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"COUNTING DROPS AND OBSERVING COLOR": TEACHERS' AND STUDENTS' FIRST EXPERIENCES IN SMALL-SCALE CHEMISTRY PRACTICUM OF ACID-BASE SOLUTIONS

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Abstract

This study introduces a small-scale chemistry practicum technique with the concept of acid-base identification, determination of pH with indicators, and neutralization reactions with the concept of titration. The first experiences of teachers and students in small-scale chemistry practicums are revealed. Action research was carried out to introduce small-scale chemistry (SSC) practicum techniques as solutions for minimizing chemical tools and materials, as well as the availability of space for school chemistry practicums. This study involved 26 teacher participants in the initial process of providing experience and 36 student participants involved in the process of organizing practical classes. Quantitative data including teacher responses and student responses to the SSC practicum in the pilot class were collected using a response questionnaire on the activity. Qualitative data were collected through observation, interviews, and documentation. The practicum involves qualitative observations and quantitative calculations. The qualitative aspect relates to the observation of color changes that occur in a mixture of solutions made of acid and base solutions with certain compositions. Teachers get a lot of inspiration in terms of chemistry practicum with less material requirements, as well as modifying the tools used for laboratory activities. The package of tools and materials provided an illustration for them that practicum activities do not have to be carried out in a laboratory room, but can also be practiced in conventional classrooms, and even carried out independently by students at home. Students have a unique experience in the process of counting the number of droplets as it requires careful concentration and observation.

Keywords – Small-scale chemistry, Acid-base, Teacher's experiences, Students' experiences, Counting drop, Observing color.

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1. Introduction

Science learning has a special characteristic that cannot be missed, namely laboratory work (Berg, Bergendahl, Lundberg & Tibell, 2003; Golinski, 1999; G. M. Tesfamariam, Lykknes & Kvittingen, 2017). The laboratory learning environment provides unique learning opportunities and is effective in helping students construct their knowledge (Gupta, Hill, Valenzuela & Johnson, 2017; Lunetta, Hofstein & Clough, 2007), develop logical skills through inquiry (Dkeidek, Mamlok-Naaman & Hofstein, 2012; Hofstein & Mamlok-Naaman, 2011), and develop their psychomotor skills (Abdullah, Mohamed & Ismail, 2013; Imaduddin, Tantayanon, Zuhaida & Hidayah, 2020). Laboratory activities also encourage students to be positive and stimulate their communication and collaboration skills (Chabalengula, Mumba, Hunter & Wilson, 2009). Teaching chemistry without laboratory work activities is seen as only the transfer of factual information and laws without any in-depth knowledge construction process (Layton, 1990).

Although chemistry practicum is so crucial, many educational institutions limit students' laboratory activities due to the high cost of equipment and chemicals. Chemical experiments in schools and universities are generally associated with the large size of glassware and chemicals that can be toxic (Listyarini, Pamenang, Harta, Wijayanti, Asy'ari & Lee, 2019). Chemistry practicum activities are also usually related to chemicals; disposal of products, excess reagents, solvents, and the production of wastes that have an impact on the environment. In addition, laboratory activities can also have an impact on the health conditions of students, teachers, and laboratory staff. A shift in perspective and implementation towards experiments, that pay attention to environmental and economic concepts, is urgently needed at this time. Laboratory activities need to be designed so that they can be implemented in various school conditions, especially those with limited laboratory space, tools, and chemicals. Environmental aspects are important things that need to be considered because they can also have an impact on health and safety (Zakaria, Latip & Tantayanon, 2012).

To overcome various obstacles in the implementation of laboratory activities, one of the efforts that can be carried out by chemistry teachers is to organize small-scale chemistry practicums. Small-Scale Chemistry (SSC) is an approach by reducing the use of chemicals that are conventionally used on a macro to micro scale up to 1000 times (Mamlok-Naaman & Barnea, 2012), as well as engineering laboratory equipment to be smaller in size and can use plastic as a base material so that it is safer (Tesfamariam, Lykknes & Kvittingen, 2014). Through the techniques used, the cost of operating a laboratory becomes more efficient, the duration of work is shorter, and aspects of occupational safety and environmental health become more conditioned (Mohamed, Abdullah & Ismail, 2012; Singh, Szafran & Pike, 1999). The SSC concept is related to the use of miniature laboratory equipment, minimization of materials in the learning process, and safe and easy laboratory work procedures. Teachers can modify the variety of practicum activities with the SSC approach (Abdullah, Mohamed & Ismail, 2009).

One of the chemistry labs that requires a lot of materials and produces a lot of waste is a practical activity that involves a solution. One of the chemistry practicums in the curriculum that is implemented in schools is an acid-base identification practicum, as well as the neutralization of acids and bases with titration techniques to determine acid concentrations. Most students are still unable to reassemble pieces of information and relate them through calculations involving acid-base titrations (Harta, Rasuh & Seriang, 2020). Four problems for students in understanding acids and bases, namely (1) fragmentation of student understanding, (2) inappropriate use of mathematical symbols and formulas, (3) ignoring the actual chemical context, and (4) generalization of the problem (Muchtar & Harizal, 2012). Students have great difficulty in acid-base concepts and are not able to explain acid-base concepts accurately, such as pH, neutralization, acid-base strength, and acid-base theory (Sheppard, 2006). Misconceptions in practical activities and mastery of concepts about acid-base titrations also mainly occur in macro and symbolic skills in choosing to measure instruments for titration, using titration tools, and calculating concentration (Widarti, Permanasari & Mulyani, 2017). Practicals related to acid-base, pH determination, and the concept of titration require materials and tools that are not widely available in schools, such as burettes and statives, various indicators, and standard solutions (Haryani & Prasetya, 2010). In addition, the preparation and implementation of this practicum activity also require a lot of time. In this research, students will be introduced to small-scale chemistry practicum techniques on the concept of acid-base identification, determination of pH with indicators, and neutralization reactions with the concept of titration. In this research, students will be introduced to small-scale chemistry practicum techniques on the concept of acid-base identification, determination of pH with indicators, and neutralization reactions with the concept of titration. This research aims to reveal teachers' and students' first experiences in small-scale chemistry practicum. It is very essential as a form of reflection and evaluation for designing advanced small-scale chemistry lab designs.

2. Design/Methodology/Approach

2.1. Research Design

This research is action research to introduce a small-scale practicum technique for the solution of minimizing chemical tools and materials, as well as the availability of space for school chemistry practicum. Action research is an exploratory effort that leads to improving some aspects of the professional context (Taber, 2007). The fundamental purpose of action research is to improve practice rather than to generate knowledge. From this process, it will continue to the production and utilization of knowledge (Elliott, 1991). This small-scale practicum will be followed up by designing a variety of practicums that are environmentally friendly, economical, and sustainable. This action research describes an understanding of what is happening (Sagor, 2005). The action research design is shown in Figure 1.

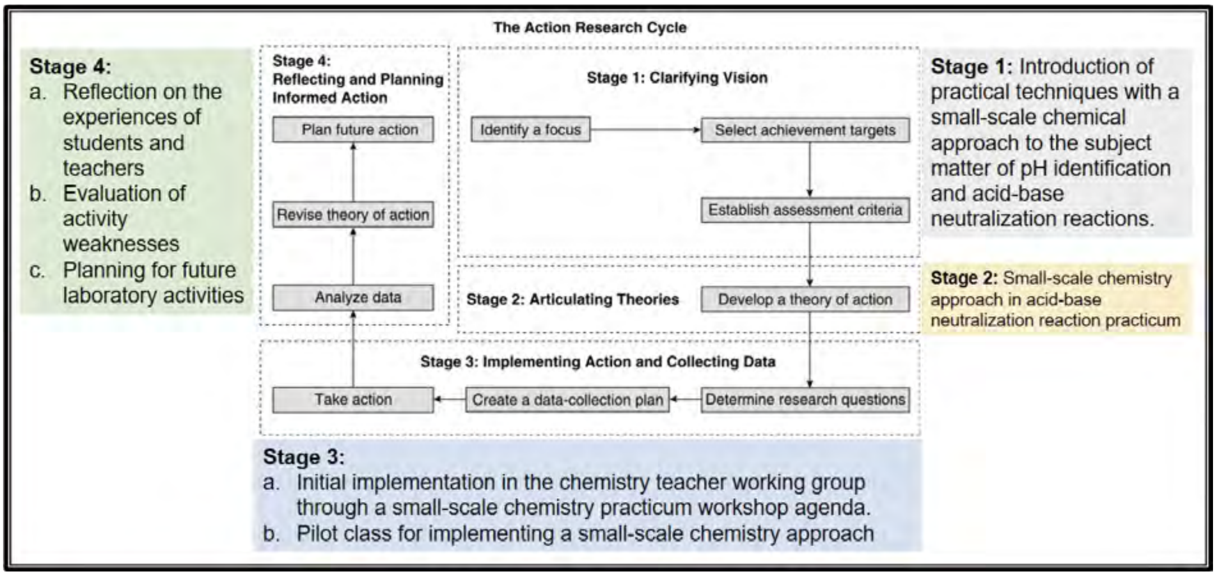

Figure 1. The action research cycle (Sagor, 2005)

2.2. Participants in Action Research

This study involved 26 teacher participants who were members of the chemistry teacher working group and 36 student participants from the same regency. Teachers consist of 9 male and 17 female teachers. This study involved 6 junior teachers (with less than 10 years of experience), while there were 20 senior teachers. The students involved were 11^{th}-grade high school students with 36 students consisting of 13 boys and 23 girls. The stages in this action research are shown in Figure 1. modified from the action research stage by Sagor (2005). The stages that specifically involve teacher and student participants are in the third stage, namely two main activities which include a workshop agenda for teachers and implementation in a pilot class for chemistry practicum with a small-scale approach.

2.3. Laboratory Activity Design with a Small-Scale Chemical Approach

Teachers work individually in chemistry practicum activities during the workshop. The practicum related to the neutralization reaction is one of the practicums that are practiced on the workshop agenda. This practicum is followed up as a design that will be implemented in the pilot class. The practicum is carried out in groups with a maximum number of 6 students. The practicum design is a modification of teachers' conventional practicums related to acid-base identification, and acid-base neutralization reactions using titration techniques. The chemicals include (1) a strong acid solution, namely 0.01 N HCl, (2) a weak acid solution, namely 0.025 N CH_3COOH, and (3) a strong base solution, namely 0.01 N NaOH. The indicators used are Methyl Orange (MO), Methyl Red (MR), Bromthymol Blue (BTB), and Phenolphthalein (PP).

Preparation of basic NaOH solution is made by dissolving 2 grams of solids into 5 liters of distilled water. The preparation of 0.01 N HCl solution was made by dissolving 12.06 M concentrated HCl as much as 4.15 ml into 5 liters. Preparation of 0.025 N CH_3COOH solution was made by dissolving 7.14 ml of concentrated solution with a concentration of 17.5 M into 5 L of solution. Each indicator was prepared by dissolving 10 grams of powder in 1 L of ethanol. Each solution will be placed in 50 ml bottles that have been provided to be included in the package of tools and materials for practical activities. The main tools used include a 96-well microplate, a micro-doing pipette, and a toothpick. The practicum activity consists of three activity sessions consisting of (1) calibration of the use of a micro-doing pipette, (2) identification of pH using a color indicator in a mixture of acid-base solutions, and (3) neutralization reactions in acid-base solutions. The dangerous thing about this practical experiment is in the process of making the solution if the materials used are blinded from concentrated materials (HCl and CH_3COOH) or sodium hydroxide in the form of caustic solids.

2.4. Data Collection and Analysis

Quantitative data including teacher responses and student responses to the SSC practicum in the pilot class were collected using a response questionnaire on the activity. The questionnaire to explore how the teacher's response relates to assistance in implementing the chemistry practicum with the SSC approach consists of 14 items that show how the process of organizing activities is and whether they have confidence and are interested in further developing the concept of the SSC approach in other practicum events. Questionnaire for students related to their response to the implementation of chemistry practice in classroom learning which consists of 10 items including 5 positive responses and 5 negative responses. Each item is scored on a scale of 1-5 corresponding to the level of agreement on the item where 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree. Quantitative data were analyzed by descriptive statistics and qualitative data were analyzed interpretively. Quantitative data obtained on each item of the questionnaire were interpreted with categorization by considering the average score with criteria $1 \leq \bar{x} < 2{,}7$ = Poor; $2{,}7 \leq \bar{x} < 3{,}3$ = Neutral; $3{,}3 \leq \bar{x} \leq 5$ = Good.

Qualitative data is collected through observation, interviews, and documentation. Observations are made by noting the interesting parts that appear and documenting them through videos and photos. Students' expressions and practice group situations are important things to show so that they can show the conditions that occur in the implementation of this small-scale chemistry practicum. Furthermore, the qualitative responses of students and teachers obtained from interview transcripts became the basis for evaluation to improve the design of practicum activities. Traditionally, existing action research only creates data, furthermore, this research interprets existing data findings. In qualitative data analysis, what often happens is that data interpretation is integrated with analysis and carried out simultaneously (Cohen, Manion & Morrison, 2007). Qualitative data analysis in this study was carried out through three activities that occurred simultaneously, namely data reduction, data presentation, and drawing conclusions or verification (Miles & Huberman, 1994).

3. Discussion

3.1. Design of Small-Scale Chemistry Practicum

Chemistry practicum activities certainly require specific space, tools, and materials. A laboratory room with complete facilities is very important, but it does not always have to be forced to be held if it is not able to fulfill it. The implementation strategy on the use of practical equipment by reducing the scale with the same functionality as standard conventional macro tools is one of the efforts to optimize laboratory chemistry learning (Bradley, 2000; Hanson, 2014; Huang, 2007). The design of this small-scale chemistry practicum modifies the tools used conventionally by teachers based on laboratory activities in the Indonesian curriculum. The practicum that has been introduced for this first project is a practicum on acid-base identification, and acid-base neutralization reactions using titration techniques. The modifications to the tools used in the chemistry lab are shown in Table 1. Details of the main tools used in the chemistry lab carried out in this action research are shown in Figure 2.

Conventional Laboratory Equipment	Laboratory equipment on a small-scale chemistry approach	Purpose of Using the Equipment
Drop pipette	Micro-dosing pipettes which are plastic cupcake pipettes	To drip a solution or liquid material
A set of apparatus consisting of a burette, a stative, and a clamp		To measure the need (ml) of the standard solution used to neutralize and change the color of the solution mixed with the acid-base indicator in the test sample solution.
Glass stirrer	Wooden Toothpick	To stir the ingredients to mix well
Erlenmeyer Flask	Holes in 96-well microplate	As a place where the reaction takes place

Table 1. Modification of types of equipment for small-scale chemistry practicum activities

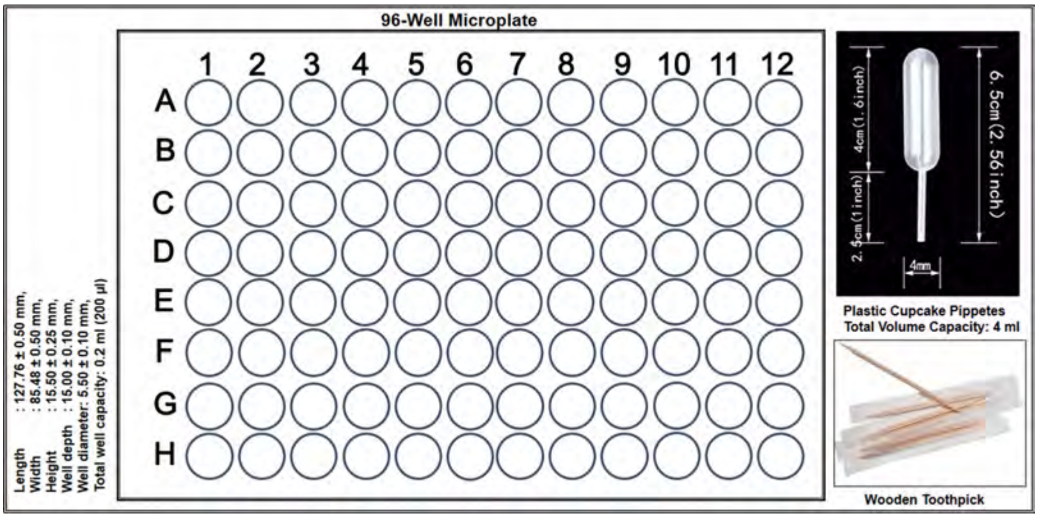

Figure 2. The main tools used for practicum with a small-scale chemistry approach

The introduction of a small-scale chemical approach to teachers and students consisted of three activity sessions consisting of (1) calibration of the use of a micropipette, (2) identification of pH using a color indicator in a mixture of acid-base solutions, and (3) neutralization reactions in acid-base solutions. Details of the activities carried out are shown in Figure 3.

At the initial stage of introducing the SSC approach, it is necessary to emphasize how the use of small-scale tools differs from conventional tools. The teacher and students have been explained the position of the pressure of the micro-doing pipette and the force of compression that affects the droplet size and volume produced. Thus, a calibration process is needed, in this case, the setting and checking of the accuracy of the droplet size. This is done by doing drills in several holes with various drip positions, and by observing the number of drops needed to fill one hole on a 96-well microplate with a maximum capacity of 0.2 ml. The approximate volume of one drop produced can be measured.

In the next session, the practicum involves qualitative observations and quantitative calculations. The qualitative aspect relates to the observation of color changes that occur in the mixture of solutions made from acid and alkaline solutions with a certain composition as shown in Table 2. The number of drops in each hole is different in composition. This is to obtain solutions with different acidity conditions. Table 2. shows that the conditions in columns A1-A11 have an increasingly alkaline mixture.

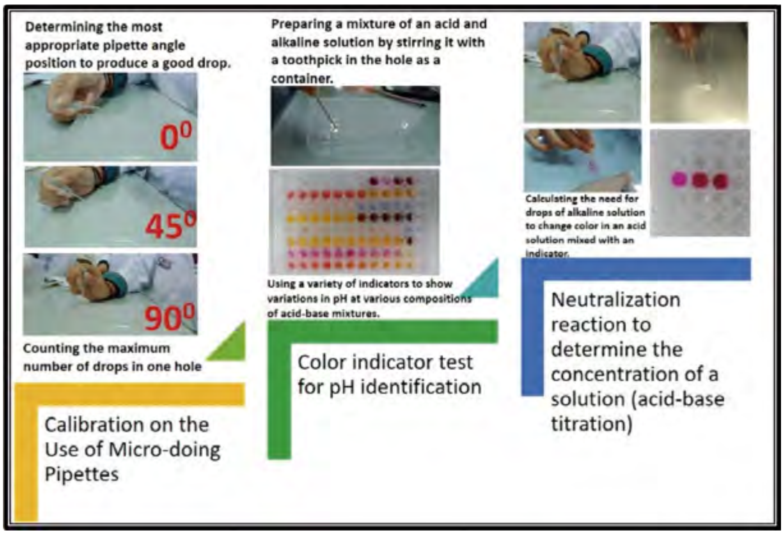

Figure 3. Practical activities introduced to teachers and students

Well No.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
Drops, acid	10	9	8	7	6	5	4	3	2	1	0
Drops, base	0	1	2	3	4	5	6	7	8	9	10

Table 2. The composition in the preparation of a mixed solution of an acid and a base made in the holes of a 96-well microplate

Acid-base indicators are also often referred to as pH indicators which are substances (dyes) that change color with changes in pH. These substances are usually weak acids or bases, which when dissolved dissociate slightly and form ions (Sabnis, 2008). Several types of indicators used in the practicum design that has been implemented show a variety of color changes in a certain pH range. Details of the color change phenomenon in each pH indicator are shown in Figure 4.

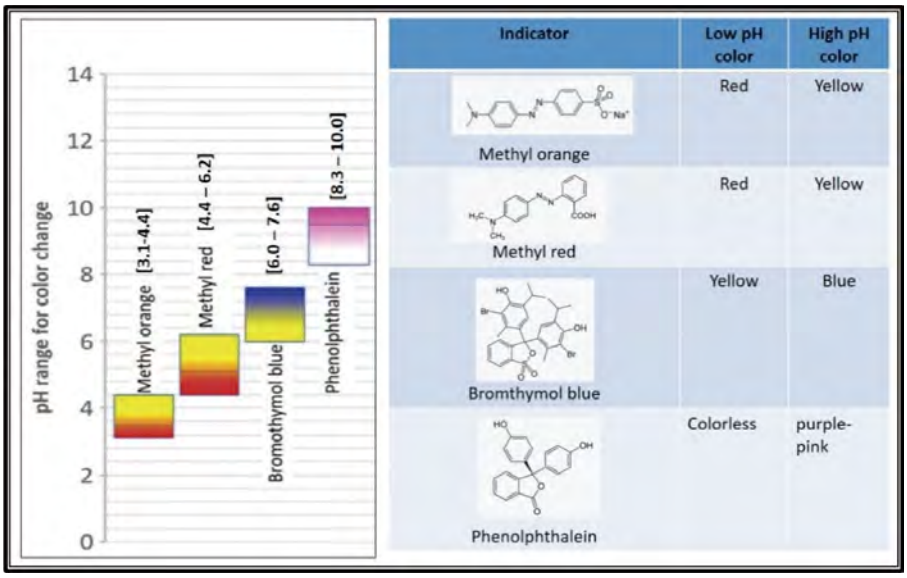

Figure 4. The color change phenomenon in each pH indicator

The teacher and students were shown the mechanism of the neutralization reaction to determine the concentration of HCl using 0.01 N NaOH (standard solution). The most common titrations involve the neutralization of a strong acid with a strong base (Sheppard, 2006). Students are assigned to calculate the unknown concentration using this method. Most titrations require an indicator that produces a sudden color at the equivalence point. The indicator that can be used for titration in the practical activity of the reaction between a strong acid and a strong base is phenolphthalein, $HC_{20}H_{13}O_4$ (Moore, Shorb, Prat-Resina, Wendorff & Hahn, 2020). Phenolphthalein, whose structure is shown in Figure 5., is a colorless weak acid (Ka = 3×10^{-10} mol/L). Its conjugate base, $C_{20}H_{13}O_4^-$ has a strong pink color. For simplicity, the phenolphthalein molecule is written as HIn (a protonated indicator) and its pink conjugate base as In^-. In an aqueous solution, phenolphthalein will present equilibrium as shown in Figure 5.

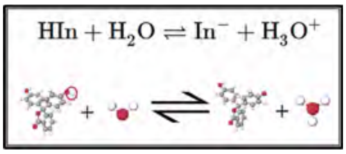

Figure 5. Equilibrium of phenolphthalein in aqueous solution (Moore et al., 2020).

Basically, this small scale chemistry technique will never replace the conventional chemistry laboratory approach. In this case, the titration volumetric analysis technique using a burette cannot be completely replaced by a pipette. This research provides a broader dimension of perspective on volumetric analysis (Worley, 2012). Teachers and students can compare the quantitative results with the standard method that has been set in the titration so that they can identify the sources of analytical errors that occur in the use of pipettes through the SSC approach.

Comparison between conventional titration and SSC shows that there is a difference that is not too striking for quantitative calculations that exist in determining the concentration of the solution. Triplo titration was carried out on HCl with a certain concentration with 0.1 N NaOH. For conventional practicums, the average waste was 32 ml, while on the small scale with the procedures practiced, the waste was found to be around 0.8 ml.

3.2. Teachers' and Students' First Experiences in Small-scale Chemistry Practicum of Acid-Base Neutralization Reaction

An interesting finding related to this process is that the SSC approach is a perspective that has not been widely practiced by chemistry teachers in the implementation of laboratory-based learning. They are used to doing practical activities by referring to the guidebook in the curriculum and have not been able to modify it with a small-scale approach. The teacher group also revealed information that practicum activities were very limited due to many factors related to time and the target for completion of teaching materials in each semester.

The experience of the teacher practicing this approach shows that there is a nuance of enthusiasm in the mentoring process. In the workshop agenda, several chemical practicum activities were modified with the SSC approach such as Cu electrolysis, reactions that produce oxygen gas, gas diffusion, and acid-base neutralization. Henceforth, one of the practicums will be held in a pilot class organized by one of the selected teachers. In this case, the practicum carried out is to identify the pH of the solution using an indicator and determine the concentration of the solution through a titration or neutralization reaction. The details of the activities are shown in Figure 6.

Figure 6. Workshop activities in the working group of chemistry subject teachers related to the concept of the SSC approach

Teachers got a lot of inspiration in terms of practicing chemistry with fewer material requirements, as well as modifying the tools used for laboratory activities. The tool and material box package illustrated to them that practicum activities do not have to be carried out in a laboratory room, but can also be practiced in conventional classrooms, even done independently by students at home. Some of the teacher's interesting statements regarding the small scale of the tools used are:

> "*These oldmen's eyes -that I have- is difficult to observe and examine the use of the tool accurately. The young students, whose eyes are still very healthy, will be happy because they can try independently.*" [T1]

> *"We also need to find other ideas for other quantitative chemistry labs because the tools used are still limited."* [T2]

> *"Wow, you can think like that...we can also use a wooden toothpick to stir the reactants*." [T3]

> "*The plastic used makes us not worry about the tools used can break.*" [T4]

T1 & T2 showed some obstacles in the use of tools and observations on the results, as well as limited ideas for modifications to quantitative chemistry labs. T3 showed how the approach introduced is a new perspective for chemistry teachers. In addition, T4 revealed how the security opportunities for practical activities using plastic materials in the tools used. With a small-scale approach, students can conduct experiments safely and at a lower cost (Mohamed, Abdullah & Ismail, 2013a). It is also very clear that not all experimental requirements can be met with plastic lab equipment. Some aggressive chemicals and some organic substances can damage plastic materials. There is also a temperature limitation for carrying out experiments when using plastic materials. Heating with the combustion process is not possible to do (Bradley, Durbach, Bell, Mungarulire & Kimel, 1998; Worley, 2018). The overall evaluation of the workshop activities that have been carried out with the chemistry teacher group showed that the conditions for the implementation of mentoring are responded well. This is as shown in Table 3.

At the moment of implementing the SSC practice in the pilot class, many students responded well to the existence of a package of tools for practicum that looks simple and portable. Students try to use a micro-doing pipette and try to compare its use with a conventional dropper. Students make observations to determine the accuracy of removing droplets from a micro-doing pipette. The SSC approach leads to reaction at the droplet level (Worley, 2021). The students' expressions showed that they were serious in the initial process of explaining the concept and introducing the SSC practicum equipment as shown in Figure 7. This was because the equipment and methods they practiced were new experiences.

No	Items	Average score	SD
1	The purpose of the program is clearly explained	3.83	0.38
2	Trainers encourage participation and interaction between participants	3.83	0.38
3	The topics discussed by the mentoring are relevant to my needs as a chemistry teacher	3.84	0.37
4	Delivery of content and materials is well organized so that it is easy to follow	3.79	0.42
5	The handbooks and small-scale chemistry tools that were distributed helped to actively participate in this activity	3.63	0.50
6	This training experience will be useful in my work	3.95	0.23
7	Trainers mastered the topics covered in this program	3.74	0.45
8	Trainers have prepared the activities well	3.63	0.50
9	The purpose of the mentoring is to get clearer with the activities currently being carried out	3.74	0.45
10	There is enough time for mentoring activities	3.32	0.48
11	The rooms and facilities provided are sufficient and good	3.63	0.50
12	I have the confidence to do small-scale chemistry practice at school	3.42	0.51
13	I am interested in designing a practicum with small-scale chemistry concepts	3.47	0.51
14	I will try to apply the small-scale chemistry approach to teaching chemistry	3.42	0.51

Note: (N = 19, There were seven teachers who were not willing to fill out the questionnaire)

Table 3. Evaluation of workshop activities implemented in the chemistry teacher group

Figure 7. Expression of students' curiosity in the process of finding the accuracy of the solution dripping process

Students have a unique experience in the process of counting the number of droplets because it requires concentration and careful observation. One of the experiences is shown of the group in the process of completing the filling of holes on a 96-well microplate as shown in the dialogical footage.

[S1]: (while pointing at one of the holes), *this one is filled with zero drops, right?*. (pointing to the hole next to the one previously indicated), *this one is filled with 1 drop, right?*.

S1 continues to drip on the available holes.

[S2]: *Stop* (a rather loud tone that aims to stop S1 from dripping again)

[S1]: *two…"tes!"…three…"tes!"…four…"tes!"*.

"Tes!" shows "drops" which is the Indonesian language for drops.

Then all group members, consisting of 6 people, count the number of drops together:

- *1,2,3,4,5*

- *1,2,3,4,5,6*

- *1,2,3,4,5,6,7*

- *1, 2, huh* (disappointed)...(the solution in the pipette has run out even though they still need a solution)

[S1]: *We just counted to two, right?.*

[S3]: *two..yes..two.*

[S1]: *Which hole did we get to....which part?...Seriously?.*

[S4]: *Yes, really.*

[S5]: *This part.*

[S1]: *3, 4, 5, 6, 7....how many drops does this hole take?*

[S2]: *Eight.*

[S1]: *Only eight?.* (Ensures the required amount of drops for the hole that is trying to be filled)

S1 continues to fill in the other holes while counting by making sounds: *1, 2, 3, 4, 5, 6, 7, 8, 9*.

One more hole. Together with his friends, count the number of drops: *1, 2, 3, 4, 5, 6, 7, 8, 9....9* (in a steady tone, confirming the last drop done on this number).... *one less....10* (with a slow tone).

[S2]: *Stop…Stop...don't squeeze it again* (the pipette).

In this practical activity, the group also showed how serious they were in counting the number of droplets and observing the color changes that occurred in the identification of pH with an indicator as well as determining the endpoint of the titration as shown in Figure 8. The SSC approach can improve students' skills in handling small-scale equipment, encourage them to carry out modified experiments, and also require them to carry out experiments carefully and patiently (Abdullah et al., 2009).

Figure 8. The seriousness of students and their groups to count the number of droplets and observe color changes.

The acquisition of specific objectives in laboratory teaching includes (1) mastery of subject matter; (2) scientific reasoning skills; (3) understanding the nature of science; (4) interest in science and technology; (5) understanding the complexity and ambiguity in empirical work; (6) development of practical skills; and (7) development of teamwork skills. In this pilot class, it was very clear how students worked collaboratively and interacted in the process of counting the number of droplets and observing color changes as shown in Figure 9. The laboratory experience also stimulates students to collaborate well in carrying out complex tasks, dividing tasks appropriately, taking roles under certain conditions, and responding to work, ideas, and opinions. (National Research Council, 2006). The experience of laboratory learning activities can improve the quality of students' conceptual understanding (Bradley, 1999; Lunetta et al., 2007) and has the potential to instill positive attitudes and interests towards the subject and to develop students' communication and collaboration skills (Hofstein & Lunetta, 2004).

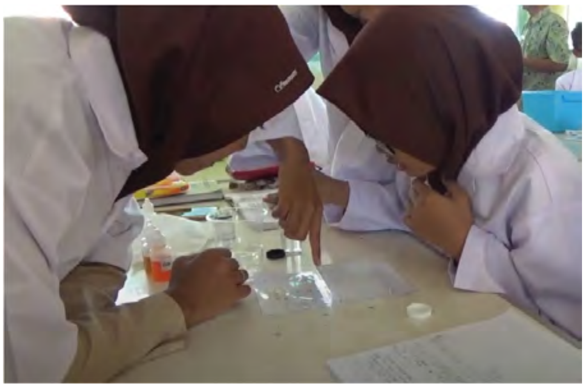

Figure 9. Group collaborative work and their interactions in the process of counting and observing color changes

When properly developed, designed, and structured, laboratory learning provides process meaning, conceptual understanding, and appreciation of the nature of science. Many studies have stated how students enjoy laboratory activities (Bradley, 2000; Imaduddin et al., 2020; Imaduddin & Hidayah, 2019; Mohamed, Abdullah & Ismail, 2013b; Zakaria et al., 2012). There is also a positive relationship between chemistry laboratory-based experiments and different types of attitudes (Hofstein & Mamlok-Naaman, 2011). The students in the pilot class showed their happiness through smiles and curious expressions when they first started using laboratory equipment with the SSC approach and completed the task, as well as obtaining a unique observation, namely a change in color. This is as shown in the photo of students' expressions in Figure 10.

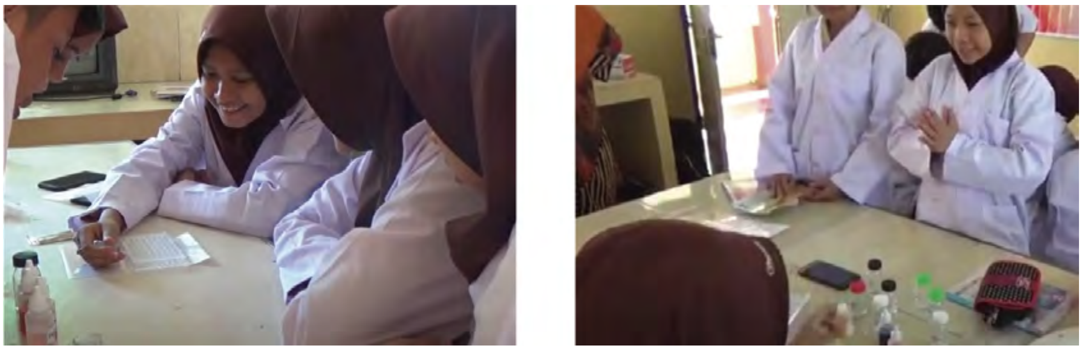

Figure 10. A student's smile when she tried the tools for the first time, and the joy of another student when she observed color changes and finished counting.

Overall, the responses from students showed a good category as shown in Table 4. The lowest average score was on how students experienced difficulties in observing the results and the time of practicum implementation. Design optimization related to the way of observation and time for practicum can be done further. Abdullah et al. (2009, 2013) & Imaduddin et al. (2020) also showed how implementation constraints in small-scale chemistry are related to small tools that are difficult to control and easy to lose, difficulty in cleaning small tools, and low accuracy for lab work involving volumetric and mass measurements. This time efficiency is also related to the management of the student grouping system, the management of the tools provided, as well as skills in setting strategies for completing laboratory work assignments. Maimunah and Lewin (1993) showed that practical work is more often done in groups than individually or in pairs, leading to active work for two to three students while other members tend to be passive observers.

No	Item	Score Average	SD
1	[-] I have trouble using the SSC equipment	1.74	1.16
2	[+] Through doing my own experiments with the SSC equipment, I understand better about experiments and concepts	4.15	0.99
3	[+] I am interested in doing a micro-scale experiment with the SSC equipment	4.37	0.88
4	[-] The results of small-scale experiments cannot be observed easily	2.41	1.26
5	[-] I am afraid to try this experiment with the SSC equipment	1.85	1.29
6	[+] Experiments can be done quickly	3.85	1.10
7	[+] I really enjoy trying to do small-scale experiments	4.67	0.48
8	[+] I want to do more small-scale experiments in chemistry lessons	4.59	0.57
9	[-] Experiments with a small-scale chemistry approach are not actual chemistry experiments.	1.74	0.98
10	[-] Small-scale chemistry equipment is a cheap version: we should use actual chemical equipment which is more expensive.	2.00	1.21

Table 4. Student responses to the implementation of chemistry practicum with a small-scale chemistry approach on acid-base topics (N= 36)

4. Conclusions

This research introduced small-scale chemistry practicum techniques on the concept of acid-base identification, determination of pH with indicators, and neutralization reactions with the concept of titration. The practicum involves qualitative observations and quantitative calculations. The qualitative aspect relates to the observation of color changes that occur in the mixture of solutions made from acid and alkaline solutions with a certain composition. Teachers got a lot of inspiration in terms of practicing chemistry with fewer material requirements, as well as modifying the tools used for laboratory activities. The tool and material box package illustrated to them that practicum activities do not have to be carried out in a laboratory room, but can also be practiced in conventional classrooms, even done independently by students at home. Students have a unique experience in the process of counting the number of droplets because it requires concentration and careful observation. Opportunities for contribution are very possible in the implementation and further dissemination to teacher groups related to efforts to modify other chemistry topic practicum activities with the SSC approach. This approach is also very urgent to be implemented in schools that have limited potential for practicum implementation with a standard laboratory scale.

The limitation of this research is the need to review how the condition of understanding the chemical concept of each student is obtained after carrying out practical activities. In the future, it is necessary to have a dialogical study with chemistry teachers to jointly develop this practicum technique so that it can be more practical and potential in terms of implementation in classes that are taught by teachers.

Declaration of Conflicting Interests

The authors declare that there is no potential conflict of interest related to the research, authorship, and/or publication activities of this article.

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References

Abdullah, M., Mohamed, N., & Ismail, Z.H. (2009). The effect of an individualized laboratory approach through microscale chemistry experimentation on students' understanding of chemistry concepts, motivation and attitudes. *Chemistry Education Research and Practice*, 10(1), 53-61. https://doi.org/10.1039/b901461f

Abdullah, M., Mohamed, N., & Ismail, Z.H. (2013). Introducing Microscale Experimentation in Volumetric Analysis for Pre-service Teachers. In Chiu, M.H., Tuan, H.L., Wu, H.K., Lin, J.W., & Chou, C.C. (Eds.), *Chemistry Education and Sustainability in the Global Age* (311-320). Springer Science & Business Media. https://doi.org/10.1007/978-94-007-4860-6_27

Berg, C.A.R., Bergendahl, V.C.B., Lundberg, B.K.S., & Tibell, L.A.E. (2003). Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment. *International Journal of Science Education*, 25(3), 351-372. https://doi.org/10.1080/09500690210145738

Bradley, J.D. (1999). Hands-on practical chemistry for all. *Pure Applied Chemistry*, 71(5), 817-823. https://doi.org/10.1351/pac199971050817

Bradley, J.D. (2000). *The microscience project and its impact on pre-service and in-service teacher education*. The World Bank.

Bradley, J.D., Durbach, S., Bell, B., Mungarulire, J., & Kimel, H. (1998). Hands-On Practical Chemistry for All: Why and How? *Journal of Chemical Education*, 75(11), 1406. https://doi.org/10.1021/ed075p1406

Chabalengula, V., Mumba, F., Hunter, W., & Wilson, E. (2009). A model for assessing students' science process skills during science lab work. *Problems of Education in the 21st Century*, 11(2), 28-36.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research Methods in Education* (6th ed.). Routledge. https://doi.org/10.4324/9780203029053

Dkeidek, I., Mamlok-Naaman, R., & Hofstein, A. (2012). Assessment of the laboratory learning environment in an inquiry-oriented chemistry laboratory in Arab and Jewish high schools in Israel. *Learning Environments Research*, 15(2), 141-169. https://doi.org/10.1007/s10984-012-9109-3

Elliott, J. (1991). *Action research for educational change (Developing teachers and teaching)* (163). Open University Press. Available at: https://books.google.com/books?id=TX5EBgAAQBAJ&pgis=1

Golinski, J. (1999). *Science as Public Culture: Chemistry and Enlightenment in Britain, 1760-1820*. Cambridge University Pres.

Gupta, A., Hill, N., Valenzuela, P., & Johnson, E. (2017). Introducing Chemical Reactions Concepts In K-6 Through A Hands-On Food Spherification And Spaghetti-Fication Experiment. *Journal of STEM Education: Innovations and Research*, 18(1), 6-10.

Hanson, R. (2014). Using small scale chemistry equipment for the study of some organic chemistry topics- a case study in an undergraduate class in Ghana. *Journal of Education and Practice*, 5(18), 59-63.

Harta, J., Rasuh, N.T., & Seriang, A. (2020). Using HOTS-Based Chemistry National Exam Questions to Map the Analytical Abilities of Senior High School Students. *Journal of Science Learning*, 3(3), 143-148. https://doi.org/10.17509/jsl.v3i3.22387

Haryani, S., & Prasetya, A.T. (2010). Sosialisasi Penerapan Pemanfaatan Indikator Bahan Alam Dalam Pembelajaran Titrasi Asam-Basa Bagi Guru Kimia Dalam Mgmp Kota Semarang. *Rekayasa*, 8(2). Available at: http://journal.unnes.ac.id/nju/index.php/rekayasa/article/view/298

Hofstein, A., & Lunetta, V.N. (2004). The Laboratory in Science Education: Foundations for the Twenty-First Century. *Science Education*, 88(1), 28-54. https://doi.org/10.1002/sce.10106

Hofstein, A., & Mamlok-Naaman, R. (2011). High-school students' attitudes toward and interest in learning chemistry. *Educacion Quimica*, 22(2), 90-102. https://doi.org/10.1016/S0187-893X(18)30121-6

Huang, Z. (2007). Study on Micro-organic Chemistry Experiment Teaching. *Journal of Guangxi University for Nationalities*, 2-6.

Imaduddin, M., & Hidayah, F.F. (2019). Redesigning Laboratories for Pre-service Chemistry Teachers: From Cookbook Experiments to Inquiry-Based Science , Environment , Technology , and Society Approach. *Journal of Turkish Science Education*, 16(4), 489-507. https://doi.org/10.36681/tused.2020.3

Imaduddin, M., Tantayanon, S., Zuhaida, A., & Hidayah, F.F. (2020). Pre-service Science Teachers' Impressions on The Implementation of Small-Scale Chemistry Practicum. *Thabiea: Journal of Natural Science Teaching*, 3(2), 162. https://doi.org/10.21043/thabiea.v3i2.8893

Layton, D. (1990). Student laboratory practice and the history and philosophy of science. In Hegarty, E. (Ed.), *The student laboratory and the science curriculum*. Routledge.

Listyarini, R.V., Pamenang, F.D.N., Harta, J., Wijayanti, L.W., Asy'ari, M., & Lee, W. (2019). The Integration of Green Chemistry Principles into Small Scale Chemistry Practicum for Senior High School Students. *Jurnal Pendidikan IPA Indonesia*, 8(3), 371-378. https://doi.org/10.15294/jpii.v8i3.19250

Lunetta, V.N., Hofstein, A., & Clough, M.P. (2007). Learning and teaching in the school science laboratory: An analysis of research, theory, and practice. In Abell, S.K., & Lederman, N.G. (Eds.), *Handbook of research on science education* (393-441). Erlbaum.

Maimunah, S., & Lewin, K.M. (1993). *Insights into science education: Planning and policy priorities in Malaysia*. International Institute for Educational Planning & Educational Planning and Research Division Ministry of Education Malaysia.

Mamlok-Naaman, R., & Barnea, N. (2012). Laboratory activities in Israel. *Eurasia Journal of Mathematics, Science and Technology Education*, 8(1), 49-57. https://doi.org/10.12973/eurasia.2012.816a

Miles, M.B., & Huberman, A.M. (1994). *Qualitative Data Analysis: An expanded Sourcebook* (2nd ed.). Sage Publications.

Mohamed, N., Abdullah, M., & Ismail, Z. (2012). Ensuring Sustainability through Microscale Chemistry. In Sanghi, R., & Singh, V. (Eds.), *Green Chemistry for Environmental Redemption*. Scivener Publishing. https://doi.org/10.1002/9781118287705.ch5

Mohamed, N., Abdullah, M., & Ismail, Z.H. (2013a). Practical Science Activities in Primary Schools in Malaysia. In Chiu, M.H., Tuan, H.L., Wu, H.K., Lin, J.W., & Chou, C.C. (Eds.), *Chemistry Education and Sustainability in the Global Age* (97-109). Springer Science & Business Media. https://doi.org/10.1007/978-94-007-4860-6_9

Mohamed, N., Abdullah, M., & Ismail, Z.H. (2013b). Practical Science Activities in Primary Schools in Malaysia. In Chiu, M.H., Tuan, H.L., Wu, H.K., Lin, J.W., & Chou, C.C. (Eds.), *Chemistry Education and Sustainability in the Global Age* (97-108). Springer Science & Business Media. https://doi.org/10.1007/978-94-007-4860-6_9

Moore, J.W., Shorb, J., Prat-Resina, X., Wendorff, T., & Hahn, A. (2020). Indicators. *Chemical Education Digital Library (ChemEd DL)*. Available at: https://chem.libretexts.org/@go/page/49692

Muchtar, Z., & Harizal, H. (2012). Analyzing of Students' Misconceptions on Acid-Base Chemistry at Senior High Schools in Medan. *Journal of Education and Practice*, 3(15), 65-74.

National Research Council (2006). In Singer, S.R., Hilton, M.L., & Schweingruber, H.A. (Eds.), *America's Lab Report: Investigations in High School Science*. The National Academies Press. https://doi.org/10.17226/11311

Sabnis, R.W. (2008). *Handbook of Acid-Base Indicators*. https://doi.org/10.1201/9780849382192

Sagor, R. (2005). *The action research guidebook: A four-step process for educators and school teams*. Corwin Press.

Sheppard, K. (2006). High School Students' Understanding of Titrations and Related Acid-Base Phenomena. *Chemistry Education Research and Practice*, 7(1), 32-45. https://doi.org/10.1039/B5RP90014J

Singh, M.M., Szafran, Z., & Pike, R.M. (1999). Microscale Chemistry and Green Chemistry: Complementary Pedagogies. *Journal of Chemical Education*, 76(12), 1684. https://doi.org/10.1021/ed076p1684

Taber, K.S. (2007). *Classroom-based research and evidence-based practice: A guide for teachers*. Sage Publicatios. https://doi.org/10.4135/9781849208734

Tesfamariam, G., Lykknes, A., & Kvittingen, L. (2014). Small-Scale Chemistry for a Hands-on Approach To Chemistry Practical Work in Secondary Schools: Experiences From Ethiopia. *Ajce*, 4(May), 48-94.

Tesfamariam, G.M., Lykknes, A., & Kvittingen, L. (2017). 'Named Small but Doing Great': An Investigation of Small-Scale Chemistry Experimentation for Effective Undergraduate Practical Work. *International Journal of Science and Mathematics Education*, 15(3), 393-410. https://doi.org/10.1007/s10763-015-9700-z

Widarti, H.R., Permanasari, A., & Mulyani, S. (2017). Students' Misconceptions on Titration. *Journal of Physics: Conference Series,* 812(2017) 012016. https://doi.org/10.1088/1742-6596/755/1/011001

Worley, B. (2012). *Microscale chemistry revisited*. Royal Society of Chemistry. Available at: https://edu.rsc.org/feature/microscale-chemistry-revisited/2020193.article

Worley, B. (2021). Little wonder: microscale chemistry in the classroom. *Science in School: The Europe Journal for Science Teachers*, 53, 2-5.

Worley, R. (2018). «In a little you can see a lot»: the impact of practical microscale chemistry on chemical education. *Educació Química EduQ*, 24, 58-62.

Zakaria, Z., Latip, J., & Tantayanon, S. (2012). Organic Chemistry Practices for Undergraduates using a Small Lab Kit. *Procedia - Social and Behavioral Sciences*, 59, 508-514. https://doi.org/10.1016/j.sbspro.2012.09.307

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