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Designing Small-scale Chemistry for General Chemistry Practical Work Course

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Abstract: Hands-on chemistry activity or practical work is an important aspect of teaching at the high school and college level as part of the science education curriculum. This study aims to design Small-scale Chemistry (SSC) for general chemistry practical work. The product are laboratory work manual and practical kit. The development model used is ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). At the analysis stage, five experiment will be designed to become SSC. There are five experiments, namely determining the order of the reaction, observation the shift in chemical equilibrium, identification acid-base with indicators, determining the strength of the acid and water electrolysis. The feasibility of the manual and practical kit in content feasibility (0.84), language feasibility (0.90), presentation feasibility (0.84), graphic feasibility (0.90), and kit feasibility (0.94). All are categorized as valid based on the validity criteria of Aiken's V. The results of the implementation show that the SSC design can be implemented and the results can be observed for General Chemistry experiment learning activities. The chemicals used for the experiment are far less than the macro-scale practical work. This is in accordance with the SSC principle.

Keywords: General chemistry; Small-scale chemistry; Practical work; Hands-on

Introduction

Hands-on chemistry activity is an important aspect of teaching at the high school and college level as part of the science education curriculum. Hands-on experience can increase students' conceptual understanding (J. Bradley, 2021; Furtak et al., 2019), develop positive attitudes, motivation, improve collaboration and communication skills (Godínez Castellanos et al., 2021; Hofstein et al., 2004). Similarly, learning chemistry cannot be separated from actual activity. Through practical work or hands-on chemistry activity, students can improve conceptual understanding, acquire practical laboratory skills, and motivate learning (Tesfamariam et al., 2017; Ural, 2016).

The hindrance of implementation of hands-on chemistry activity namely short experiment time, unavailability of equipment and chemicals, limited support from schools, lack of laboratory management, low training of teachers and trainers, and practical teaching assistants do not support practical implementation (Mardhiya et al., 2017). There are many barriers, including poor room management (J. Bradley, 2021). Various solutions were provided for these problems, such as implementing demonstration learning, learning in a virtual lab, movies, videos, and blackboard illustrations. However, practical works are still essential for laboratory learning (J. D. Bradley, 1999; Reid et al., 2007). Hands-on chemistry activities are not always expensive, but they must be able to offer a variety of affordable, sustainable, and environmentally friendly practical strategies (Kelley, 2021; Mitarlis et al., 2018).

Universities as one of the agents promoting Education for Sustainable Development (ESD). Universities need to be prepared for student thinking and action to be a leader in sustainable change. Therefore, chemistry education and research programs should contribute to the promotion of ESD in today's and future societies (Hamidah et al., 2017). ESD is implemented by integrating into the vision, mission, curriculum, and practice of chemistry education courses. Green chemistry (GC) can be used as an approach to promote ESD (Ballard et al., 2021). It is important to promote GC as a way of thinking in education and work in the laboratory (Carangue et al., 2021). The integration of GC into higher education was taught through

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bachelor's or graduate-level courses (Gross, 2013; Kennedy, 2016; Loste et al., 2020).

Even with the high cost of equipment and chemicals, chemistry lessons integrated with hands-on learning are very important. Chemistry internships at schools and colleges are usually associated with big equipment and large amounts of chemicals. Contrary to ESD goals, chemistry laboratories typically deal with chemicals, excess reagents, solvents, and waste that cause environmental problems (Loste et al., 2020). Another challenge is laboratory health hazards for students, teachers, and laboratory staff. Therefore, there is a need for a shift to more sustainable and economical experiments. This task can be learned with the principles of GC. Direct application of GC is visible in chemistry laboratories by minimizing waste and replacing toxic and dangerous non-renewable materials. One solution for this is Small-scale Chemistry (SSC). SSC was introduced to overcome the problems of shortages and expensive laboratory facilities and to minimize waste generation (Imaduddin et al., 2020).

SSC is an approach that minimizes laboratory activity compared to traditional laboratory activity (macroscale). This approach significantly reduces the use of chemicals (up to 1000 times), organizes existing laboratory equipment into smaller sizes and use plastic equipment (Tesfamariam et al., 2017). SSC is a small-scale chemistry experiment that uses a small number of chemicals and is often a simple device that transitions from glass to plastic (Skinner, 1999). With 25 -100 mg solids and 100 - 200 ml liquids, chemical work can be performed without compromising the quality and standards of education and industry (Singh et al., 1999). In addition, this approach can save costs and working time, improve labor safety in the laboratory, and environmentally friendly (Albert et al., 2012; Zakaria et al., 2012). SSC is an innovative approach and an effective educational tool. This concept pertains to a significant reduction in the number of chemicals in laboratory activities, the use of small lab ware, and the operation of safe and simple work processes. The accuracy of the experiment is not an issue, and teachers can also apply it as a design for new practical activities (Abdullah et al., 2009).

SSC offers profound educational benefits along with enormous potential in terms of environment, economy, and security (Eggen et al., 2004). Benefits of SSC include (1) promoting collaborative learning through student engagement and performance; (2) Encourage students to have the courage to handle small amounts of chemicals; (3) Works faster, allowing students to do more in the lab; (4) Reduce lab work and enjoy the class; (5) Enhancing students' work ethic regarding data preservation (Mafumiko, 2008). The advantage of SSC is that it improves students' laboratory skills and increases their confidence by performing experiments on small amounts of chemicals (Tesfamariam et al., 2017). By handling a smaller amount of material, students can save time for more in-depth discussion and reflection (Eggen et al., 2004).

SSC advocates for sustainability goals in education. Green chemistry and SSC have the same goal of minimizing the devastating effects of chemicals on the environment and human health. Therefore, green chemistry and SSC approaches can be used together for educational purposes. Based on this background, efforts are needed to overcome problems related to waste and efforts to achieve ESD. This study aims to design SSC for general chemistry practicum activities based on green chemistry.

Method

This study was conducted at Department of Chemistry Education UIN Walisongo Semarang from July-September 2021. The development model used is ADDIE. The model consists of five phases: (1) analysis, (2) design, (3) development, (4) implementation, and (5) evaluation. First phase is analysing the need for small chemistry practice sessions and analysing curriculum goals and lesson plans to identify practical work that can be converted into SSC through focus group discussion (FGD) with research teams. Then, identifiying chemicals and tools that can be used to develop SSC. The product design of SSC is practical guide dan kit. At this stage, there are five experiments with the SSC concept with chemicals and equipment based on the results of the previous analysis. The design of SSC validated by expert validators to know the strengths, weaknesses, and suggestions to support the improvement. Verification of practical experts and material experts was conducted using a questionnaire. In implementation phase, demonstrations were conducted to determine the implementation of the SSC's design. Field test data were obtained from data tables from observations sheet. The evaluation phase is evaluation of each phase to ensure that the learning design objectives are met and the learning needs can be met.

Assessment instruments in this study include (a) interview sheets for analysis of SSC needs in general chemistry practical work course; (b) analysis sheet of learning achievement for general chemistry practical work course; (c) validation questionnaire of practical guide and kit; (d) datasheet on the results of the observation of the implementation of the SSC based Basic Chemistry experiment. Then, analyze the data for the validation of instructions and kits using the Aiken's V validity formula.

Result and Discussion

The product designed of Small-scale Chemistry for General Chemistry is practical guide and kits. The development is based on analysis of the needs for small-scale experiment and analysis of instructional objective of General Chemistry Practical Course. The results of the analysis are used to design the practical guide and kits. The product is validated by five expert's laboratory learning design. At the implementation stage, a trial of the developed instructions and experiment kit was carried out. The results of all these stages are then evaluated.

The initial procedure of this research is the analysis phase. At this stage need analysis from interview with lecturers. The analyzing the curriculum and lesson plans to determine experiments that can be developed into small-scale chemistry experiments through Focus Group Discussions (FGD) with the research team. Based on the results of interviews with lecturers who supervise General Chemistry Practical Course, there are several note for designing SSC, namely basic chemistry experiment learning still uses macro-scale experiment designs so that a lot of chemicals are used. Therefore, it is needed as an alternative in carrying out chemistry experiment learning. Tools and materials are smaller so that they are more practical and reduce the use of materials. The application of small-scale chemistry experiment is also support for the program at We Green UIN Walisongo Semarang.

Analysis of the instructional objectives of the general chemistry practical course plays a role in determining what learning achievement indicators will be achieved in the design of the SSC. This is important to know because it becomes the basis for determining the experiment activities to be designed. The analysis was carried out by taking into account the curriculum and lesson plan. The description of instructional objectives shows in Table 1.

Based on the results of the analysis of instructional objectives and analysis of experiment activities that have been carried out in the previous stage and considering aspects of the application SSC, the results of the identification of materials, tools, and equipment are obtained. Experiment titles that can be used for experiment SSC in table 1. This design is made in the form of a practical manual and kit.

One of the principles of SSC is the use of materials in small quantities and tools with smaller sizes than macro scale experiments. The experiment kit is designed as part of the SSC. The SSC kit is expected to make it easier for students to carry out practical activities because the tools and chemical have been designed in a box. The SSC kit container is made of plastic. Furthermore, the composition of the contents of the SSC kit is designed as shown in Figure 2.

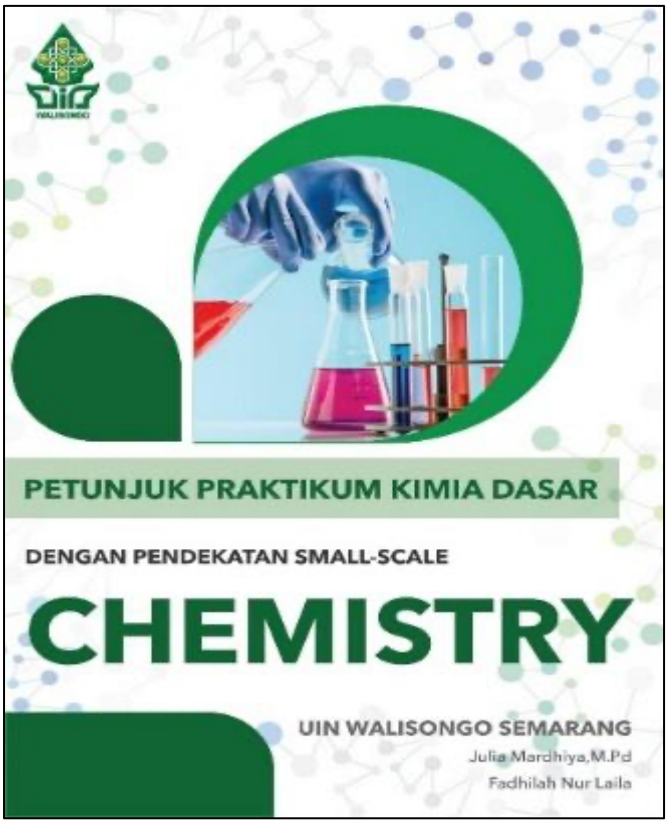


Figure 1. Practical guide

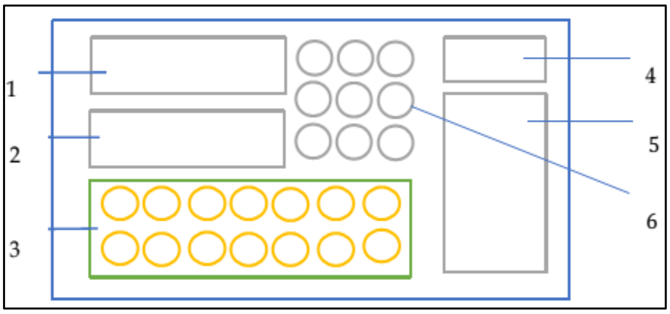
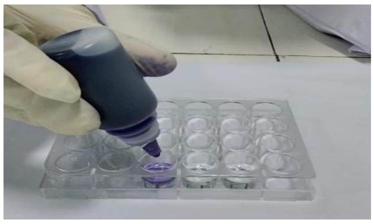
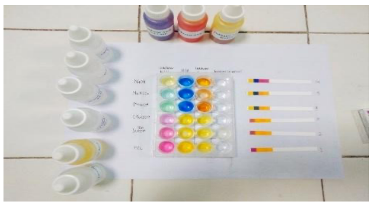
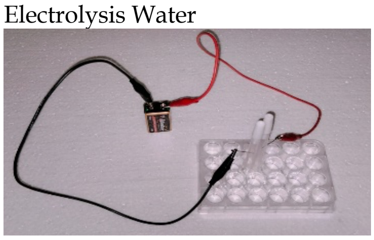


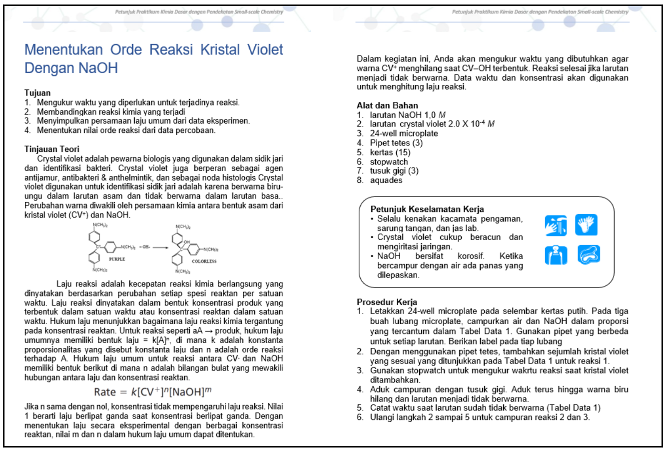
Figure 2. SSC kit design

Descryption:
1 = Solid chemicals
2 = Pipette
3 = Liquid chemicals
4 = 24 and 96 plat wells
5 = Test tube and test tube rack
6 = another equipment (beaker glass, graduated cylinder, etc)

The first step in development phase to describe indicators based instructional objective from course, then experiments are designed that will be included in the developed experiment instructions. Next, the SSC-based basic chemistry experiment manual was made. The format used in making chemical experiment 5 instructions is A5 size paper with a weight of 70 gsm. The font is Arial with a size of 12 pt.

Table 1. Design of SSC

Practical Work Objective	Small-Scale Chemistry Activity	Chemicals	Equipment
Measure the time required for a reaction to occur in an experiment Conclude the reaction rate equation from experimental data Determine the value of the reaction order from experimental data	Determine the Order Reaction 	NaOH of 1.0 M crystal violet 2.0 x 10^{-4} M	24-well microplate dropper (3) paper stopwatch toothpick (3) aquades
Observing the color changes associated with the shift in equilibrium. Connecting changes in reactant concentrations with the direction of the shift in equilibrium	Chemical Equilibrium Observation 	$Fe(NO_3)_3$ 0.1 M KSCN 0.1 M NaOH.0 M $AgNO_3$ 0.1 M $Fe(NO_3)_3$ 0.5 g NH_4SCN 0.5 g KCl 0.5 g Aquades	10 mL graduated cylinder (2) 100 mL beaker (1) dropper (5) medium test tube (5) test tube rack stirring rod (1)
Make extracts of natural indicators Identify acid and base solutions with natural indicators Determine the pH of solutions with universal indicators	Identification of Acids and Bases with Indicators  	Natural Indicators BTB NaOH $NaHCO_3$ NH_4OH Lemon Juice CH_3COOH HCl NH_4Cl Salt Citric acid Milk Soap	24-well microplate 96-well microplate Litmus paper Universal indicator Pipette (10) Mortar and pestle Funnel
Measuring the pH of standard and dilute solutions. Calculate the concentration of H+ ions from each solution and Ka from each weak acid. Sort acids by the strength.	Determination of Acid Strength 	Boric acid 0.1 M Citric acid 0.1 M H_2O_2 0. M Acetic acid 0.1 M Aquades	24-well microplate pipettes (12) pH paper Universal
Determine the reaction at the anode and cathode when an electric current is applied to a solution. Observing water electrolysis	Electrolysis Water 	BTB indicator Na_2SO_4 0,5 g Distilled water	transparent straw disposable pipette beaker glass stirrer crocodile clamp 24-well microplate Pin silicone stoppers (2)


Petunjuk Praktikum Kimia Dasar dengan Pendekatan Small-scale Chemistry

Menentukan Orde Reaksi Kristal Violet Dengan NaOH

Tujuan
1. Mengukur waktu yang diperlukan untuk terjadinya reaksi.
2. Membandingkan reaksi kimia yang terjadi
3. Menyimpulkan persamaan laju umum dari data eksperimen.
4. Menentukan nilai orde reaksi dari data percobaan.

Tinjauan Teori
Crystal violet adalah pewarna biologis yang digunakan dalam sidik jari dan identifikasi bakteri. Crystal violet juga berperan sebagai agen antijamur, antibakteri & anthelmintik, dan sebagai noda histologis Crystal violet digunakan untuk identifikasi sidik jari adalah karena berwarna biru-ungu dalam larutan asam dan tidak berwarna dalam larutan basa.. Perubahan warna diwakili oleh persamaan kimia antara bentuk asam dari kristal violet (CV^+) dan NaOH.

Laju reaksi adalah kecepatan reaksi kimia berlangsung yang dinyatakan berdasarkan perubahan setiap spesi reaktan per satuan waktu. Laju reaksi dinyatakan dalam bentuk konsentrasi produk yang terbentuk dalam satuan waktu atau konsentrasi reaktan dalam satuan waktu. Hukum laju menunjukkan bagaimana laju reaksi kimia tergantung pada konsentrasi reaktan. Untuk reaksi seperti aA → produk, hukum laju umumnya memiliki bentuk laju = $k[A]^n$, di mana k adalah konstanta proporsionalitas yang disebut konstanta laju dan n adalah orde reaksi terhadap A. Hukum laju umum untuk reaksi antara CV· dan NaOH memiliki bentuk berikut di mana n adalah bilangan bulat yang mewakili hubungan antara laju dan konsentrasi reaktan.

$$\text{Rate} = k[CV^+]^n[NaOH]^m$$

Jika n sama dengan nol, konsentrasi tidak mempengaruhi laju reaksi. Nilai 1 berarti laju berlipat ganda saat konsentrasi berlipat ganda. Dengan menentukan laju secara eksperimental dengan berbagai konsentrasi reaktan, nilai m dan n dalam hukum laju umum dapat ditentukan.

Petunjuk Praktikum Kimia Dasar dengan Pendekatan Small-scale Chemistry

Dalam kegiatan ini, Anda akan mengukur waktu yang dibutuhkan agar warna CV^+ menghilang saat CV–OH terbentuk. Reaksi selesai jika larutan menjadi tidak berwarna. Data waktu dan konsentrasi akan digunakan untuk menghitung laju reaksi.

Alat dan Bahan
1. larutan NaOH 1,0 *M*
2. larutan crystal violet 2.0 X 10^{-4} *M*
3. 24-well microplate
4. Pipet tetes (3)
5. kertas (15)
6. stopwatch
7. tusuk gigi (3)
8. aquades

Petunjuk Keselamatan Kerja
- Selalu kenakan kacamata pengaman, sarung tangan, dan jas lab.
- Crystal violet cukup beracun dan mengiritasi jaringan.
- NaOH bersifat korosif. Ketika bercampur dengan air ada panas yang dilepaskan.

Prosedur Kerja
1. Letakkan 24-well microplate pada selembar kertas putih. Pada tiga buah lubang microplate, campurkan air dan NaOH dalam proporsi yang tercantum dalam Tabel Data 1. Gunakan pipet yang berbeda untuk setiap larutan. Berikan label pada tiap lubang
2. Dengan menggunakan pipet tetes, tambahkan sejumlah kristal violet yang sesuai yang ditunjukkan pada Tabel Data 1 untuk reaksi 1.
3. Gunakan stopwatch untuk mengukur wakrtu reaksi saat kristal violet ditambahkan.
4. Aduk campuran dengan tusuk gigi. Aduk terus hingga warna biru hilang dan larutan menjadi tidak berwarna.
5. Catat waktu saat larutan sudah tidak berwarna (Tabel Data 1)
6. Ulangi langkah 2 sampai 5 untuk campuran reaksi 2 dan 3.

Figure 3. Practical guide

The components of the tools contained in the chemistry lab kit are test tubes, test tube racks, graduated cylinder, beakers glass, funnels, dropper pipettes, plastic pipettes, 24 plate wells, 96 plate wells, mortar, and pestle. The chemicals in place in containers made of plastic in the form of drop bottles and ordinary bottles. The selection of drop bottles aims to make use more practical and easy. In terms of preparation of materials must also pay attention to aspects of the nature and ease of reacting materials.

At this stage, the feasibility test of the guide and kits that have been developed is carried out. The Assessment was carried out by five expert validators, namely lecturers from several universities. Assessment is done by giving a checklist (√) on each score. The scoring sequence is 1 = strongly disagree, 2 = disagree, 3 = agree, 4 = strongly agree. Rating expert validators on experiment instructions obtained an average of 0.90 based on the Aiken's V assessment criteria which were declared very valid. Suggestions given by the validator include improving the size of the image that is less proportional and the use of fonts must be consistent (Table 3).

The objective of the first experiment to determine the reaction order of NaOH with crystal violet, the practitioner uses 50 drops of NaOH and 13 drops of crystal violet. The volume of the solution used is much less than the macro-scale experiment. This is following the SSC principle, namely the reduction of the volume of the substance. The pedagogical aspect of this experiment emphasizes the ability to measure time and observe changes in the color of the reaction of NaOH solution which is dripped with crystal violet. Furthermore, after observing, the experiment must calculate the reaction order based on the results of time measurements and calculations of reactant concentrations.


Figure 4. Contents of the SSC kit

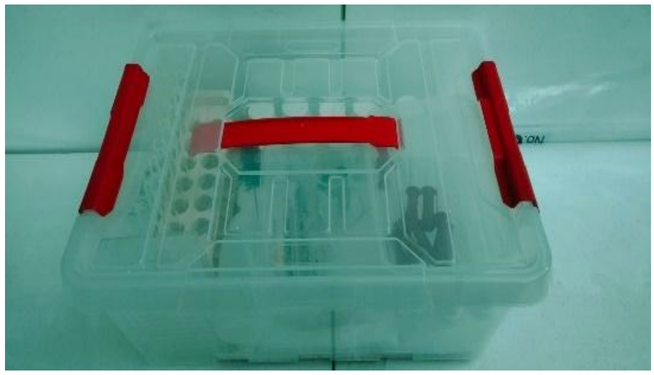


Figure 5. SSC kit front view

Table 2. The Results of the Feasibility Test For Practical Guide and Kit

Feasibility	Aiken's V Value
Content of Practical Guide	0.84
Language of Practical Guide	0.90
Presentation of Practical Guide	0.84
Graphical of Practical Guide	0.90
SSC lab kit	0.89

The second experiment is observation shift of chemical equilibrium. The practitioner observes how the equilibrium shifts by adding certain substances to an equilibrium system. Psychomotor abilities that can be observed are the practitioner's ability to transfer substances into test tubes, measure the volume of the solution and identify color changes during the reaction. Furthermore, the practitioner can analyze the data obtained to determine the direction of the equilibrium shift to prove the theory that has been studied.

The third experiment is identification acid and base with indicator. In the experiment, the volume of material used is 2 drops per sample and indicator solution. Because the containers used were 24 wells microplate and 96 wells microplate. Observations also show color gradations that can be distinguished between solutions. The aspect of psychomotor learning in this experiment is that the experiment can transfer the solution from the sample bottle to the microplate and observe how the color changes. The data obtained were then analyzed based on the existing theory.

The fourth experiment is identifying the strength of the acid. The first step is to calculate the initial concentration of the acid. The solution in each of these holes was prepared in two 10-fold dilutions. Record the results in the table of observations. Next calculate the concentration of H+ ions at equilibrium using the formula that relates pH and $[H^+]$. Next calculate the acid ionization constant, Ka, for each acid, using the equilibrium concentrations of the acid and H^+. Next, calculate the average Ka for each acid. In this experiment the volume of material used is 20 drops per sample and indicator solution. Because the container used is 24 wells microplate. This is in accordance with the SSC principle, namely the reduction of the volume of a substance.

The last experiment is observing water electrolysis. This experiment aims to perform electrolysis of water and observe the reaction results. Through this practical activity, the practitioner can perform electrolysis of water with a small volume of material. Because only 2 ml of sodium sulfate is used, the procedure does not require much chemical but the results can be observed, namely the change in color and the solution becomes pink and gas is formed. The use of materials is following the principle of Small-scale Chemistry, namely the use of materials in small quantities to reduce waste.

Evaluation is carried out to assess the functioning of the guide and kits after getting input from experts and implementing it. The data obtained from experiment and analyzed descriptively for the improvement of instructional products and subsequent learning experiment kits. The results of the evaluation at each stage are as follows:

Table 3. Evaluation Results

Phase	Evaluation Results
Analyze	Need for innovation to save more on costs and test materials on a small scale but must be accurate from the practical work to be carried out so as not to produce more waste
Design	At the design phase, it is necessary to consider the safety aspects of tools and materials that will be used as kits practice.
Develop	At this development phase, some chemicals set design stage to be replaced as an effort to adjust to some of the material provided
Implementation	At this stage, it is necessary to test several times so that the work procedures and results can be observed by the practitioner. At this stage, there are some suggestions from experts validator is Conformity to the contents page Composing pictogram safety in the laboratory with the latest international standards (GHS) Make sentences clearer instructions and understandable In the practical identification of acids and bases with natural indicators, there are practical procedures that can be arranged more practically. Due to a repetition of the procedure several times in the lab manual Need to show illustrations of practical activities The amount of material in the chemical equilibrium experiment can be reduced as a principle of the small-scale experiment
Evaluation	All stages of small-scale chemistry evaluated and improvements are made on the suggestions given by the validator

Practical works are an important aspect of daily practice in learning chemistry. This is because practical works almost involve all the five senses of students. Practical activities are an effective form of teaching to achieve three competencies simultaneously, namely cognitive, affective, and psychomotor. Cognitive competence is manifested in the form of applying knowledge and proving exercises. Affective competence appears through curiosity, cooperation, and communication. While psychomotor competence can be seen from the skills to use tools and materials and apply work procedures.

Based on the results of observations on students' skills during learning using a chemistry guide and experiment kit, the average skills of students are in a good category. The skill indicators observed were (1) checking the completeness of tools and materials following those in the experiment procedure; (2) taking the solution from the stock bottle with a dropper properly; (3) dispensing the solution from the pipette into the measuring cup properly; (4) pouring the solution from the measuring cup into the test tube properly; (5) mix the solution into the test tube properly; (6) read the volume of the solution using a measuring cup correctly; (8) cleaning the tools used in the experiment; (9) cleaning the workplace; (10) return and organize tools in kit box; (11) return and arrange materials to kit box.

From the data obtained, it is known that students' skills in taking a solution from a bottle using a dropper, removing the solution from a pipette, measuring the height of the precipitate using a ruler, reading the volume of the solution using a measuring cup correctly must be trained more often because the value in these aspects is deep enough category improvement of student skills after using a guide and experiment kit (J.

Bradley, 2021). Project-based experiment to prospective chemistry teachers in South Africa also reported that the learning approach using experiment kits contributed to active learning in applying science (Van De Heyde et al., 2019). Learning with experiment children will use their minds to carry out various concepts or principles. In the process of discovery, students perform mental operations in the form of measurement, prediction, observation, inference, and grouping (Tawil et al., 2014). Experiences for students in laboratory situations should be an integral part of any science learning including chemistry (Irwanto et al., 2018; Talbot-Smith, 2013). Practical activities in schools have special potential as learning media that can promote important science learning outcomes for students.

Conclusion

Based on the analysis of the small-scale chemistry design for the general chemistry practical work carried out at the Chemistry Education study program of UIN Walisongo, the following conclusions are based on needs analysis with interviews, it is known that SSC-based Basic Chemistry experiment is needed for practical learning to support the application of green chemistry. The product are laboratory work manual and practical kit. The development model used is ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). At the analysis stage, five experiment will be designed to become SSC. There are five experiments, namely determining the order of the reaction, observation the shift in chemical equilibrium, identification acid-base with indicators, determining the strength of the acid and water electrolysis. The feasibility of the manual and practical kit in content feasibility (0.84), language feasibility (0.90), presentation feasibility (0.84), graphic feasibility (0.90), and kit feasibility (0.94). All are categorized as valid based on the validity criteria of Aiken's V. The results of the implementation show that the SSC design can be implemented and the results can be used for General Chemistry experiment learning activities.

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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

Albert, D. R., Todt, M. A., & Davis, H. F. (2012). A low-cost quantitative absorption spectrophotometer. *Journal of Chemical Education*, *89*(11), 1432–1435. https://doi.org/10.1021/ed200829d

Ballard, J., & Mooring, S. R. (2021). Cleaning Our World through Green Chemistry: Introducing High School Students to the Principles of Green Chemistry Using a Case-Based Learning Module. *Journal of Chemical Education*, *98*(4), 1290–1295. https://doi.org/10.1021/acs.jchemed.9b00312

Bradley, J. (2021). Achieving the Aims of Practical Work with Microchemistry. *Research in Chemistry Education*, *6*(1), 23–30. https://doi.org/10.1007/978-3-030-59882-2_2

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

Carangue, D., Geverola, I. M., Jovero, M., Lopez, E. N., Pizaña, A., Salmo, J., Silvosa, J., & Picardal, J. (2021). Green Chemistry Education among Senior High School Chemistry Teachers: Knowledge, Perceptions, and Level of Integration. *Recoletos Multidisciplinary Research Journal*, *9*(2), 15–33. https://doi.org/10.32871/rmrj2109.02.04

Eggen, P. O., & Kvittingen, L. (2004). A small-scale and low-cost apparatus for the electrolysis of water. *Journal of Chemical Education*, *81*(9), 1337–1338. https://doi.org/10.1021/ed081p1337

Furtak, E. M., & Penuel, W. R. (2019). Coming to terms: Addressing the persistence of "hands-on" and other reform terminology in the era of science as practice. *Science Education*, *103*(1), 167–186. https://doi.org/10.1002/sce.21488

Godínez Castellanos, J. L., León, A., Reed, C. L., Lo, J. Y., Ayson, P., Garfield, J., Alva, M., Moreno, M. U., Drake, M. D., Gordon, M., Phillips, S., & Alemán, E. A. (2021). Chemistry in Our Community: Strategies and Logistics Implemented to Provide Hands-On Activities to K-12 Students, Teachers, and Families. *Journal of Chemical Education*, *98*(4), 1266–1274. https://doi.org/10.1021/acs.jchemed.0c01120

Gross, E. M. (2013). Green chemistry and sustainability: An undergraduate course for science and nonscience majors. *Journal of Chemical Education*, *90*(4), 429–431. https://doi.org/10.1021/ed200756z

Hamidah, N., Prabawati, S., Fajriati, I., & Eilks, I. (2017). Incorporating Sustainability in Higher Chemistry Education in Indonesia through Green Chemistry: Inspirations by Inquiring the Practice in a German University. *International Journal of Physics and Chemistry Education*, *9*(1), 1–7. https://doi.org/10.12973/ijpce/79220

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

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

Irwanto, Rohaeti, E., & Prodjosantoso, A. K. (2018). Undergraduate students' science process skills in terms of some variables: A perspective from Indonesia. *Journal of Baltic Science Education*, *17*(5), 751–764. https://doi.org/10.33225/jbse/18.17.751

Kelley, E. W. (2021). Sample plan for easy, inexpensive, safe, and relevant hands-on, at-home wet organic chemistry laboratory activities. *Journal of Chemical Education*, *98*(5), 1622–1635. https://doi.org/10.1021/acs.jchemed.0c01172

Kennedy, S. A. (2016). Design of a Dynamic Undergraduate Green Chemistry Course. *Journal of Chemical Education*, *93*(4), 645–649. https://doi.org/10.1021/acs.jchemed.5b00432

Loste, N., Chinarro, D., Gomez, M., Roldán, E., & Giner, B. (2020). Assessing awareness of green chemistry as a tool for advancing sustainability. *Journal of Cleaner Production*, *256*. https://doi.org/10.1016/j.jclepro.2020.120392

Mafumiko, F. M. S. (2008). The Potential of Micro-scale Chemistry Experimentation in enhancing teaching and learning of secondary chemistry: Experiences from Tanzania classrooms. *NUE Journal of International Educational Cooperation*, *3*, 63–79. file:///L:/Visiting/The Potential of Micro-scale Chemistry Experimentation in enhancing teaching and learning of secondary chemistry.pdf

Mardhiya, J., Silaban, R., & Mahmud, M. (2017). *Analysis of Chemistry Laboratory Implementation in Senior High School*. *104*(Aisteel), 52–56. https://doi.org/10.2991/aisteel-17.2017.12

Mitarlis, M., Azizah, U., & Yonata, B. (2018). *Learning Design to Integrate Scientific Character Values with Green Chemistry Insight in Basic Chemistry Course*. *173*(Icei 2017), 222–225. https://doi.org/10.2991/icei-17.2018.58

Reid, N., & Shah, I. (2007). The role of laboratory work in university chemistry. *Chemistry Education Research and Practice*, *8*(2), 172–185. https://doi.org/10.1039/B5RP90026C

Singh, M. M., Szafran, Z., & Pike, R. M. (1999). Microscale Chemistry and Green Chemistry: Complementary Pedagogies. *Journal of Chemical Education*, *76*(12), 1684–1686. https://doi.org/10.1021/ed076p1684

Skinner, J. (1999). *Microscale Chemistry*. The Royal Society of Chemistry.

Talbot-Smith, M. (2013). Learning and Teaching in the School Science Laboratory: An Analysis of Research, Theory and Practice. *Handbook of Research on Science Education*, *January 2007*, 393–441.

Tawil, M., & Liliasari. (2014). *Keterampilan – Keterampilan Sains dan Implementasinya dalam Pembelajaran IPA*. Badan Penerbit UNM.

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

Ural, E. (2016). The Effect of Guided-Inquiry Laboratory Experiments on Science Education Students' Chemistry Laboratory Attitudes, Anxiety and Achievement. *Journal of Education and Training Studies*, *4*(4), 217–227. https://doi.org/10.11114/jets.v4i4.1395

Van De Heyde, V., & Siebrits, A. (2019). Students' attitudes towards online pre-laboratory exercises for a physics extended curriculum programme. *Research in Science and Technological Education*, *37*(2), 168–192. https://doi.org/10.1080/02635143.2018.1493448

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