanding of (1) the correct sequence and the use of volumetric flasks for preparing a standard solution and (2) the awareness of how to write the chemical equation for the reaction between an acid and a base. Many similar studies have emphasized that bringing forth various pedagogical approaches together and creating an optimal laboratory learning environment for students is necessary for the development of students' improved scientific understanding [59,60]. It should be noted that students in the control group showed a statistically significant pretest-posttest improvement in their conceptual understanding of acid–base and solution chemistry in the post-test. This may be because of the question–answer sessions in the regular instruction that has helped them to better learn the investigated concepts. Aflalov and Raviv [62] contended that enhancing classroom discourse using questions and answers might promote better science learning in a "traditional frontal teaching in an ordinary classroom (p. 182)". Our classroom observations of the control classrooms revealed that the control teachers constrained the classroom discourse by providing the answers themselves, which forfeited opportunities to conduct effective discussions. We noticed that while the control teachers asked questions and rarely involved students to reflect on the questions, many of the questions were answered by the teachers themselves. A possible reason for such a positive effect of SLI on students' learning as compared to regular instruction may be that the SLI learning approach took students' misconceptions into account during the design process. This result appears to be in line with similar studies (e.g., Karslı-Baydere et al. [59] and Çetin et al. [63]) that investigated gas concepts.

5.2. Aspects of SLI That Students Find Motivating and Useful for Their Chemistry Learning, as Well as Challenging Aspects(RQ2)

The analysis of interview transcripts revealed that students found that SLI supports their deep-level learning, persistence and enjoyment, which is their intrinsic motivation. Students also felt that SLI promoted their understanding related to personal value, relevance and importance of science to attain future performance goals or ego goals, such as aspiring to be a forensic scientist, that is, their extrinsic motivation.

Students' motivation to learn science, particularly chemistry, as elicited in this manuscript, is consistent with the findings of previous studies by Kusurkar et al. [64] and Vaino et al. [65]. In these studies, the increase in students' motivation to learn chemistry was due to the use of reflective, small-group and leading discussions, which encouraged their active participation in the learning process. Collaborative learning that facilitates socially shared regulation among students is thought to be crucial for creating a conducive classroom environment in which students influence and motivate each other [66].

Another possible explanation for the positive influence of SRL–SLI on students' motivation may be the utilization of explicit teaching by applying challenging tasks and incorporating a variety of active teaching–learning approaches (reflective group discussions, teachers' scaffolding and pre-laboratory activities) that might have encouraged students to think more about the laboratory teaching–learning process and make use of different learning strategies, as stated in previous studies [27,35,36,67].

The qualitative analysis underscored that SLI and the experiments used (1) make chemistry more relevant to their lives, (2) develop individual and social learning abilities and (3) promote students' autonomy in scientific investigations, thereby enhancing their practical laboratory skills and active involvement in the learning activities. Consistent with this finding, Mandler et al. [46] and Araújo et al. [68] found that teaching chemistry through relevant laboratory activities helps students make connections between chemical concepts and real-world phenomena. Science educators assert that the meaningful application of chemical concepts and ideas in relevant contexts yields productive settings for effective science learning, especially when students address real-life problems through participation in communities of practice [69].

Participants reiterated that collaborative learning with "[reflective] group discussions and questioning as part of SLI activities were beneficial for understanding chemical concepts", as indicated by Ucan and Webb [70]. In addition, it is argued that "group discussion gives affordances for making students' thinking visible leading to correction, modification, and knowledge–building through collaboration" [71] (p. 169). Thus, maximizing students' abilities to enact higher-order thinking skills through coached and supervised group discussion activities may enhance their collaborative learning, thereby enhancing their knowledge construction. This result echoes NRC's [72] report thatstudents' enhancement of mastery of science content knowledge and development of scientific reasoning abilities can be achieved when the laboratory experiences are designed with clear integration of learning of science content and process and incorporation of ongoing student reflection and discussion. As such, group discussions in which students proactively engage in thought-provoking tasks can create favourable educational experiences that are challenging to them, albeit inevitably encouraging higher levels of engagement in scientific work [73].

As noted in the qualitative results, the SLI project equipped students with procedural knowledge and practical skills that contributed to their development of learning skills, predominantly through the use of practical laboratory activities. Students' responses indicated that SLI is an appropriate method to develop their laboratory-learning techniques, materials and knowledge of laboratory rules.

Our results align well with Araújo et al. [68], in which middle school students who participated in a 'water quality citizen science project' showed the development of laboratory skills and performed practical activities with a high degree of autonomy using an enlightened laboratory workgroup environment. In the present study, students mentioned that they were actively involved in the learning process and that SLI-based lab activities were pivotal to delving into the scientific investigations autonomously, as they were offered multiphase cyclical and collaborative learning opportunities through self-regulated learning.

As for challenges with SLI, the respondents listed a lack of laboratory facilities, skilled manpower (qualified teachers and lab technicians), and time, as well as problems coping with the laboratory teaching–learning materials. Similar challenges have been identified in other studies, such as that by Yalcin-Celik et al. [74], Nivalainen et al. [75], and Cossa and Uamusse [76], who reported that a lack of laboratory facilities still hampers their laboratory learning–teaching processes in high schools in Africa and elsewhere.

Some students mentioned the shortage of trained manpower as an important challenge for laboratory learning in the Ethiopian context. Indeed, studies have indicated that a lack of qualified teachers and technicians is likely to threaten students' perceptions oftheir future achievements [77]. The participants expressed concern that the teachers' lack of competence in implementing SLI will affect their SRL. Peeters et al. [78] found that it is possible to promote learners' SRL by training teachers so that they can acquire the necessary knowledge, skills and self-efficacy to support, guide and scaffold their students' learning. Likewise, Akani [79] pointed out that qualified chemistry teachers can rejuvenate students' learning in laboratory settings. Students also felt that it was difficult to comprehend the SLI-based teaching–learning materials. Previously, since SLI students were commonly taught using a teacher-centred approach, their anxiety in the SLI learning process was not surprising. Since the development of students' learning is a long-term process, the participants' inability to easily comprehend the teaching–learning materials is understandable when the complexities and factors that influence the self-regulatory processes are considered [80].

5.3. Limitations of the Study

This study on SLI was conducted for more than four weeks in a "one-shot" fashion, which made it difficult to comprehensively examine the effects of SLI in improving conceptual change. One of the limitations of this study was that the SLI's were only performed for two broad learning objective categories (acid–base and solution chemistry). Adopting these types of SLI interventions for abroader set of learning objectives commonly included in high-school chemistry curricula would provide evidence for the broader applicability of this instructional approach. Moreover, in the SLI, students were administered a pre- and post-test exams only; however, using retention post-tests along with pre- and post-test exams would have been decisive in documenting the effect of the method in understanding whether the students held a firm conceptual understanding of scientific concepts in general and chemical concepts in particular, which aligns with the conception held by the scientific community.

Since we selected those students who showed an interest in being taught using SLI and the regular instruction method, there might be a possibility of confirmation bias.

Finally, because it was the first author to conduct FG discussions, it is possible that the students provided socially desirable responses.

6. Implications for Practice and Research

The current study sheds light on and provides further empirical support for previous studies in science education, showing the effectiveness of the SLI learning model (and related instructional approaches) over regular instruction (e.g., see Refs. [35,36,59,60,67]).

Students' laboratory experiences with SLI revealed that learning science by performing in a complex laboratory learning environment is a demanding process, as argued by Agustian and Seery [27]. High-school teachers could potentially design and implement SLI in a way that the reflective group discussion sessions are conducted, at the very least, within a week's gap after completing the SLI-based laboratory activities and experiments to provide students with sufficient time and opportunity to interact, reflect, explain and modify their conceptions, as expressed by Hofstein and Hugerat [81]. How are senior high-school students prepared in their teaching laboratories? In the present context, participants were less likely to have encountered SLI prior to this study, which in turn may have created some sort of confusion in adopting the teaching–learning materials within a short time period. To acquaint students with the SLI model, we recommend that effective scientific enquiry practices be started in earlier grades by realizing teachers' professional competencies and allocating sufficient funds to furnish laboratories. In addition, we suggest that pre-service and in-service chemistry teachers should regularly spend sufficient time learning from and practicing in chemistry laboratories, if effective laboratory instruction is to be conducted in schools. Similarly, recent studies have pointed out that pre-service middle-school mathematics educators should receive PD training to develop competence in supporting students in making links between mathematical concepts and real-world life contexts [82]. Thus, we highlight the need for professional development programs that focus on laboratory training.

For future studies, collecting data through audio-recorded group discussions of students and written surveys during teachers' enactment of SLI practices could be useful to obtain richer data. Further research could also be carried out by following up on the students' learning progression in a longitudinal study with a larger student population. In addition, researchers can investigate the impact of SLI on developing students' transferable skills (such as critical thinking, decision-making and adaptability skills).

Author Contributions: All the authors collaborated in the conceptualization, design, methodology, data interpretation and analyses, writing, and project administration processes. M.T.A. was responsible for the investigation, data collection, and curation process, and he was present during the implementation of SLI and regular instruction. He also wrote the first draft of the manuscript while A.L.& D.T.T. were actively involved in the conceptualization, analysis, review and revision processes, as well as the final write-up of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: The study was supported by the BDU-NORHED project [grant code: QZA 0483 ETH 16/0029].

Institutional Review Board Statement: The ethical consideration of this study was reviewed and approved by the Norwegian Centre for Reasearch Data.

Informed Consent Statement: Informed consent was obtained from all the study participants.

Data Availability Statement: Not applicable.

Acknowledgments: Authors wish to thank Ethiopian High−school students and teachers who participated in this project.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Three-Tier Multiple-Choice Chemistry Concept Test (CCT)

1. Which statement is correct about pH?

(A) A solution that has a pH of 3 has hundred-fold times greater H^+ ions than a solution with a pH of 5
(B) pH is a measure of 'strength' and 'powerfulness' of a solution
(C) As the number of hydrogen atoms increases in the formula of an acid, its pH values decrease
(D) If the pH = 0, the substance is neither an acid nor a base

1.1. What is your reason or explanation for your response above?

(A) Because pH measures the degree to which an acid or base reacts
(B) Because the more hydrogen atoms in the formula of an acid means that there are higher H^+ ions in the solution
(C) Because the pH of a solution is the negative logarithm of H^+ ion concentration, a solution with a pH of 3 has 100 times greater H^+ ions than that of pH 5
(D) Because a substance with pH = 0 contains no H^+ and OH^- ion concentrations

1.2. Are you confident/sure that the responses given above are correct?

(A) Yes
(B) No

2. Which statement is correct about titration?

(A) In acid-base titration, before the end point of the titration there will be no change in pH
(B) In neutralization titration, at the equivalence point of titration, a single drop increase in acidic solution leads to a large decrease in pH
(C) In acid-base titration, acids and bases physically mix together to form a solution
(D) The end point of complexometric titration occurs at acidic pH

2.1. What is your reason or explanation for your response above?

(A) Because the dissolution of an acid with the base to give a neutral solution predominantly occurs instead of chemical reactions
(B) Because the metal-EDTA complex will be highly stable at a lower pH and the analyte and titrant are essentially completely reacted at the end point of titration
(C) Because at the equivalence point when approximately all OH^- ions are consumed, a small increase in acid leaves the solution with an excess H^+ ions
(D) Because it is only at the equivalence point that reaction will start taking place

2.2. Are you confident/sure that the responses given above are correct?

(A) Yes
(B) No

3. Which statement is correct about the properties of the solutions?

(A) Sugar dissolved in water conducts electricity
(B) Sugar molecules are mostly present at the top of the sugared water mixture

(C) Electrical conductivity of solutions depends on the availability of only negatively charged ions
(D) Sodium chloride is much more soluble in water than in benzene

3.1. What is your reason or explanation for your response above?

(A) Because all solutions conduct electricity and conductivity doesn't depend on the type of solution
(B) Because the benzene molecules lack a dipole moment, they cannot effectively solvate Na^+ and Cl^- ions
(C) Because negatively charged ions have a more active role than positively charged ions in supporting electrical conduction
(D) Because the sugar molecules are regularly arranged at the top of the sugared water mixture

3.2. Are you confident/sure that the responses given above are correct?

(A) Yes
(B) No

4. Which statement is correct about the concentration of a solution?

(A) The concentration of a solution helps to determine the strengths of acids and bases
(B) If the volume of aqueous ethanol solution in beaker A is twice the volume in beaker B, there should be more particles in beaker B than in A with equal concentration
(C) Adding a saturated solution of a bit more of its solid increases ion concentration
(D) Concentration has a non-linear relationship with absorbance

4.1. What is your reason or explanation for your response above?

(A) Because absorbance has an inversely proportional relationship to concentration
(B) Because the concentration of acids and bases affects the degree to which acids and bases dissociate in solutions
(C) Because there should be more particles in a smaller volume than in the more diluted solution with equal concentration
(D) Because the same solute can be dissolved in a saturated solution regardless of the amount of its solute dissolved in the solution

4.2. Are you confident/sure that the responses given above are correct?

(A) Yes
(B) No

5. Which statement is correct about the physical and chemical properties of acids and bases?

(A) A neutralization reaction does contain H_3O^+ and OH^- ions
(B) When an acidic solution is ultra-diluted, it will become a basic solution
(C) A strong acid doesn't dissociate in water solution, because its intra-molecular bonds are very strong
(D) Acid-base reactions result in a solution that does not possess any acidic or basic properties

5.1. What is your reason or explanation for your response above?

(A) Because ultra-diluted acidic solutions will have higher pH values that make it a basic solution
(B) Because the neutralization process can contain either acids or bases that are left unreacted in the resulting solution
(C) Because the neutralization process indicates that acids have consumed all bases, and the resulting solution is neutral
(D) Because the strong intramolecular bond in HCl that is hydrogen bond prevents separating its molecules into hydrated anions and cations in solution

5.2. Are you confident/sure that the responses given above are correct?

(A) Yes
(B) No

6. Which statement best describes the formation of aqueous solutions?

(A) Dissolving sugar molecules in water is a chemical process
(B) Powdered detergent soap dissolves in water and forms bubbles on top, so it's an exothermic reaction
(C) In completely dissolved aqueous solutions, there are molecules of ionic compounds
(D) Sodium chloride that is completely dissolved in water will have no undissociated NaCl units in solution

6.1. What is your reason or explanation for your response above?

(A) Because once ionic compounds are dissolved in water, hydration destabilizes ions in solution and helps to recombine anions with cations
(B) Because the sodium chloride that enters the aqueous solution is disintegrated into Na^+ and Cl^- ions
(C) Because reaction between sugar and water molecules can result in a new substance-sweet water
(D) Because the formation of bubbles shows the dissolution of detergent soap in water by releasing energy and is thus an exothermic reaction

6.2. Are you confident/sure that the responses given above are correct?

(A) Yes
(B) No

7. Which statement best describes the right practical laboratory knowledge/practices about the preparation of solid–liquid solutions?

(A) During carrying out the given task of preparing solid-liquid solution, female students need not to use a hair clip to tie their hair back
(B) Reading the top of the meniscus instead of the bottom gives precise volume measurement
(C) When precise measurement of liquid is needed using graduated cylinder is the right equipment instead of volumetric flask
(D) To prepare 1 M NaCl solution, we should not combine 1 mole of NaCl with 1 L of water

7.1. What is your reason or explanation for your response above?

(A) Because the probability of having an accident on the hair is very low and it is not considered necessary to act up on it
(B) Because the top of the meniscus provides a more precise volume measurement than the bottom
(C) Because a graduated cylinder is easy to measure out volume, and it is the right equipment to get precise measurement of volume
(D) Because the resulting solution would have a total volume exceeding 1 L and therefore a molarity of less than 1 M

7.2. Are you confident/sure that the responses given above are correct?

(A) Yes
(B) No

8. Which statement is correct about the indicators?

(A) Indicators are used to measure the strength of acids and bases
(B) Indicators neutralize acids and change colour
(C) All indicators change colour at the same pH value and this is invariably at pH 7
(D) Indicators provide a clear indication by a colour change in the presence of neutral, acidic or basic solution

8.1. What is your reason or explanation for your response above?

(A) Because indicators can define the degree to which acids and bases react to each other
(B) Because indicators are basic organic compounds that can react with acids to show the end point of the neutralization reaction
(C) Because the role of indicators is to show the colour change of neutralization reaction, which always results in neutral solution
(D) Because indicators are acidic or basic organic compounds that indicate whether the titration process ends up with neutral, acidic or neutral solution

8.2. Are you confident/sure that the responses given above are correct?

(A) Yes
(B) No

9. Temporary hardness of tap water occurs when Ca^{2+} ions come from chlorite compound, $Ca(OCl)_2$, but not from the hardness of ground water. This can be removed when tap water is heated.
9.1. Which statement is correct about the chemical phenomena that occur when tap water is heated?

(A) The $CaCO_3$ will precipitate after tap water is heated and the water evaporates
(B) Coagulation of $CaCO_3$ will occur after tap water is heated
(C) The density of crystals of $CaCO_3$ is greater than the solution of tap water, and then they precipitate
(D) The CaCO3 will precipitate after ionization of chlorite compound and dissolution of CO_2 gas

9.2. What is your reason or explanation for your response above?

(A) Because when tap water is heated, it will evaporate and $CaCO_3$will be precipitated at the bottom of the container
(B) Because heating of tap water triggers the coagulation process and $CaCO_3$will be removed through filtration
(C) Because heating tap water increases the precipitation of $CaCO_3$since it has a higher density than tap water
(D) Because $CaCO_3$will be formed through the chemical process that occurs between the chlorite compound found in tap water and the CO_2 gas in the environment

9.3. Are you confident/sure that the responses given above are correct?

(A) Yes
(B) No

Appendix B. Interview Questions Employed in the Semi-Structured Focus-Group Interviews

Semi-structured interview questions

- How do you evaluate the way you were taught the topics ofacids–bases and solution chemistry through SLI?
- What do you think are the benefits of SLI approach compared to the approaches you were familiar with?
- Which components of the SLI do you think are relevant for conducting an experiment at high school level?
- What types of support do you think is important for SLI to be effective for your laboratory learning?
- What factors, if any, may hamper your learning from the SLI approach?

References

1. Ministry of Education [MoE]. *Ethiopian Education Development Roadmap (2018–30): An Integrated Executive Summary (Draft)*; Ministry of Education, Education Strategy Center: Addis Ababa, Ethiopia, 2018.
2. Ministry of Education [MoE]. *Education Statistics Annual Abstract September 2019–March 2020*; Ministry of Education, Education Management Information System (EMIS) and ICT Directorate: Addis Ababa, Ethiopia, 2020.
3. Zimmerman, B.J. Becoming a self-regulated learner: An overview. *Theory Pract.* **2002**, *41*, 64–70. [CrossRef]
4. Anderson, R.D. Reforming science teaching: What research says about inquiry. *J. Sci. Teach. Educ.* **2002**, *13*, 1–12. [CrossRef]
5. Asheim, J.; Kvittingen, E.V.; Kvittingen, L.; Verley, R. A simple, small-scale Lego colorimeter with a light-emitting diode (LED) used as detector. *J. Chem. Educ.* **2014**, *91*, 1037–1039. [CrossRef]
6. Ali, M.T.; Lykknes, A. In-service chemistry teachers' reflections on and experiences with supervised laboratory instruction in Ethiopia. *Afr. J. Chem. Educ.* **2022**, *12*, 60–95.
7. Childs, P.E.; Hayes, S.M.; O'dwyer, A. Chemistryand everyday life: Relating secondary school chemistry to the current and future lives of students. In *Relevant Chemistry Education*; Eilks, I., Hofstein, A., Eds.; Brill Sense: Rotterdam, The Netherlands, 2013; pp. 33–54.
8. Jiménez-Liso, M.R.; López-Banet, L.; Dillon, J. Changing how we teach acid-base chemistry. *Sci. Educ.* **2020**, *29*, 1291–1315. [CrossRef] [PubMed]
9. Calik, M.; Kolomuç, A.; Karagölge, Z. The effect of conceptual change pedagogy on students' conceptions of rate of reaction. *J. Sci. Educ. Technol.* **2010**, *19*, 422–433. [CrossRef]
10. Duis, J.M. Organic chemistry educators' perspectives on fundamental concepts and misconceptions: An exploratory study. *J. Chem. Educ.* **2011**, *88*, 346–350. [CrossRef]
11. Barke, H.-D.; Hazari, A.; Yitbarek, S. *Misconceptions in Chemistry. Addressing Perceptions in Chemical Education*; Springer: Berlin/Heidelberg, Germany, 2009.
12. Hoe, K.Y.; Ramanathan, R. On the prevalence of alternative conceptions on acid–base chemistry among secondary students: Insights from cognitive and confidence measures. *Chem. Educ. Res. Pract.* **2016**, *17*, 263–282. [CrossRef]
13. Sheppard, K. High school students' understanding of titrations and relatedacid-base phenomena. *Chem. Educ. Res. Pract.* **2006**, *7*, 32–45. [CrossRef]
14. Ebenezer, J.V.; Erickson, G.L. Chemistry students' conceptions of solubility: A phenomenography. *Sci. Educ.* **1996**, *80*, 181–201. [CrossRef]
15. Çalik, M. A cross-age study of different perspectives in solution chemistry from junior to senior high school. *Int. J. Sci. Math.* **2005**, *3*, 671–696. [CrossRef]
16. Pinarbasi, T.; Canpolat, N. Students' understanding of solution chemistry concepts. *J. Chem. Educ.* **2003**, *80*, 1328–1332. [CrossRef]
17. Özden, M. Prospective science teachers' conceptions of the solution chemistry. *J. Balt. Sci. Educ.* **2009**, *8*, 69–78.
18. Amin, T.G.; Smith, C.L.; Wiser, M. Student conceptions and conceptual change. In *Handbook of Research on Science Education*; Lederman, N.G., Abell, S.K., Eds.; Routledge: New York, NY, USA; London, UK, 2014; pp. 57–81.
19. Özdemir, G.; Clark, D.B. An overview of conceptual change theories. *Eurasia J. Math. Sci. Technol. Educ.* **2007**, *3*, 351–361. [CrossRef] [PubMed]
20. Potvin, P.; Malenfant-Robichaud, G.; Cormier, C.; Masson, S. Coexistence of misconceptions and scientific conceptions in chemistry professors: A mental chronometry and fMRI study. *Front. Educ.* **2020**, *5*, 542458. [CrossRef]
21. Limón, M. On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. *Learn Instr.* **2001**, *11*, 357–380. [CrossRef]
22. Demircioğlu, G.; Ayas, A.; Demircioğlu, H. Conceptual change achieved through a new teaching program on acids and bases. *Chem. Educ. Res. Pract.* **2005**, *6*, 36–51. [CrossRef]
23. Asterhan, C.S.; Dotan, A. Feedback that corrects and contrasts students' erroneous solutions with expert ones improves expository instruction for conceptual change. *Instr. Sci.* **2018**, *46*, 337–355. [CrossRef]
24. Abrahams, I.; Millar, R. Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *Int. J. Sci. Educ.* **2008**, *30*, 1945–1969. [CrossRef]
25. Abrahams, I. Does practical work really motivate? A study of the affective value of practical work in secondary school science. *Int. J. Sci. Educ.* **2009**, *31*, 2335–2353. [CrossRef]
26. Abrahams, I.; Reiss, M.J. Practical work: Its effectiveness in primary and secondary schools in England. *J. Res. Sci. Teach.* **2012**, *49*, 1035–1055. [CrossRef]
27. Agustian, H.Y.; Seery, M.K. Reasserting the role of pre-laboratory activities in chemistry education: A proposed framework for their design. *Chem. Educ. Res. Pract.* **2017**, *18*, 518–532. [CrossRef]
28. Sesen, B.A.; Tarhan, L. Promoting active learning in high school chemistry: Learning achievement and attitude. *Procedia Soc. Behav. Sci.* **2010**, *2*, 2625–2630. [CrossRef]
29. Tarhan, L.; Sesen, B.A. Investigation the effectiveness of laboratory works related to "acids and bases" on learning achievements and attitudes toward laboratory. *Procedia Soc. Behav. Sci.* **2010**, *2*, 2631–2636. [CrossRef]
30. Priyambodo, E.; Fitriyana, N.; Primastuti, M.; Artistic, F.A.D. The role of collaborative learning based STSE in acid base chemistry: Effects on students' motivation. In Proceedings of the 7th International Conference on Research, Implementation, and Education

of Mathematics and Sciences (ICRIEMS 2020), Yogyakarta, Indonesia, 25–26 September 2020; Atlantis Press: Dordrecht, The Netherlands, 2021; pp. 253–263.

31. Wong, J.; Baars, M.; de Koning, B.B.; Paas, F. Examining the use of prompts to facilitate self-regulated learning in massive open online courses. *Comput. Hum. Behav.* **2021**, *115*, 106596. [CrossRef]
32. Zumbrunn, S.; Tadlock, J.; Roberts, E.D. *Encourage Self-Regulated Learning in the Classroom*; Metropolitan Educational Research Consortium (MERC), Virginia Commonwealth University: Richmond, VA, USA, 2011; pp. 1–29.
33. Carneiro, R.; Lefrere, P.; Steffens, K.; Underwood, J. *Self-Regulated Learning in Technology Enhanced Learning Environments: A European Perspctive*; Sense: Roterdam, The Netherlands, 2012; Volume 5.
34. Cera, R.; Mancini, M.; Antonietti, A. Relationships between metacognition, self-efficacy and self-regulation in learning. *J. Educ. Cult. Psychol. Stud.* **2013**, *4*, 115–141. [CrossRef]
35. Labuhn, A.S.; Bögeholz, S.; Hasselhorn, M. LernförderungdurchAnregung der Selbst regulation imnaturwissenschaftlichen, [Fostering learning through stimulation of self-regulation in science lessons]. *Unterr. Z. Pädagogische Psychol.* **2008**, *22*, 13–24. [CrossRef]
36. Cleary, T.J.; Platten, P.; Nelson, A.C. Effectiveness of the self-regulation empowerment program with urban high school students. *J. Adv. Acad.* **2008**, *20*, 70–107. [CrossRef]
37. Williams, A.E.; Aguilar-Roca, N.M.; Tsai, M.; Wong, M.; Beaupr'e, M.M.; O'Dowd, D.K. Assessment of learning gains associated with independent exam analysis in introductory biology. *CBE Life Sci. Educ.* **2011**, *10*, 346–356. [CrossRef] [PubMed]
38. Zimmerman, B.J.; Moylan, A.R. Self-regulation: Where metacognition and motivation intersect. In *Handbook of Metacognition in Education*; Hacker, D.J., Dunlosky, J., Graesser, A.C., Eds.; Routledge: New York, NY, USA, 2009; pp. 299–315.
39. Hullinger, A.M.; DiGirolamo, J.A.; Tkach, J.T. Reflective practice for coaches and clients: An integrated model for learning. *Philos. Coach Int. J.* **2019**, *4*, 5–34. [CrossRef]
40. Zimmerman, B.J. Investigating self-regulation and motivation: Historical background, methodological developments, and future prospects. *Am. Educ. Res. J.* **2008**, *45*, 166–183. [CrossRef]
41. Gericke, N.; Högström, P.; Wallin, J. A systematic review of research on laboratory work in secondary school. *Stud. Sci. Educ.* **2022**, *59*, 245–285. [CrossRef]
42. Smith, C.J. Improving the school-to-university transition: Using a problem-based approach to teach practical skills whilst simultaneously developing students' independent study skills. *Chem. Educ. Res. Pract.* **2012**, *13*, 490–499. [CrossRef]
43. Hofstein, A.; Mamlok-Naaman, R. The laboratory in science education: The state of the art. *Chem. Educ. Res. Pract.* **2007**, *8*, 105–107. [CrossRef]
44. National Research Council. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*; National Academies Press: Washington, DC, USA, 2012. [CrossRef]
45. Kakisako, M.; Nishikawa, K.; Nakano, M.; Harada, K.S.; Tatsuoka, T.; Koga, N. Stepwise inquiry into hard water in a high school chemistry laboratory. *J. Chem. Educ.* **2016**, *93*, 1923–1928. [CrossRef]
46. Mandler, D.; Mamlok-Naaman, R.; Blonder, R.; Yayon, M.; Hofstein, A. High-school chemistry teaching through environmentally oriented curricula. *Chem. Educ. Res. Pract.* **2012**, *13*, 80–92. [CrossRef]
47. World Health Organization (WHO).Calcium and Magnesium in Drinking-Water: Public Health Significance. 2009. Available online: http://apps.who.int/iris/bitstream/10665/43836/1/9789241563550_eng.pdf (accessed on 16 December 2019).
48. O'Donoghue, J. Simplified low-cost colorimetry for education and public engagement. *J. Chem. Educ.* **2019**, *96*, 1136–1142. [CrossRef]
49. Dooling, K.; Bodenstedt, K.; Page, M.F. A caffeinated boost on UV spectrophotometry: A lab for high school chemistry or an introductory university chemistry course. *J. Chem. Educ.* **2013**, *90*, 914–917. [CrossRef]
50. Liampa, V.; Malandrakis, G.N.; Papadopoulou, P.; Pnevmatikos, D. Development and evaluation of a three-tier diagnostic test to assess undergraduate primary teachers' understanding of ecological foot print. *Res. Sci. Educ.* **2019**, *49*, 711–736. [CrossRef]
51. Cetin-Dindar, A.; Geban, O. Development of a three-tier test to assess high school students' understanding of acids and bases. *Procedia Soc. Behav. Sci.* **2011**, *15*, 600–604. [CrossRef]
52. Khairani, A.Z.; Shamsuddin, H. Assessing Item Difficulty and Discrimination Indices of Teacher-Developed Multiple-Choice Tests. In *Assessment for Learning within and beyond the Classroom*; Tang, S.F., Logonnathan, L., Eds.; Springer: Singapore, 2016; pp. 417–426. [CrossRef]
53. Dilshad, R.M.; Latif, M.I. Focus group interview as a tool for qualitative research: An analysis. *Pak. J. Soc. Sci.* **2013**, *33*, 191–198.
54. Gill, P.; Stewart, K.; Treasure, E.; Chadwick, B. Methods of data collection in qualitative research: Interviews and focus groups. *Br. Dent. J.* **2008**, *204*, 291–295. [CrossRef] [PubMed]
55. Braun, V.; Clarke, V.; Hayfield, N.; Terry, G. Thematic analysis. In *Handbook of Research Methods in Health Social Sciences*; Liamputtong, P., Ed.; Springer: Singapore, 2019; pp. 843–860.
56. Braun, V.; Clarke, V. Can I use TA? Should I use TA? Should I not use TA? Comparing reflexive thematic analysis and other pattern-based qualitative analytic approaches. *Couns. Psychother. Res.* **2021**, *21*, 37–47. [CrossRef]
57. Braun, V.; Clarke, V. Conceptual and design thinking for thematic analysis. *Qual. Psychol.* **2022**, *9*, 3–26. [CrossRef]
58. Damanhuri, M.I.M.; Treagust, D.F.; Won, M.; Chandrasegaran, A.L. High school students' understanding of acid-base concepts: An ongoing challenge for teachers. *Int. J. Environ. Sci. Educ.* **2016**, *11*, 9–27.

59. Karslı-Baydere, F.; Ayaş, A.; Çalık, M. Effects of a 5Es learning model on the conceptual understanding and science process skills of pre-service science teachers: The case of gases and gas laws. *J. Serb. Chem. Soc.* **2020**, *85*, 559–573. [CrossRef]
60. Baydere, F.K. Effects of a context-based approach with prediction–observation–explanation on conceptual understanding of the states of matter, heat and temperature. *Chem. Educ. Res. Pract.* **2021**, *22*, 640–652. [CrossRef]
61. Spagnoli, D.; Wong, L.; Maisey, S.; Clemons, T.D. Prepare, do, review: A model used to reduce the negative feelings towards laboratory classes in an introductory chemistry undergraduate unit. *Chem. Educ. Res. Pract.* **2017**, *18*, 26–44. [CrossRef]
62. Aflalo, E.; Raviv, A. Characteristics of classroom discourse in physics lessons. *Res. Sci. Technol. Educ.* **2022**, *40*, 168–188. [CrossRef]
63. Çetin, P.S.; Kaya, E.; Geban, Ö. Facilitating conceptual change in gases concepts. *J. Sci. Educ. Technol.* **2009**, *18*, 130–137. [CrossRef]
64. Kusurkar, R.A.; Ten Cate, O.T.J.; Vos, C.M.P.; Westers, P.; Croiset, G. How motivation affects academic performance: A structural equation modeling analysis. *Adv. Health Sci. Educ. Theory Pract.* **2013**, *18*, 57–69. [CrossRef] [PubMed]
65. Vaino, K.; Holbrook, J.; Rannikmäe, M. Stimulating students' intrinsic motivation for learning chemistry through the use of context-based learning modules. *Chem. Educ. Res. Pract.* **2012**, *13*, 410–419. [CrossRef]
66. Nakata, Y.; Nitta, R.; Tsuda, A. Understanding motivation and classroom modes of regulation in collaborative learning: An exploratory study. *Innov. Lang. Learn. Teach.* **2020**, *16*, 14–28. [CrossRef]
67. Ma, Y.C. Using Participatory Teaching in Hands-On Courses: Exploring the Influence of Teaching Cases on Learning Motivation. *Educ. Sci.* **2023**, *13*, 547. [CrossRef]
68. Araújo, J.L.; Morais, C.; Paiva, J.C. Student participation in a coastal water quality citizen science project and its contribution to the conceptual and procedural learning of chemistry. *Chem. Educ. Res. Pract.* **2022**, *23*, 100–112. [CrossRef]
69. Gilbert, J.K.; Bulte, A.M.; Pilot, A. Concept development and transfer in context-based science education. *Int. J. Sci. Educ.* **2011**, *33*, 817–837. [CrossRef]
70. Ucan, S.; Webb, M. Social regulation of learning during collaborative inquiry learning in science: How does it emerge and what are its functions? *Int. J. Sci. Educ.* **2015**, *37*, 2503–2532. [CrossRef]
71. Varadarajan, S.; Ladage, S. Exploring the role of scaffolds in problem-based learning (PBL) inan undergraduate chemistry laboratory. *Chem. Educ. Res. Pract.* **2022**, *23*, 159–172. [CrossRef]
72. National Research Council [NRC]. *America's Lab Report: Investigations in High School Science*; National Academies Press: Washington, DC, USA, 2006. [CrossRef]
73. Reid, J.W.; Gunes, Z.D.K.; Fateh, S.; Fatima, A.; Macrie-Shuck, M.; Nennig, H.T. Investigating patterns of student engagement during collaborative activities in undergraduate chemistry courses. *Chem. Educ. Res. Pract.* **2022**, *23*, 173–188. [CrossRef]
74. Yalcin-Celik, A.; Kadayifci, H.; Uner, S.; Turan-Oluk, N. Challenges faced by pre-service chemistry teachers teaching in a laboratory and their solution proposals. *Eur. J. Teach. Educ.* **2017**, *40*, 210–230. [CrossRef]
75. Nivalainen, V.; Asikainen, M.A.; Sormunen, K.; Hirvonen, P.E. Preservice and inservice teachers' challenges in the planning of practical work in physics. *J. Sci. Teach. Educ.* **2010**, *21*, 393–409. [CrossRef]
76. Cossa, E.F.R.; Uamusse, A.A. Effects of an in-service program on biology and chemistry teachers' perception of the role of laboratory work. *Procedia Soc. Behav. Sci.* **2015**, *167*, 152–160. [CrossRef]
77. Hamidu, M.Y.; Ibrahim, A.I.; Mohammed, A. The use of laboratory method in teaching secondary school students: A key to improving the quality of education. *Int. J. Sci. Eng. Res.* **2014**, *5*, 81–86.
78. Peeters, J.; De Backer, F.; Reina, V.R.; Kindekens, A.; Buffel, T.; Lombaerts, K. The role of teachers' self-regulatory capacities in the implementation of self-regulated learning practices. *Procedia Soc. Behav. Sci.* **2014**, *116*, 1963–1970.
79. Akani, O. Laboratory teaching: Implication on students' achievement in chemistry in secondary schools in Ebonyi State of Nigeria. *J. Educ. Pract.* **2015**, *6*, 206–213.
80. Wigfield, A.; Klauda, S.L.; Cambria, J. Influences on the Development of Academic Self-Regulatory Processes. In *Handbook of Self-Regulation of Learning and Performance*; Zimmerman, B.J., Schunk, D.H., Eds.; Routledge/Taylor & Frncis Group: New York, NY, USA, 2011; pp. 33–48.
81. Hofstein, A.; Hugerat, M. *Teaching and Learning in the School Chemistry Laboratory, Advances in Chemistry Education Series*; Royal Society of Chemistry: London, UK, 2022; Volume 8.
82. Montesdeoca, K.K. Middle grades math with ice cream sundaes: Connecting math to the real world. *Educ. Sci.* **2023**, *13*, 615. [CrossRef]