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Effectiveness of Hands-on Practical Activities in Teaching and Learning Chemistry: An Exploration of Students' Engagement, Experience, and Academic Performance

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Abstract

The current study tends to investigates students' engagement, experience and academic performance in chemistry through the use of chemistry hands-on practical activities. The study adopted a descriptive research design. The used sample was 155 senior four and five students. A mixed research design was adopted where the data were collected from chemistry achievement test and a mixed questionnaire composed of multiple-choice questions and open-ended questions for triangulation purpose. Quantitative data were analysed by using descriptive and inferential statistics (independent t-test) while qualitative data were analysed by interpretive analysis. The results revealed that students are engaged and have a positive experience and perception on the use chemistry practical work. In addition, the study demonstrated there was high statistically significant difference between pre-and post-test after intervention ($p>0.001$). However, the study did not find a statistically significant difference of performance in terms of gender and type of school with p value of 0.12 and 0.10, respectively. Some difficulties that hinder the effective utilization of chemistry practical work and their potential solutions were identified. The difficulties identified include students' insufficient chemicals, lack of enough laboratory apparatus, small laboratory space, and shortage of time allocated to the practical works. The potential solution suggested include the provision of sufficient laboratory equipment, the use of improvised materials and locally available materials, and increasing the time of conducting laboratory works.

Keywords: hands-on practical activities; positive perception; experience; engagement; motivation; students' performance

Introduction

Attaining scientific literacy has been the central goal for education across countries. Laboratory Practical work has been and remains a core section of science education, undeniably seen to be a significant feature that distinguishes science subjects from various others in secondary schools (Sharpe, 2012). However, there is mounting debate about the effectiveness and contribution of conducting laboratory work towards the contemporary main objective of science education which is no longer acquiring scientific knowledge, but the construction of scientific knowledge. Despite this debate, Schramm (2013) argues that well-planned laboratory activities prompt a suitable learning environment intended for attaining this objective. The uniqueness of the science laboratory is evident in creating a learning environment that favors both hands-on and mind-on activities. According to (Osborn and Dillon, 2010) argue that hand

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experience obtained through experimental work imprints a permanent impression on the mind of the students. It provides an opportunity for the teacher to inculcate various process skills of science. The Science laboratory plays an essential role to help us alter the learning environment in which students cooperatively in small groups improve their understanding of scientific concepts, inquiry skills, and scientific attitude while investigating the scientific phenomena (Hofstein & Lunetta, 2003). Thus, Laboratory activities have the potential to improve constructive social relationships as well positive attitudes and cognitive development (Hofstein & Lunetta, 1982).

Science subjects, and particularly chemistry, are beneficial to students and society. It is obvious that Chemistry embraces both theory and practice, and for that reason, needs instructional laboratories designed so that they upkeep and enhance the inquiry and synthesis of both ideas and materials (O'Connell, 2013). This means that for effective learning, the laboratory should be well equipped with the necessary facilities. Singer et al. (2005) suggest that direct observation and handling of various aspects of the material world necessitate suitable laboratory facilities; comprising safe storage, space for instructor demonstrations, student discussion, and student laboratory activities.

Practical work in chemistry constitutes a major portion of chemistry education, which needed to be properly instructed; otherwise, other linked science disciplines will be affected negatively. Thus, secondary schools require well-equipped and working laboratories (Uzezi & Zainab, 2017). Laboratory practical work may be utilized as a potent learning resource of science; it is constructed on the principle of learning by doing and it constitutes a vital part of science education (Schramm, 2013). As Bretz (2019) asserts, the American Chemical Society Committee on Professional Training (CPT) explains that laboratory experiences provide a particularly attractive opportunity for inquiry-driven and open-ended investigations that promote independent thinking, critical thinking and reasoning, and a perspective of chemistry as a scientific process of discovery.

An interesting aspect of laboratory experiences relies on how they aim at achieving the cognitive, psychomotor, and affective objectives (Iyamuremye et al., 2023). However, teachers do have not to be nervous in seeking to include all the objectives in one single laboratory activity. Osborne and Dillon (2010) argue that no single activity can be intended to meet all the objectives, but an array of activities. According to Singer et al. (2005), highlight the goals of the laboratory experience; these are mastering the subject matter, increasing scientific reasoning, understanding the intricacy and ambiguity of empirical work, enhancing practical skills, understanding the nature of science, fostering interest in science and awareness in learning science and increasing teamwork abilities. This indicates that there is strong interconnection between the laboratory work and objectives of science education in general in developing cognitive abilities, process skills scientific attitude, and understanding the nature of science.

Helping the students to achieve the objectives of laboratory practical work is a challenge that teachers need to address; a well-equipped laboratory and best science curriculum will serve little unless the teacher's role is fulfilled (Iyamuremye et al., 2023). In addition, teachers need to know not only how to set up equipment but also how to carry out procedures and manage students' activities. Thus, teachers must take into account how to align the curriculum with the instruction they use and laboratory experiences (Iyamuremye et al., 2022). For instance, they must know how to choose different laboratory activities intended to fit most properly in their science sessions as they owe their students a clear communication of the learning goals of the laboratory experience (Iyamuremye et al., 2023). Inspiring students to observe and investigate as well as developing critical thinking on a given laboratory activity can expedite them to the construction of some principles and abstract concepts of science, to arouse inquisitiveness about the world surrounding them, and to appreciate the nature of science (Iyamuremye, Nsabayezu, et al., 2023).

To get an insight into what effectiveness of practical work is, Millar and Abrahams (2009) explain two senses of effectiveness; the first sense is illustrated by the match between what students are intended to do and see and what they do and see, the second sense of effectiveness refers to the extent to which practical work helps students to learn what we wanted them to learn. Thus, thinking of effective practical work begins from elaborating the learning objectives. While designing tasks, it is important to reflect on the fact that doing things simply with apparatus and chemicals cannot lead to learning scientific ideas and concepts. Therefore, it is evident that teachers play a significant role in making practical work effective. Eilks and Hofstein (2013) argue that for improving the effectiveness of practical work in chemistry, teachers need to increase awareness concerning practical tasks; they are required to help students to understand and make links between the domain of objects and the domain of ideas. Shah (2004) concurs that the effectiveness of laboratory work is not only skills acquisition and the empirical verification of facts but also includes the development of meaningful practical situations, which illuminate, challenge, and cause inquiry.

Research questions

The study was intended to systematically explore students' engagement, experiences, and academic performance in response to hands-on practical activities, to address a critical gap in understanding the impact of active learning approaches. It was therefore guided by the following research questions:

1. How do students engage in and experience the use chemistry practical work?
2. Is there any relationship between conducting chemistry practical work and student's academic performance?
3. What are challenges faced by students while conducting chemistry practical work?

Significance of the study

The study holds significant implications for the enhancement of chemistry education. Its findings can inform pedagogical practices and curriculum development, providing evidence-based insights into the effectiveness of incorporating hands-on experiences in chemistry classrooms. For educators, the research offers guidance on optimizing teaching methods to promote student engagement and understanding. Additionally, the outcomes can contribute to the broader discourse on science education, influencing policies and practices to better align with contemporary educational needs. Ultimately, the significance of this study lies in its potential to elevate the quality of chemistry education by highlighting the value of experiential learning, fostering a more interactive and meaningful educational experience for students.

Methodology

This study used the descriptive research design. According to Waltz and Bausell, as stated by Mukabatsinda (2016), a descriptive design may be used to develop a theory, pinpoint problems with existing practice, justify the current practice, make conclusions, or determine what others are doing in similar situations. The target population for this study included all advanced secondary students in chemistry and their teachers from Kayonza district, East Province, Rwanda. However, only one hundred fifty-five (155) senior four and five students were purposely selected to participate in the study. The schools selected one is boarding school while the other is day school. The sample was comprised by 71 (45.8%) male and 84 (54.2%) female.

A mixed research design was adopted where achievement test and mixed questionnaires composed of a Likert scale and open items were used to collect data. The mixed method is useful for this study as it provides greater depth and breadth of information that is not possible by using single approaches in isolation (Almalki, 2016).

The students have received the intervention which integrate the use of hand-on practical activities in chemistry education. This intervention includes designing and incorporating a variety of laboratory experiments and activities that align with the curriculum objectives, allowing students to directly engage with chemical concepts, phenomena, and techniques. The practical activities were designed to promote active learning, foster critical thinking, and enhance students' understanding of theoretical principles through direct application. The study explored how these hands-on experiences impact students' engagement levels, overall learning experiences, and academic performance in chemistry. The intervention was done in the period of one month during daily teaching and learning process to assess their influence on student outcomes.

Chemistry achievement test was used to assess the impact of chemistry practical work towards student's academic performance after intervention. This test was criterion - referenced and marked out of 25 marks. On the other, questionnaire was used to investigate student's experience and perception towards the use of chemistry practical work. The use of questionnaire was adopted because it is a fundamental tool that helps to acquire information on a certain issue or public knowledge (Bird, 2009). With a questionnaire, the researcher's objective is especially achieved on one side by keeping respondents motivated to deliver information and on the other side by providing the researcher with suitable information. Descriptive and inferential statistics was used to analyse quantitative data. The obtained data from chemistry achievement test were analyzed by descriptive and inferential statistics (independent sample t-test) with aid of Excel 2016 and SPSS 26. Inferential analysis was used to test whether or not there is significant difference in terms of performance between pre-and post-test, between students from male and female schools, day and boarding schools. On the other hand, the data obtained by questionnaires were analyzed in two ways, the data on the Likert scale items were analyzed by using descriptive statistics such as mean ($\overline{x}$) and standard deviation (SD) while the data on open-ended questions were analyzed by using interpretive analysis.

Validity and reliability were also considered. Validity is referred to as measuring what is measured what is supposed to measure (Tan & Kim, 2012). To ensure the validity of this study, the research instruments were checked and approved by the experts of the research from the University of Rwanda, college of education. Reliability refers to the repeatability of the result (Tan & Kim, 2012). The reliability was tested by using the same instruments administered to another school that has the same characteristics as the schools under the study to make sure whether their responses were concurring with those schools under the study. The reliability coefficient of questionnaire was calculated by using Cronbach's was found to be 0.82 while reliability of chemistry achievement test was calculated by using split-half reliability coefficient was found to be 0.715. The researcher promised the participants that the information collected is confidential and not shared with any other person.

Results and Discussion

Students' engagement and experience in chemistry practical work.

To explore student's engagement and experience du ring chemistry practical work, students were asked to rate, on a 5-point Likert-scale (almost always (5), very often (4), often (3), sometimes (2) and rarely (1) to the statement related to student's participation during practical work. The Figure1 below shows the summary students' responses about their engagement and experience during chemistry practical work.

While exploring students' engagement during practical works, only 25(16.1%) agreed that almost always, 23.8% often, 32.3% sometimes and 27.7% rarely do pre-lab activities. Some students show that never do pre-lab activities during chemistry practical work. Students respond at the rate of 22.6% almost always, 21.3% often, 38.1 sometimes, and 18.1% that they watch teacher demonstration of the experiment. A high number of students watch teacher demonstration of the experiment during chemistry practical work. Most of the students agreed at a higher rate of 89.9%agree that they design practical work whereas 18.1% agree that rarely design practical work. Also, a considerable number of students at a rate of 66.8% agreed that they conduct practical experiments whereas 23.2% agree that they rarely conduct practical work. Students work conduct experiments in small groups at the rate of 85.2% whereas 23.2% rarely do. Most students do lab-report after experiment 83.2% whereas 16.8% rarely do laboratory reports after practical work. From the above results, the study finds out some difficulties that hinder effective teaching and learning chemistry through practical work such as students do not conduct pre-lab activities and make laboratory report after the experiment.

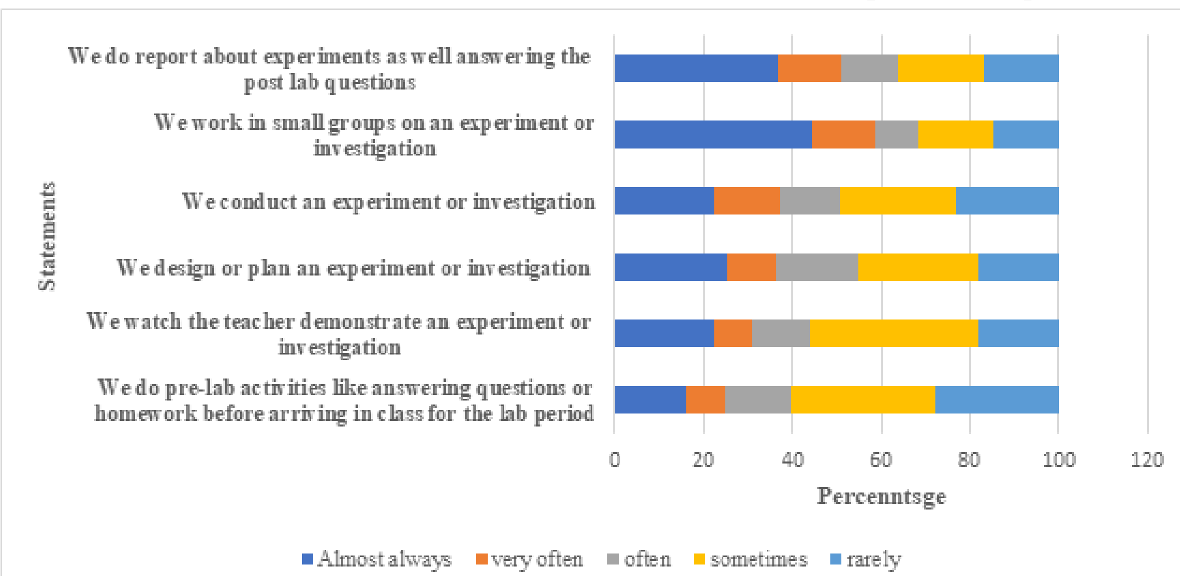

Figure 1 Students' responses about their engagement and experience during chemistry practical work

Those results agree with Shana and Abulibdeh (2020) found that when students are the engagement of students during practical work is important and increase their academic outcomes. It is also in agreement with (Mwangi, 2016) found that the use of chemistry practical work promotes students' engagement and interest.

Impact of chemistry practical work on student's academic performance

To investigate the impact of chemistry practical work, a pre-and post-test was conducted. The Table 1 shows descriptive analysis of pre- and post-test.

In Table 1, the descriptive analysis revealed that the mean score of post-tests was increased by 10.06 % from pre- to post-test. To test whether if there is statistical significance difference in mean score of pre- and post-test, males and females, and type of school (day school and boarding) the inferential statistic independent sample t-test was used. The independent t-test results for the effectiveness of practical work on student performance in chemistry yielded noteworthy findings. The comparison of pre and post-test scores showed a highly significant p-value of 0.000, indicating a substantial improvement in student performance following the practical work intervention. This suggests that engaging students in practical laboratory activities has a significant positive impact on their understanding and application of chemistry concepts. Furthermore, the gender-based analysis revealed a p-value of 0.12, indicating a non-significant difference in performance between female and male students. This implies that the practical work approach is equally effective for both genders. Similarly, the comparison between boarding school and day school students resulted in a p-value of 0.10, suggesting a non-significant difference in the effectiveness of practical work on student performance between these two groups (see Table 2).

Table1 Descriptive statistic of pre and post-test

Test	N	Mean	Std. Dev.
Pre-test	155	55.62	7.29365
Post-test	155	66.22	9.80464

In the discussion of these findings, it is essential to highlight the substantial improvement in student performance indicated by the highly significant p-value for the pre and post-test comparison. This

Table 2 Inferential statistics of pre and post-test

Variable	Group	N	Mean	SD	Sig. (2-tailed)
Test	Pre-test	91	18.32	2.22	.000
	Post-test	81	15.87	2.91	
Gender	Male	71	19.12	3.43	.120
	Female	84	14.84	2.11	
School Type	Boarding	76	19.78	3.78	.100
	Day s	79	14.21	3.12	

underscores the pedagogical value of incorporating practical work in chemistry education. The non-significant differences in performance between female and male students and between boarding school and day school students are also crucial observations. The uniform effectiveness across gender and school type implies that the benefits of practical work are not biased or restricted to specific demographic groups or educational settings. These findings have practical implications for educators and curriculum developers, supporting the integration of practical laboratory activities in chemistry instruction as a universal strategy for enhancing student performance. Additionally, further research could explore specific aspects of practical work that contribute most significantly to improved performance and investigate potential factors influencing any observed gender or school-type differences, providing valuable insights for refining educational practices in the future.

Challenges faced by students while conducting chemistry practical work

To find out difficulties uncounted by students while conducting chemistry practical work, a Likert scale questionnaire with five-point rating option that are strongly agree (5), agree (4), Neutral (3), disagree (2) and strongly disagree (1) was used. The obtained results were analyzed in terms of percentages. During analysis we found that students difficulties in during chemistry practical work were classified into two categories that are: School's laboratories and equipment's, and insufficient time allocated to chemistry timetable. The Figure 2 shows students response on the challenges associated with school's laboratories and equipment.

While identifying students' and teachers' difficulties related to schools' laboratories and equipment. A larger number of students at a higher rate of 69.6% responded that chemicals are insufficient in their laboratories, only a low level of participants at the rate 14.8% responded that their schools have sufficient chemicals while 15.5% of students were neutral to this point. Also, a larger number of respondents at a rate of 59.4% accept that laboratory equipment is not enough, only a lower number of participants at the rate of 11% responded that their schools have enough equipment in the school's laboratories whereas 9.7% were neutral to this point. 72.3% of students responded that their laboratories spaces are not enough, a lower-level rate of 13.5% agreed that their school's

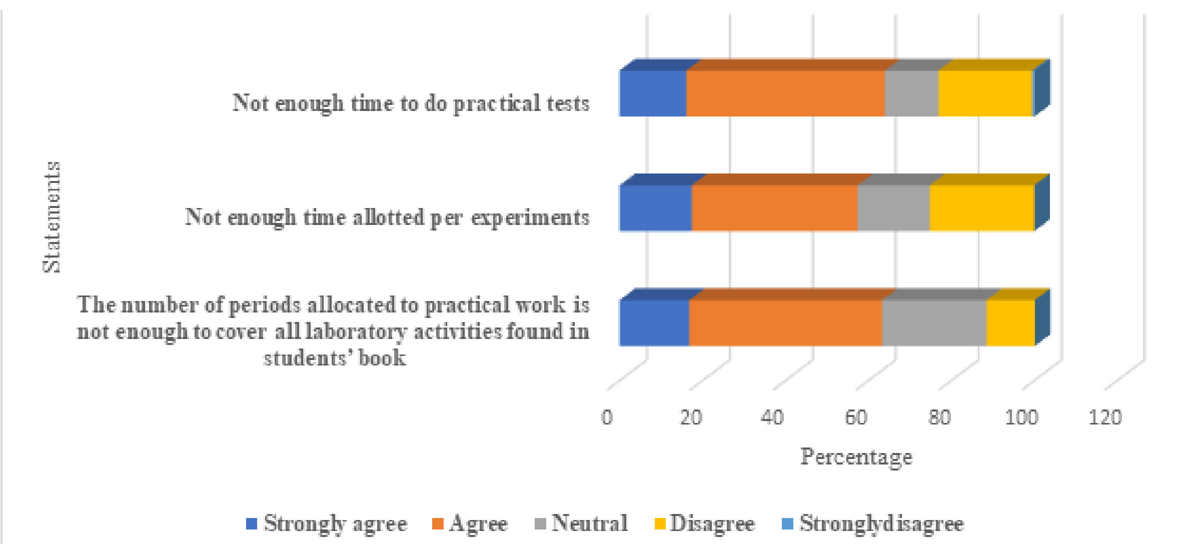

Figure 2 **Students response on the challenges associated with school's laboratories and equipment**

laboratories space are not enough whereas 14.2% were neutral to this point. Most of the participants at the level of 67.1% responded that textbooks and laboratory manuals were available, 14.8% responded that textbooks and laboratory manuals were not enough whereas 18.1% shows neutrality to this point. From those results, this study finds out some difficulties that hinder effective conducting chemistry practical such as availability of chemicals, equipment's and laboratory space are not enough. The study also finds out difficulties uncounted by teachers during chemistry practical work, Table 5 shows teachers' responses to the school's laboratories and their equipment. The Figure 3 displays challenges associated with insufficient time allocated on the school time table.

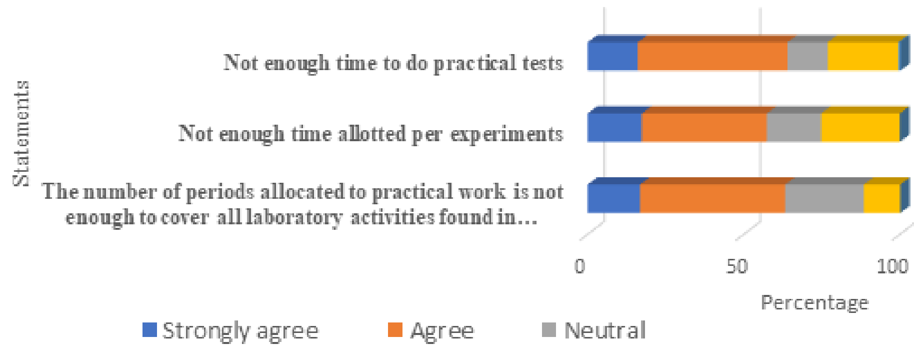

Figure 3 Challenges associated with insufficient time allocated on the school time table

While finding out the difficulties related to the insufficient time allocated to the chemistry timetable, most of the students at a rate of 63.5% responded that the number of periods allocated to the practical is not enough, only a lower number of students at the rate of 11.6% responded that the number of periods allocated to the practical's is enough whereas 25.2% are neutral to this point. A larger number of students at the level of 57.4% responded that there is not enough time allotted per experiment, low level of students at the rate of 25.20% agree that there is enough time allotted to the experiment whereas 17.4% are neutral to this point. Also, most of the students at the rate of 63.8% responded that time to do the practical test is not enough, only a lower number of students at the rate of 23.2% agree that time to do practical is enough whereas 12.9% were neutral. From the above results, the study finds out some difficulties that hinder effective teaching and learning chemistry through practical work including the number of periods allocated to the experiments, time allocated to the experiments, and time of practical test are not enough. To identify difficulties associated with the insufficient time allocated to the chemistry timetable teacher's questionnaires were also used. The identification of two primary categories contributing to students' difficulties during chemistry practical explored are related to school laboratories and equipment, as well as insufficient time allocated to the chemistry timetable provides valuable insights into potential areas for improvement in the educational context. In this sense, the challenges associated with school laboratories and equipment suggest that there may be a need for investments in infrastructure and resources to enhance the quality of practical work environments (Atar, 2002). In addition, adequate provision and maintenance of laboratory facilities and equipment are essential for fostering a conducive learning environment and ensuring that students can fully engage in hands-on experiments (Shitaw, 2017). Simultaneously, the recognition of insufficient time allocated to the chemistry timetable underscores the importance of a well-balanced curriculum that allows for comprehensive coverage of theoretical concepts and practical applications. Addressing these challenges may require collaborative efforts among educators, administrators, and policymakers to allocate resources effectively, optimize scheduling, and prioritize practical learning experiences, ultimately enhancing the overall effectiveness of chemistry education (Bruce et al., 2021).

Potential solutions to the identified challenges

To identify potential solutions to identified problems incorporation of students ideas from one open question for all students was used. The potential solutions highlighted are provision of a laboratory assistant, sufficient equipment, and increase time for experimenting. To achieve this, laboratory assistant can manage equipment, provide guidance, and troubleshoot technical issues, creating a supportive environment. Ensuring equipment supply encourages hands-on learning and reinforces theoretical concepts. There is commonly a shortage of technical support to help the setting up and organization of laboratory practical works (Eilks & Hofstein, 2013). Thus, recruiting qualified chemistry teachers and laboratory assistants is also recommended. There should be further scrutiny of the curriculum and learning standards for chemistry practical in secondary school chemistry and an in-depth study of teacher competence in the teaching of practical chemistry is suggested. The curriculum developers can increase time for practical for chemistry timetable.

Moreover, increasing the time allocated for experimenting addresses the issue of insufficient time in the chemistry timetable. Extended laboratory periods or additional practical sessions can afford students the opportunity for more in-depth exploration of experimental procedures, fostering a deeper understanding of chemical principles. This solution acknowledges the importance of balancing theoretical instruction with hands-on experience and reflects a commitment to providing a comprehensive education in chemistry. Implementing these solutions requires collaboration among educational institutions, administrators, and policymakers to allocate resources effectively and adapt curricular structures to prioritize practical learning. By addressing these identified challenges through practical solutions, educators can contribute to an enriched and more effective learning experience for students in the field of chemistry.

Conclusion and Recommendations.

The study tends to examine students' engagement, experience, and student's academic performance towards the utilization of chemistry practical work. It was found that students have a positive experience and are engaged of chemistry practical work by doing the organized activities. The study investigated that the use of chemistry practical work increases students' academic performance but there was no significant difference in terms of performance in terms of gender and type of school. This implies that there is a positive linear relationship between the quality of practical work and students' academic performance chemistry. As a result, when teaching and learning chemistry, the quality of practical work should be taken into account. That is, consistent planning and use of high-quality practical work by teachers is required if students' chemistry performance is to improve. The difficulties that hinder effective teaching and learning of chemistry through practical include students' lack of chemicals, equipment, and laboratory space is not enough, the shortage of time allocated were also identified. Some strategies identified to overcome those difficulties include the provision of sufficient laboratory equipment and increasing the time of conducting practical works. Therefore, The authors advocate for students to have the opportunity to be engaged in deep learning. Deep learning allows for the identification of the main objectives of the work as well as its planning and execution, the identification of conceptual and practical difficulties encountered, the recording and discussion of the results and observations, and the suggestion of practical alterations and improvements.

Conflict of interest

Authors declare no conflict of interest

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