Development of chemistry learners' problem-solving skills through hands-on instructional model

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ABSTRACT

Learners can experience science in the real world by interacting with materials, collaborating with peers, and engaging in a problem-solving process. Notwithstanding, secondary school learners' problem-solving skills (PSS) can be developed by using an instructional strategy that actively involves them in the learning process instead of sorely focusing on content learned. This paper shows how the production of materials for teaching and learning can go hand-in-hand with the development of learners' PSS through the implementation of a Hands-on Instructional Model (HIM) in chemistry lessons. This study was a Design-based Research using a convergent mixed-method approach. The data was collected using lesson observation protocol, focus group discussions guide, and problem-solving test. On the aspect of the development of PSS, learners were enhanced with the skills to solve an ordinary chemistry problem and the criteria of observation were on the ways learners identify a problem, the approach used to solve the problem, and whether they could reflect on the answer they obtained. The findings indicate a substantial impact of HIM on learners' PSS. Therefore, it is suggested that HIM should be used frequently to enhance learners' active engagement in chemistry lessons and for further development of their PSS.

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1. INTRODUCTION

There has been the emphasis of a paradigm shift in recent decades in the field of science and mathematics education in most developing countries. The shift focuses on the active application of concepts that are familiar to learners, as well as the use of instructional strategies which enhance and improve learners' problem-solving skills (PSS). Learners of this era need some learning skills of which problem-solving ability is one [1]. PSS is not only necessary for solving problems in the context of formal education it is rather needed in other aspects of life outside the classroom. Besides, some teaching and learning strategies are noted to improve learners' PSS [2], [3], activity-based kind of learning such as the use of hands-on activities is highly advocated. It is also argued that hands-on activities are strategies in which learning is situated in the context of meaningful activity for knowledge to be used in similar situations later in life [4]. However, the shift of paradigm has called for curriculum reforms in most countries to suit the demands of the fast-growing words economy [5]. Thus, the paradigm shift should be adhered to in the context of the classroom to incorporate the instructional strategies which can enhance the development of PSS.

For a learner to have PSS there must be a problem to be solved. Problems appear in all fields of life [6]. This is why teachers should prepare learners for lifelong learning. Besides, a problem becomes a problem if you do not know how to go about solving it [5]. If a problem has no 'surprises', and can be solved easily by routine or familiar procedures; such problem is considered to be only an exercise. Learners must develop the skills to resolve problems and have the personal resilience to meet the challenges and pressure that may be the result of a problem. However, problem-solving (P-S) as situations in which an individual is reacting to a problem that he or she does not know how to solve 'easily' with predictable or familiar procedures [7], [8]. Also, P-S is when a learner uses previously acquired knowledge, skills, and understanding to fulfill the demands of an unfamiliar problem [9]. Therefore, learners should be able to combine the knowledge that they acquire and apply it to solve given problems.

Studies done in this field show that, when P-S is well emphasized, learners become more confident, develop a positive attitude, and ease transition to further studies and work [10], [11]. Problem-Solving aid to improve learners' ability to work [12], communicate with others [13], as well as cultivate awareness and control on their thinking practices [10], [14]. Also, to let students improve their PSS [13], to allow learners to be innovative and use divergent or lateral thinking [15], to show learners that science is more than 'getting the correct answer' and that it can involve decision making, being creative and using lateral or divergent thinking [7], [12]. Thus, P-S is as vital in chemistry as it is in other fields of education.

In chemistry education, P-S should not be examination-oriented. It should not be emphasized only in examination classes as [12] advocates it be emphasized to all classes. Apart from that he also recommends P-S to be emphasized in all lesson sessions other than practical only. However, a person with P-S skills is considered to be a problem solver. The major components of a problem solver to be; knowledge, heuristics, and metacognition [16], [17]. Whilst, knowing a problem is the first step to getting its solution [18]. When there is less basic knowledge and skills on the problem, the more the working memories are burdened [19]. Nevertheless, heuristics are defined as a kind of method, process, or set of guidelines that a person applies to various situations [5]. Thus, when learners possess well-connected knowledge, heuristics, and facts, as well as their ability to manage their emotional responses they can precisely obtain solutions to problems [20].

Apart from heuristic, metacognition is associated with designing, monitoring, and evaluating cognitive processes in P-S [20], [21]. Good problem solver tend to gain from personal experience and general knowledge, from being able to use analogies, and from metacognitive skills [15]. Although heuristics help problem solver break down problem into more manageable pieces, but self-monitoring and goal management are central features of metacognition [14]. Therefore, to solve the problem, learners ought to connect the past and present knowledge, use appropriate P-S strategies, and reflect on the process and the solution.

However, literature proposes in-class interactive learning to be among the learning instructions where learners actively participate in P-S and the teacher can get real tome evidence of learners learning [2], [3]. The use of hands-on instruction in 21st-century classes fosters the need for learners to be successful in critical thinking, PSS, communication, creativity, and collaboration [22], [23]. Besides, hands-on generally means learning by experience. Learners manipulate objects and handle scientific instruments within the learning process [2]. Also, it is assumed that learning becomes more realistic and learners get the exciting experience of the content learned. Therefore, integration of hands-on activities in the learning process is essential to enhance the acquisition of soft skills required in this learning era.

A successful chemistry learner ought to have PSS from the early age of learning. It was also proposed that P-S should be emphasized in lower-level chemistry as it is done in universities and colleges [19], [20]. One way of achieving this is through a careful and thoughtful selection of appropriate teaching strategies that will help in promoting learners' ability to create meaning of science and mathematical concepts rather than passive reception of ideas [13]. Therefore, the need for problem-solving skills as one of the basic learning skills among Ordinary-level chemistry learners triggered us to conduct this research.

2. RESEARCH METHOD

2.1. Research design and approach

This study was conducted in three community secondary schools in Dar es Salaam, Tanzania. Community secondary schools are public schools constructed by the community but owned and aided by the government. However, this study was Design-Based Research (DBR) following a pragmatic philosophical view [24], [25] because the focus of the study was to bridge the gap between theory and practice [26], [27]. DBR is a grounded and interactive research methodology because researchers need to integrate a variety of research methods and approaches from both qualitative and quantitative research paradigms depending on the needs of the research [28]. Whereas, pragmatism emphasizes creating shared meaning and joint actions by complementing qualitative and quantitative approaches [25]. Besides, the intervention was designed during the study where learners were empowered with the skills to design the instructional materials which could be appropriately used in chemistry lessons and at the same time stimulate their P-S ability. Furthermore, this study being design-based research did not involve a control group [29]. Therefore, all learners who were involved in the study went through the intervention.

2.2. Sample

A total of 169 Senior Three learners (101 male, 60%, and 68 female, 40%) with the facilitation of their chemistry teachers in their respective schools were selected based on the purpose of this work. Both learners and teachers were purposively selected from three intact Senior Three science classes in three community secondary schools. The learners had a mean age of 16.12 with a standard deviation of 0.854. Apart from that, the three community schools were also purposively selected from 138 public schools in Dar es Salaam, which is the capital business city of the United Republic of Tanzania.

2.3. Instruments and data collection procedure

In this study, we used Lesson Observation Protocol (LOP) and Focus Group Discussions (FGDs) guide for learners as qualitative research instruments and Problem-Solving Test (PST) as quantitative instruments for the data collection process. The credibility of the LOP and the FGD guide was checked by experienced science educators to establish their worthiness and whether they can produce reliable and credible results. Then, two raters checked for the inter-rater reliability and they reached a consensus. The changes suggested by the raters were incorporated before the LOP and FGD guide was used for data collection. Also, the conformability of the information obtained was observed to ensure all information obtained is based on participants' responses [29]. Besides, we formulated the PST based on the Senior Three chemistry syllabus and the current Tanzania curriculum. The test was checked for clarity and if it measures the intended competencies. Also, the test was piloted to 22 learners from one school with a similar class and learning environment as those of the three schools in the study. The reliability check gave the Cronbach Alpha Coefficient Value of 0.73. Finally, triangulation of information obtained from the three research instruments was done to ensure the trustworthiness and accuracy of the research findings [29], [30].

A total of 42 lessons (14 lessons in each school) were observed in all three schools, where 14 lessons of the total were single (40 minutes) while 18 lessons were double (80 minutes). The field notes were taken in addition to the information taken using LOP. Also, the FGDs were conducted once a week after lesson observation at a convenient time for the research participants and a total of 21 FGDs interviews were conducted in all three schools, seven per school. All FGDs were audio-recorded to help the researchers to capture learners' experiences during the chemistry lessons.

2.4. Data analysis

The analysis of the data collected in this study was done concurrently with the data collection process on daily basis. Constant reflection of information obtained from lesson observations and FGDs was done to monitor the ongoing process of data collection and identify issues that needed clarity and follow-up during the intervention process. All the qualitative data were analyzed thematically in two forms i.e. preliminary analysis and retrospective analysis [29]. The preliminary analysis was done for the pre-test-PST to obtain qualitative information which informed the designing of the Hands-on Instructional Model (HIM) intervention. Besides, the retrospective analysis was continuously performed on the information obtained daily from lesson observation using LOP, field notes, and the audio recorded information from interviews and FGDs. The whole process began with transcription of audio data, translation, and organization for better interpretation of the information obtained. Thereafter, the information was organized hand-in-hand with the field notes and data from classroom observation to generate raw data for the coding process [30]. Then, the coded information was sorted and sifted through to identify similar and coherent phrases [29], relationships between variables, patterns, and themes to differentiate distinct and common sequences of categories about the research question [31], [32]. Lastly, meaningful information that gave better answers to research questions was obtained from the developed themes and sub-themes [33]. Besides, the analysis of quantitative data from both pre- and post-intervention PST was done using Statistical Package for Social Sciences (SPSS) version 20. The analysis involved descriptive (mean, standard deviation, and percentage) as well as inferential (dependent samples t-test and effect size) statistics [32]. Further, interpretation of the results obtained was done using the SPSS guide by [34].

3. RESULTS AND DISCUSSION

3.1. Results

The analysis of data from lesson observations and students' FGDs was done based on the purpose of this study and collaboration between stages of conducting DBR as well as the P-S process. On the aspect of the development of learners' PSS, students were enhanced with the skills to solve an ordinary chemistry problem, and the criteria of observation were based on the way learners started a problem, the approach used to solve the problem, and whether they could reflect on the answer obtained. The findings led to the formulation of four themes for P-S processes: identification, prioritization, alternatives, and implementation.

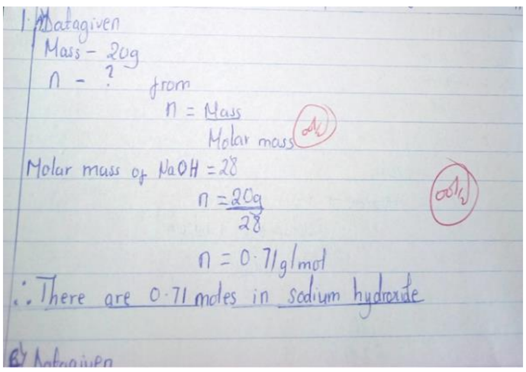
3.1.1. Theme 1: Identification

Learners were given an orientation on the focus and success criteria of the study. Besides, learners were supposed to identify the problem from the activities given by the teachers in the chemistry lesson about mole concept and volumetric analysis. Also, learners were supposed to identify home-based materials that could appropriately be used to facilitate learning or used to make apparatus that could alternatively be used to carry out some simple experiments in their respective classrooms. The instructional materials made from home-based materials were meant to increase efficiency in the assimilation of lesson content as well as increase learners' engagement in the lesson due to the association of lesson content and the materials. Thus, through this kind of learning mode learners' PSS was expected to improve despite the insufficient commercially made instructional materials.

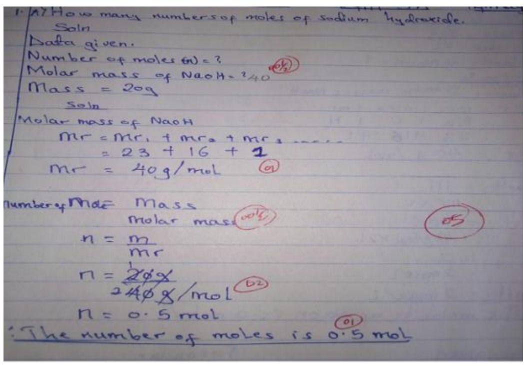
On identification of a problem from various activities given to them, learners were supposed to elicit what was exactly required in a given activity. For instance: from a question; what is the molarity of a solution containing 80 g of sodium hydroxide in 2 liters of the solution? This kind of question looks like a simple exercise that any learner who has learned basic concepts of the mole concept topic is capable of solving. Yet, most of the learners had little understanding of what molarity means and what is referred to in a question like that. When such questions were written on the board for the learners to solve as an activity in their groups or as individuals, they could mostly sit and wait for their teachers to work it out on the board and for them to copy in their notebooks. Most of the learners left the question blank in their pre-test and they failed to at least identify the information given in that particular question. Perhaps, this was because previously learners were taught formulas and other theoretical concepts without contextualization of the teaching and learning process through drawing meaning in real life.

The analysis done on learners' answers revealed some improvement in their P-S abilities between pre and post-test results. Before the intervention, most of the learners were not able to identify a required task from a simple chemistry question. Nevertheless, similar questions became easier for them after they were accustomed to the P-S procedures introduced to them during the intervention. For instance, a learner from school B failed to compute the number of moles of NaOH during the pre-test. She failed to solve a problem because she could not calculate the molar mass of NaOH. It should be noted that this question was the easiest question which most of the learners answered correctly in both pre and post-test as displayed in Figure 1. Not only in the PST but also during some classroom activities learners struggled to critically analyze a problem to obtain the solution. Eventually, after the intervention students' P-S ability was noted to have been stimulated due to the emphasis and the effective use of the intervention design.

Nevertheless, the observation done in the sessions where learners were designing the instructional materials revealed that learners can do better if they are continuously motivated. In the beginning, searching for the materials seemed not to interest most learners and this exercise become like a burden to them. But, with time it became an easy process for the learners and they were able to associate chemistry content with home-based materials which facilitated the learning of the content. This was also confirmed in some of the learners' FGDs excerpts.



(a)



(b)

Figure 1. Students' improvement of problem-solving abilities between (a) pre-test before the intervention design and (b) post-test after the intervention design

3.1.2. Theme 2: Prioritization

The orientation that was given to learners was to enable them to gain skills to work on ordinary problems in a given classroom activity using general P-S procedures. After identification of the problem, learners were supposed to identify possible routes and procedures to get the expected solution. These routes could probably be prioritized based on the order of importance towards an intended scientific solution. There was no need for all the learners to use the same procedures to arrive at the answer or get the answer for the particular question perfectly and correctly. For instance: a question like 'For complete neutralization of 25 cm^3 of 0.120M sodium hydroxide solution 28.4 cm^3 of the sulphuric acid solution is required. What is the concentration of the acid in grams per liter? What is the molarity of the acid?' has no single route to get the answer. It was up to the students to decide on the easier route to follow based on the P-S process.

Under the aspect of prioritization, learners were required to generate the alternative solution to a particular problem and the components of the activity that could enable them to arrive at the desired outcome. For instance, in the previous question knowing the components of the problem like the molecular formula of the reagents, molar mass of each reagent used, writing the balanced equation, the data which is given, and the formula to be used could enable the learner to get at least part of a solution to the question. Knowing the molecular formula can enable the learner to compute for molar mass but if the learner does not know precisely the atomic number of the elements making up a particular reagent, cannot precisely get the respective molar mass of the reagent. Besides, the experience gained from the intervention demonstrates the vital impact of the emphasis put on procedures in the P-S process.

The analysis of learners' answer sheets for pre and post-test revealed a notable difference between the way they answered the questions before and after the intervention. In the pre-test, some learners did not know what they were supposed to do in the test and they ended up copying questions. Some failed to identify the data that was given in the respective questions. Others failed to write the formula for the reagents given while others managed to write the formula and failed to compute molar masses of the respective formula. Other learners managed to write the chemical reactions but failed to balance the equations. On the other hand, the learners' post-test results showed a substantial improvement in the learners' problem-solving abilities as a result of the emphasis put on the intervention. There was much improvement in the way learners handled the components of the questions. Most of them were able to comprehend what was demanded in the questions although they could fail to obtain correct answers in some instances.

Working on the instructional materials related to each chemistry lesson content by making effective use of home-based materials was done before every lesson as part of the P-S process. The process was enhanced by the teachers relating the lesson objectives with materials in the learners' surroundings which could appropriately make materials that can facilitate the learning of the mole concept and volumetric analysis. For instance, learners were able to identify materials that could best be used to make a well-calibrated burette. In the end, learners preferred the use of a clinical syringe which could be easily used to make a burette that could give an accurate volume as a commercially manufactured one.

3.1.3. Theme 3: Alternatives

Analysis of the alternatives available to obtain a better solution for the identified problems in classroom activities was also emphasized to the study participants. With time learners managed to acquire the skills to generate solutions that suit a particular problem. This was possible because learners were encouraged to evaluate not only the solution to the problem but also the value that was supposed to be obtained at the end. Immediately after working out a solution to particular question learners developed a tendency of revising the end value several times to ensure, it is precise. This helped to increase the probability of obtaining the right answer.

When learners were given some activities to perform in their groups and some questions to solve by their teachers, they were highly motivated to read the questions carefully. Through careful reading of the questions, learners could identify the important aspects of that particular activity. From the alternatives identified as well as the components of the questions learners were able to identify steps that were dependent on each other to arrive at the final solution. For instance, learners were able to work out the molarity of a solution by working the associated number of moles. In the other way, learners could also use the alternative of the relationship between concentration in molarity (M), volume (cm^3), and the number of moles (N). Therefore, the analysis of the alternative routes and steps of the question made it easier to obtain the solution.

3.1.4. Theme 4: Implementation

After critical analysis of the activities given, learners applied the alternative routes that they expected to give the best solution. If there was a question to be solved either individually or in collaboration with peers, only the best alternative procedures were employed in solving these questions. It was not just that the alternative answer chosen give the correct answer but it minimized the risks of getting the wrong answer. The emphasis of the critical analysis of the solution came after going through the learners' pre-test scripts.

The analysis of the papers informed the orientation process on the gaps faced by learners and what the teachers were supposed to do for them to fluently solve the problems. Also, after the orientation given to them on the use of hands-on activities in the classroom and searching of instructional materials, learners implemented all the procedures in their classroom setting under the guidance of their teachers. It is through the implementation of the alternative solutions to the particular question that is when learners were able to identify if the proposed solution is appropriate. Immediately after the answer was obtained learners were supposed to go through the process of solving that particular problem again to check whether the answer is promising to be correct. Sometimes learners used the alternative route towards the answer to check if the same answer can be obtained again.

Apart from observations done during the chemistry lessons, information obtained from FGDs complemented the evidence gathered on the contribution of the designed intervention to the development of learners' P-S abilities. In groups of six learners, FGDs were conducted and Table 1 shows some of the learners' excerpts corresponding to each theme. It should be noted that the names used in the presentation of learners' excerpts are not real names, rather they are pseudonyms. Teachers employed the modeled intervention on the use of hands-on activities to ensure that learners develop P-S abilities while manipulating the instructional materials designed to facilitate learning as well as solve classroom problems in given classroom activities. The questions asked in FGDs were semi-structured.

Table 1. Learners' responses in FGDs corresponding to the themes

Themes	Excerpts
Identification	*The experience obtained since you came is good because it is now interesting to participate in activities given in chemistry lessons.* (FGD 5: school B; Amiel)
	I am now aware of what to do and the procedures to follow when I face a problem in chemistry activities. For example, when the teacher started to teach mole concepts it was difficult for me to grasp and participate in classroom activities. But now I can see the changes myself. (FGD 3: school A; Kharith)
	I almost dropped chemistry… because it seemed to be difficult in general and the attempt of the questions was difficult to me. I can be a witness because I left blank almost all the questions in that test you gave us. (FGD 2: School A; Naomi)
	For me, I can say that it is a good experience. Now I understand that there are materials that can enhance my learning which I ignored before. (FGD 6: School C: Geoff)
	For example, empty bottles, ball pen tubes, and tins, boxes, pegs are among the materials which can be used to make simple apparatus for our classroom experiments. (FGD 6: school C; Menad)
	Within this short period, I can associate well what I learn with my environment…. for example, I now understand that talking of measurement of different quantities, simple materials like coins, sand, water, and others can be used. (FGD 7: School A; Kengwa)
Prioritization	*We have learned varieties of formulas and ways to answer questions which were difficult for me to know which formula can be used to a question…sometimes to know what starts and what follows is the problem.* (FGD 3: School B; Huruma)
	For example (student wrote on a paper and explained) to get the number of moles one can use n=m/Mr or n=MV but it depends on what data do you have in that question. These formulas can also be used in the procedures to work for concentration depending on the data available. (FGD 7: School A; Malaika)
Alternatives	*I would rather use the direct route (student wrote on a paper) of the MaVanb=MbVbna formula than using the route of working for the number of moles.* (FGD 4: School C; Elisha)
	Although finding molarity by working for the numbers of moles is a long route but it is giving me a precise answer. (FGD 7: School A; Jackob)
	Previously I was not checking whether my answer is correct…this time am using just a short time to answer a question and I prefer using the alternative way to check whether the answer I got is correct or not…. Even when I don't use an alternative way but I should check for the accuracy of the answer I got. (FGD 5: school B, Jemimah)
Implementation	*When this system of learning was used in the first place I saw it as the long route and saw it as a waste of time …these days I'm enjoying using it and I frequently get the answers correct.* (FGD 7: School C; Mehsack)
	It feels interesting to me because I systematically solve the questions in all activities given and I rarely get the answers wrong. (FGD 6: School B; Ziporah)
	I can identify the appropriate formula to use and implement in a particular question. (FGD 4: School A; Nimrod)
	With this learning style of working by cooperating with my fellow students, I am becoming fond of chemistry and I could never see the necessity of it being part of my life if we could not directly involve materials that I know from home. (FGD 6: School C; Kuruthum)

Quantitative data analysis of pre- and post-intervention PST results was done to complement the qualitative data as well as give the measure of the impact of hands-on activities done using learning resources designed by learners on their PSS and ability as shown in Table 2. The descriptive statistics results gave the mean and standard deviation was (M=5.590, SD=2.532) before the designed intervention and (M=12.820, SD=3.560) after implementation of the designed intervention. Also, a dependent samples t-test was performed on pre and post-test PST results from t (168)=48.465, p<0.0005, and the effect size of 0.934 was obtained from t-test results. The effect size value confirms that there was a significant impact of hands-on activities on learners' PSS and abilities.

Learners' performance in the post-test was much better than that of the pre-test due to the impact of the intervention design. The effect size of 0.934 computed from the *t*-test results revealed that learners' ability to solve mole concept and volumetric analysis problems was stimulated by engaging them in hands-on activities using learning resources obtained from their immediate environment.

Table 2. Dependent samples t-test for pre and post-problem-solving test

		Paired differences					*t*	*df*	*P*
		M	SD	SE Mean	95% of the CI difference Lower	Upper			
Problem-solving tests	Pre- Post-test	7.231	1.940	.149	6.936	7.525	48.465	168	.000

3.2. Discussion

The information obtained from the four themes and the quantitative information obtained from PST was triangulated to answer the two posed research questions. The information is discussed based on the related literature. The discussion is presented in subsection.

3.2.1. Research question 1

We triangulated information from lesson observations, FGDs, and PST to generate collective information on the contribution of HIM to the development of learners' PSS in chemistry. The results from lesson observations done in the three schools give evidence on how the learners' problem-solving skills developed from time to time. This was detected based on the first impression that learners had before attempting various classroom activities. At the onset of the intervention, some learners could just stay sitting without doing anything, and sometimes when given activities some could just copy questions and not work out the solution; while others could start immediately by writing without reading, digesting, and getting to understand the concept behind a particular question. Besides, based on the fact that the study aimed at developing learners' basic P-S abilities, the criteria of success of the study was to see whether learners take time to read and understand the demand of the question to arrive at the desired final answer This was detected when learners were able to begin answering the question by identifying all the information given in the question, missing data, and the demands of the question. Thus, it is important to note that for learners to better solve a problem in a particular question should spend time reading the question, understanding the concept behind it, as well as major components of the question.

As seen in Table 2 the t-value of 48.465 which gave the effect size of 0.934 gives evidence of the significant difference of learners' P-S abilities between pre and post-test results of the PST. This result reveals that engaging learners in hands-on activities have an impact on the development of their P-S abilities as the activities give them chance to be actively engaged in the learning process. This is in line with [3], who said that when learners interact in hands-on activities with a well-thought-out plan develop a better understanding of both simplified and complex algorithmic expressions of an activity. According to them, hands-on activities increase learners' positive impression and a sense of ownership of the learning process as well as prepare them better for the exams. Also, hands-on activities enable learners to familiarize themselves with the concepts to reduce memorization [35]. Thus, learners with these features can subsequently gain the ability to solve problems in ordinary classroom activities.

If learners have understood the concept behind a particular question it is obvious the time that may be used to work for the solution will be reduced [21]. This is because the problem in a given question is already clear to learners. Therefore, working for the solution will not demand much time. Also, when learners can identify steps of the question like the formula to be used to get the solution; or whether the question requires the writing of a balanced chemical equation; or if the concept behind the question involves alternative formula to get the answer. Working for the solution is expected not to be much harder and will consume lesser time. Indeed, it seems that when learners are familiar with a problem or some aspects of a problem [36], [37] helps to create a bridge between the problem and the solution which later improves their P-S abilities [38], [39].

Again, it was noted from the findings that the PST seemed to be like a simple exercise to few learners. These learners did not struggle to work for solutions in both pre and post-test. This brought to our notice that these learners either had some prior understanding of the content or knowledge of the P-S process. Perhaps it is because these learners got time to evaluate and reflect on their answers to see whether they are correct [36], as claimed by one learner in FGD. Also, these are among the learners who participated fully in lessons and they seemed to have understood well the concept underlying the questions. Therefore, their attempt at the questions was not only to work for the answers but also to express the knowledge obtained in the relationship between the concept and the questions [40]. Learners with such capacity demonstrate similar behaviors as the experienced problem-solvers rather than novice problem solvers [17], [18], [36]. From this finding, we conclude that researchers interested in conducting a related study should consider structuring PST that caters to all learners' learning abilities.

3.2.2. Research question 2

We triangulated information from only lesson observations and FGDs to establish how learners can interact in hands-on activities and at the same time develop their P-S abilities. Knowing the patterns of the problem enabled learners to fulfill another important aspect of this study which was searching for instructional materials appropriate for learning intended chemistry concepts. The shared learning objectives gave the picture to learners of what materials that they could bring in the class along with them to facilitate the learning of the mole concept and volumetric analysis. Also, the objectives shared by the teachers enlightened the learning intentions of the lesson which later enabled learners to elicit the success criteria of the lesson too. Besides, engaging themselves in searching for instructional materials that are home-based enabled learners to relate chemistry content with their surroundings. This is expected not only to reduce the issue of insufficient learning resources but also to create a P-S mindset that can later enable learners to solve other real-world problems [16], [37], they may encounter in their surroundings.

Also, the direct association of the content with the surroundings makes learning authentic [38], [41]. From FGD, one of the learners verified how the intervention helped her to associate learning with the surrounding environment. The association was done between what learners know, see and come across daily against various areas of mole concept and volumetric analysis. This kind of association between materials in learners' surroundings and the concepts learned did not only enable them to work for the appropriate instructional materials [42], but also enabled them to stay in a learning mood outside the learning environment [43]. Through the implementation of HIM, learners were actively engaged in the lesson irrespective of whether commercial instructional materials are sufficiently provided to sustain their learning [44]. Therefore, this kind of learning approach where learners associate their immediate environment and the lesson content make the learning process to be part of learners' daily life.

4. CONCLUSION

The study revealed that learners' PSS considerably improved due to the implementation of the designed HIM intervention. This was manifested in the way learners were able to identify problems in different given classroom activities, attempt PST, and their ability to prepare instructional materials to be used in chemistry lessons. Also, some concepts that seemed to be difficult in mole concept and volumetric analysis topics became more understandable when learning was contextualized and associated with learners' prior experiences through HIM. The designed approach has a pedagogical significance to both chemistry teachers and learners as it increased accessibility and availability of instructional materials for meaningful learning. Not only that, but learners can manage to work comfortably and independently in absence of their teachers. Besides, through the implementation of the hands-on activities, learners experienced ownership of their learning process by playing part in searching for the appropriate instructional materials for their learning. This is not only actively engaging learners in the lesson but also elevates a lifelong learning perspective. In addition to that, learners' ability to solve real-life problems related to their learning was also enhanced. Nevertheless, this research informs both curriculum developers and implementers on the essence of integrating the designed HIM in other science subjects other than chemistry at all levels with a similar learning environment as in this study. This can create a generation that can challenge scientific issues and solve the emerging problems in this ever-changing technology. Therefore, we boldly conclude that if the designed intervention is given the needed attention; learners' P-S ability and skills can be enhanced.

Based on the key findings of this study, we recommend the implementation of HIM in chemistry classrooms of similar educational contexts as those in this study. Besides, more emphasis should be directed to the frequent use of hands-on activities not only in chemistry but also in other science subjects to make the whole process of learning science authentic and improve educational practice. Besides, it is more important to note that contextualization of chemistry learning through the integration of the lesson content in real-life situations is paramount to enable learners to develop PSS. Also, researchers should endeavor to conduct studies that put the learners at the center of the learning process. The paradigm shifts from teachers being the center of all aspects of the learning process can empower learners to take charge of the learning and reduce teachers' workload. Finally, the shift of the paradigm can create a meaningful learning environment which in turn will enhance nurturing of a generation of independent learners equipped with skills essential for the fast-growing 21st-century world's economy.

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REFERENCES

[1] H. C. Çelik, "The effects of activity-based learning on sixth-grade students' achievement and attitudes towards mathematics activities," *EURASIA Journal of Mathematics, Science and Technology Education*, vol. 14, no. 5, Feb. 2018, doi: 10.29333/ejmste/85807.
[2] M. Fuad, D. Deb, J. Etim, and C. Gloster, "Mobile response system: a novel approach to interactive and hands-on activity in the classroom," *Educational Technology Research and Development*, vol. 66, no. 2, pp. 493–514, Apr. 2018, doi: 10.1007/s11423-018-9570-5.
[3] L. T. Louca and Z. C. Zacharia, "Modeling-based learning in science education: cognitive, metacognitive, social, material and epistemological contributions," *Educational Review*, vol. 64, no. 4, pp. 471–492, 2012, doi: 10.1080/00131911.2011.628748.
[4] Y. Takagi, P. Batten, and K. Rattenborg, "A collaborative exchange to improve early childhood education outcomes," *Problems of Education in the 21st Century*, vol. 78, no. 6A, pp. 1126–1136, Dec. 2020, doi: 10.33225/pec/20.78.1126.
[5] J. D. Dagdag, N. A. Palapuz, and N. A. Calimag, "Predictive ability of problem-solving efficacy sources on mathematics achievement," *International Journal of Evaluation and Research in Education (IJERE)*, vol. 10, no. 4, pp. 1185–1191, Dec. 2021, doi: 10.11591/ijere.v10i4.21416.
[6] J. Park, J. Lee, and D. Kim, "The effects of indexing prompt on problem-solving in case library learning," *Problems of Education in the 21st Century*, vol. 78, no. 3, pp. 394–409, Jun. 2020, doi: 10.33225/pec/20.78.394.
[7] Z. A. Kader, "Enhancing Students' Problem- Solving Skills Using Problem- Based Learning As An Instructional Communication Approach," Universiti Putra Malaysia, 2013.
[8] A. Downton and P. Sullivan, "Posing complex problems requiring multiplicative thinking prompts students to use sophisticated strategies and build mathematical connections," *Educational Studies in Mathematics*, vol. 95, no. 3, pp. 303–328, Jul. 2017, doi: 10.1007/s10649-017-9751-x.
[9] L. A. Cabanilla-Pedro, M. Acob-Navales, and F. T. Josue, "Improving analyzing skills of primary students using a problem solving strategy," *Journal of Science and Mathematics Education in Southeast Asia*, vol. 27, no. 1, pp. 33–53, 2004, [Online]. Available: http://www.recsam.edu.my/sub_JSMESEA/images/journals/YEAR2004/jour04no.1/33-53.pdf.
[10] C. M. Laterell, "What Is Problem-solving Ability?" *LATM Journal*, vol. 1, no. 1, pp. 1–12, 2013.
[11] K. Ndihokubwayo and H. T. Habiyaremye, "Why did Rwanda shift from knowledge to competence based curriculum? Syllabuses and textbooks point of view," *African Research Review*, vol. 12, no. 3, p. 38, Sep. 2018, doi: 10.4314/afrrev.v12i3.4.
[12] T. L. Overton and C. A. Randles, "Beyond problem-based learning: using dynamic PBL in chemistry," *Chemistry Education Research and Practice*, vol. 16, no. 2, pp. 251–259, 2015, doi: 10.1039/C4RP00248B.
[13] W. Wahyu, Kurnia, and R. S. Syaadah, "Implementation of problem-based learning (PBL) approach to improve student's academic achievement and creativity on the topic of electrolyte and non-electrolyte solutions at vocational school," *Journal of Physics: Conference Series*, vol. 1013, no. 1, p. 012096, May 2018, doi: 10.1088/1742-6596/1013/1/012096.
[14] E. M. Albay, "Analyzing the effects of the problem solving approach to the performance and attitude of first year university students," *Social Sciences & Humanities Open*, vol. 1, no. 1, p. 100006, 2019, doi: 10.1016/j.ssaho.2019.100006.
[15] B. Utami, R. M. Probosari, S. Saputro, Ashadi, and M. Masykuri, "Empowering critical thinking skills with problem solving in higher education," *Journal of Physics: Conference Series*, vol. 1280, no. 3, p. 032047, Nov. 2019, doi: 10.1088/1742-6596/1280/3/032047.
[16] J. Jumadi, R. Perdana, R. Riwayani, and D. Rosana, "The impact of problem-based learning with argument mapping and online laboratory on scientific argumentation skill," *International Journal of Evaluation and Research in Education (IJERE)*, vol. 10, no. 1, pp. 16–23, Mar. 2021, doi: 10.11591/ijere.v10i1.20593.
[17] A. E. Kesici, D. Güvercin, and H. Küçükakça, "Metacognition researches in Turkey, Japan and Singapore," *International Journal of Evaluation and Research in Education (IJERE)*, vol. 10, no. 2, pp. 535–544, Jun. 2021, doi: 10.11591/ijere.v10i2.20790.
[18] A. Matawali, S. N. S. Bakri, N. R. Jumat, I. H. Ismail, S. E. Arshad, and W. A. Din, "The preliminary study on inverted problem-based learning in biology among science foundation students," *International Journal of Evaluation and Research in Education (IJERE)*, vol. 8, no. 4, pp. 713–718, Dec. 2019, doi: 10.11591/ijere.v8i4.20294.
[19] M. Rijal, A. G. Mastuti, D. Safitri, S. Bachtiar, and S. Samputri, "Differences in learners' critical thinking by ability level in conventional, NHT, PBL, and integrated NHT-PBL classrooms," *International Journal of Evaluation and Research in Education (IJERE)*, vol. 10, no. 4, pp. 1133–1139, Dec. 2021, doi: 10.11591/ijere.v10i4.21408.
[20] A. Murni, J. Sabandar, Y. S. Kusumah, and B. G. Kartasamita, "The enhancement of junior high school students' abilities in mathematical problem solving using soft skill-based metacognitive learning," *Journal on Mathematics Education*, vol. 4, no. 2, pp. 194–203, Jul. 2013, doi: 10.22342/jme.4.2.554.194-203.
[21] S. A. Tachie, "Foundation phase students' metacognitive abilities in mathematics classes: Reflective classroom discourse using an open approach," *Problems of Education in the 21st Century*, vol. 77, no. 4, pp. 528–544, Aug. 2019, doi: 10.33225/pec/19.77.528.
[22] N. Hırça, "The Influence of Hands on Physics Experiments on Scientific Process Skills According to Prospective Teachers' Experiences," *European Journal of Physics Education*, vol. 4, no. 1, pp. 1–9, 2012, [Online]. Available: http://ejpe.erciyes.edu.tr/index.php/EJPE/article/view/82.
[23] C. O. Ekwueme, E. E. Ekon, and D. C. Ezenwa-Nebife, "The Impact of Hands-On-Approach on Student Academic Performance in Basic Science and Mathematics," *Higher Education Studies*, vol. 5, no. 6, pp. 47–51, Nov. 2015, doi: 10.5539/hes.v5n6p47.
[24] M. G. Festl, *Pragmatism and social philosophy: exploring a stream of ideas from America to Europe*. Routledge, 2021.
[25] V. Kaushik and C. A. Walsh, "Pragmatism as a research paradigm and its implications for Social Work research," *Social Sciences*, vol. 8, no. 9, p. 255, Sep. 2019, doi: 10.3390/socsci8090255.
[26] A.-K. Carstensen and J. Bernhard, "Design science research – a powerful tool for improving methods in engineering education research," *European Journal of Engineering Education*, vol. 44, no. 1–2, pp. 85–102, Mar. 2019, doi: 10.1080/03043797.2018.1498459.
[27] T. C. Reeves, "Enhancing the worth of instructional technology research through 'design experiments' and other development research strategies," *Annual Meeting of the American Educational Research Association*, 2000.

[28] T. Štemberger and M. Cencič, "Design Based Research: the Way of Developing and Implementing Educational Innovation," *World Journal on Educational Technology: Current Issues*, vol. 8, no. 3, pp. 180–189, Oct. 2016, doi: 10.18844/wjet.v8i3.621.
[29] V. Braun, V. Clarke, P. Weate, "Using thematic analysis in sport and exercise research," in *Routledge Handbook of Qualitative Research in Sport and Exercise*, Abingdon, New York, NY : Routledge, 2016, pp. 213–227.
[30] M. Pieridou and M. Kambouri-Danos, "Qualitative doctoral research in educational settings: Reflecting on meaningful encounters," *International Journal of Evaluation and Research in Education (IJERE)*, vol. 9, no. 1, pp. 21–31, Mar. 2020, doi: 10.11591/ijere.v9i1.20360.
[31] Ü. Ormanci, "Thematic content analysis of doctoral theses in STEM education: Turkey context," *Journal of Turkish Science Education*, vol. 17, no. 1, pp. 126–146, 2020, doi: 10.36681/tused.2020.17.
[32] R. Johnson, Burke and L. Christensen, *Educational Research Quantitative, Qualitative, and Mixed Approaches*, 6th ed. Thousand Oaks, California: SAGE Publications, Inc, 2017.
[33] A. D. Reid, M. A. Peters, and E. P. Hart, *A companion to research in education*, Dordrecht: Springer Netherlands, 2014.
[34] J. Pallant, *SPSS Survival Manual: A Step by Step Guide to Data Analysis Using IBM SPSS*. Routledge, 2020.
[35] M. Pirttimaa, J. Husu, and M. Metsärinne, "Uncovering procedural knowledge in craft, design, and technology education: a case of hands-on activities in electronics," *International Journal of Technology and Design Education*, vol. 27, no. 2, pp. 215–231, Jun. 2017, doi: 10.1007/s10798-015-9345-9.
[36] O. Gulacar, C. R. Bowman, and D. a Feakes, "Observational investigation of student problem solving: The role and importance of habits," *Science Education International*, vol. 24, no. 2, pp. 344–360, 2013.
[37] S. Birisci, "Identifying Effectiveness of Online Group Study on Mathematical Problem Solving Attitude: a Comparative Study," *European Journal of Education Studies*, vol. 3, pp. 2501–1111, 2017, doi: 10.5281/ZENODO.814239.
[38] G. M. Bodner, "Research on Problem Solving in Chemistry," in *Chemistry Education: Best Practices, Opportunities and Trends*, John Wiley & Sons, Inc., 2015, pp. 181–202.
[39] Q. Elvira, J. Imants, S. deMaeyer, and M. Segers, "The quality of high school students' problem solving from an expertise development perspective," *Citizenship, Social and Economics Education*, vol. 14, no. 3, pp. 172–192, 2015, doi: 10.1177/2047173416630012.
[40] M. A. Abu Bakar and N. Ismail, "Exploring Students' Metacognitive Regulation Skills and Mathematics Achievement in Implementation of 21St Century Learning in Malaysia," *Problems of Education in the 21st Century*, vol. 78, no. 3, pp. 314–327, Jun. 2020, doi: 10.33225/pec/20.78.314.
[41] K. Berková, J. Boruvková, and L. Lízalová, "Recognition of indicators for the development of the cognitive dimensions in tertiary education," *Problems of Education in the 21st Century*, vol. 76, no. 6, pp. 762–778, Dec. 2018, doi: 10.33225/pec/18.76.762.
[42] B. A. Arop, F. I. Umanah, and O. E. Effiong, "Effect of instructional materials on the teaching and learning of basic science in junior secondary schools in Cross River State, Nigeria," *Global Journal of Educational Research*, vol. 14, no. 1, p. 67, Aug. 2019, doi: 10.4314/gjedr.v14i1.9.
[43] A. Tłuściak-Deliowska, "About the school and the student teacher relationship in the 21st century: Some perspectives and challenges," *Problems of Education in the 21st Century*, vol. 76, no. 4, pp. 422–424, Aug. 2018, doi: 10.33225/pec/18.76.422.
[44] A. Manuel, D. Buque, and R. Quive, "Students' Perceptions on Distance Education: A Case Study in Mozambique," *Problems of Education in the 21st Century*, vol. 79, no. 2, pp. 229–240, Apr. 2021, doi: 10.33225/pec/21.79.229.

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