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Design and Development of the Experimental Kit for Limiting Reagent Study Using a Smartphone

การออกแบบและพัฒนาชุดการทดลอง เรื่อง การศึกษาสารกำหนดปริมาณโดยใช้สมาร์ทโฟน

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บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาสภาวะที่เหมาะสมในการสร้างชุดทดลองและทดสอบประสิทธิภาพของชุดทดลองเรื่อง การศึกษาสารกำหนดปริมาณโดยใช้สมาร์ทโฟน โดยมีกลุ่มตัวอย่างแบบเจาะจง เป็นนักศึกษาระดับปริญญาตรี จำนวน 2 กลุ่ม คือ นักศึกษาหลักสูตรวิทยาศาสตรบัณฑิต สาขาวิชาเคมี จำนวน 10 คน และนักศึกษาหลักสูตรครุศาสตรบัณฑิต สาขาวิทยาศาสตร์ทั่วไป จำนวน 26 คน สำหรับทดสอบประสิทธิภาพของชุดทดลองตามลำดับ โดยสถิติที่ใช้ในการวิจัย คือ ร้อยละ ค่าเฉลี่ย ค่าเบี่ยงเบนมาตรฐานผลการศึกษาสภาวะที่เหมาะสมของชุดการทดลองนี้พบว่าความเข้มข้นของสารตั้งต้นสองชนิดคือ สารละลายเหล็ก (III) ไนเตรท ($Fe(NO_3)_3$) และสารละลายโพแทสเซียมไทโอไซยาเนต (KSCN)มีค่าเท่ากับ 0.0020 โมลาร์ ชนิดความเข้มสีที่เหมาะสมในการวิเคราะห์สารละลายเหล็ก (III) ไทโอไซยาเนต ($FeSCN^{2+}$) จากภาพถ่ายด้วยโปรแกรมในสมาร์ทโฟนคือ ความเข้มสีน้ำเงิน ระยะห่างที่เหมาะสมจากสมาร์ทโฟนถึงแท่นวางสารในการถ่ายภาพคือ 30-40 เซนติเมตร สำหรับชนิดของสมาร์ทโฟนและชนิดของโปรแกรมวิเคราะห์ความเข้มสีให้ผลการทดลองที่ไม่แตกต่างกัน โดยผลการทดสอบประสิทธิภาพพบว่ากราฟระหว่างความเข้มสีน้ำเงินของ $FeSCN^{2+}$ และปริมาตรของ KSCN ที่เขียนโดยนักศึกษาสามารถใช้ระบุสารกำหนดปริมาณได้ร้อยละ 80 และค่าเฉลี่ยความพึงพอใจของนักศึกษาต่อชุดทดลองนี้มีค่าเท่ากับ 4.05 ซึ่งอยู่ในระดับเห็นด้วยมาก

คำสำคัญ: *ชุดทดลอง, สมาร์ทโฟน, สารกำหนดปริมาณ*

Boonmee, A., Moonrungsee, N., Jakmunee, J., Bundtichat, N., Yakantip, N., Suttiprapa, R.,… Suwancharoen, S. (2020).Design and Development of the Experimental Kit for Limiting Reagent Study Using a Smartphone. *Journal of Rangsit University: Teaching & Learning, 14(1), 177-188.*

Abstract

The objective of this research was to study the optimum condition and the efficiency of the limiting reagent experiment kit using a smartphone. Two groups of the subjects; 10 undergraduate students from chemistry major and 26 undergraduate students from general science education major, selected by purposive sampling technique, were used to determine the developed test kit efficiency, respectively. The data were statistically analyzed by percentage, means and standard deviation.The result for the optimum condition for the experimental kit design presented that the suitable concentration of reactants; $Fe(NO_3)_3$ and KSCN, was 0.0020 M. The blue intensity was the best correlation color for product analysis. The suitable distancefrom smartphone to platform holder for the good result picture capture was 30-40 cm. The types of smartphone and color analysis program showed the same result which was not significantly different. For the efficiency results, the percentage of graph between the blue color of $FeSCN^{2+}$ and volume of KSCN plotted by students that correctly specified the limiting agent was 80 and the learning satisfaction of the students was at 4.05 which was on the very satisfied level.

Keywords: *Experimental Kit, Smartphone, Limiting reagent*

Introduction

Stoichiometry, defining the relationships between reactants and products in a chemical reaction, is one of the difficult topics in chemistry for high school and first-year undergraduate students because of many reasons (Angélica, Edgardo, & Zuleika, 2014, p. 1464-1467;Chandrasegaran, Treagust, Waldrip, &Chandrasegaran, 2009, p.14-23 ; Richard, 1989, p.57-58; Steiner, 1986, p.1048)Firstly the students have a misconception of stoichiometry understanding. The second is the students lack of the mathematic solving skills and the another is that the reason they have a problem with transferring microscopic, macroscopic and chemical symbol representation. For improving the student's levels in this subject area, learning by doing practically on this is one of the way that many research reports have been presented (Boonmee, Pachain & Suwancharoen, 2017, p. 51-63 ; Laure, & Martine, 2007, p. 362-375; Liliana, Eduardo, Santiago, & Lydia, 2003, p. 1021-1022;Nobuyoshi, Tomoyasu, & Kana, 2011, p. 1309-1313;Padua, Tomoyasu, & Kana, 2000, p. 1608A; Romklao, 2003, p. 1382-1384;Zhilin, 2012, p. 649-651). In this study, we focus on the topic of stoichiometry which is the limiting reagent, the reactant that controls products quantity, by using a smartphone, the tool that many used in analytical chemistry application as a spectrometer (Choodum, Kanatharana, Wongniramaikul, & Daeid, 2013, p. 143-149; Choodum, Parabun, Klawach, Daeid, Kanatharana &Wongniramaikul, 2014, p.8-13;Edwards et al., 2017; García et al., 2011, p. 350-359; Gong, Yu, He, & Qiu, 2013, p. 162-170; Kehoe &Penn, 2013, p. 1191-1195; Moonrungsee, Peamaroon, Boonmee, Suwancharoen, & Jakmunee, 2018;Moraes, Da Silva, De Morais, Das Neves, & De Lima, 2014, p. 1958-1960; Smith, Griffin, Leny, Hagen, Chavez, & Kelley, 2014, p. 247-255)

In 21st century education, digital technologieshave become an important part of educational reforming and improving the quality of chemistry education. The important one of digital technology that widely recognized by educational researchers is smartphone. This technology can serve as powerful learning tool and comfortable laboratory tool for mobile-based chemistry learning. Several researchers reported that the use of smartphone in hands-on chemistry laboratory is very positive laboratory tool for students that information in the experiment was conducted based on smartphone (Chang, 2012, p. 549-552; Kehoe, & Lee Penn,2013, p. 1191-1195). For this research, we designed to use smartphone as a tool for the limiting reagent learning and further developed this experimental kit by using the reaction between iron(III)ion and thiocyanate ion to produce iron(III)thiocyanate presented in Equation (1).

$$Fe^{3+} + SCN^{-} \longrightarrow FeSCN^{2+} \quad (1)$$

We studied the optimum condition for the experimental kit design which was the concentration of reactants, RGB (red, green, blue) intensity, type of smartphone, and color analysis program, the distance for the picture capture, and type of volumetric measurement apparatus. Then the limiting reagent laboratory kit was developed and studied the efficiency, respectively. The way to use this kit for teaching on limiting reagent topic in the classroom was also described herein.

Research Objective

To study the optimum condition and the efficiency of the limiting reagent experiment kit using a smartphone

Definition of terms

Experimental kit described as the apparatus that uses in the experiment class, including chemical substance.

*Limiting reagent*is the substance in a chemical reaction that determines the amount of product that is formed.

*Smartphone*refer to an integrated device with mobile telephone technology and the ability to access the internet which performs many of the functions of a computer.

Research methodology

Population and sample

First group of sample was the first year undergraduate students from chemistry major selected by purposive sampling technique. After using the experimental kit, the kit was developed and tested again by the second group which was the second-third year undergraduate students from general science education major using purposive sampling technique same as the first group.

Research instrument

1. Experimental kit designed and developed by researcher
2. Limiting reagent hand-on activity
3. Students' learning satisfaction questionnaire

Optimum condition study

To optimize the suitable condition for the experimental kit design, the concentration of reactants, RGB intensity, type of smartphone, and color analysis program, the distance for the picture capture, and type of volumetric measurement apparatus were studied. For the concentration study, we designed this to use the reactants at the same concentration, fix the volume of iron(III)nitrate constantly at 1.5 mL and vary the volume of potassium thiocyanate from 0.00 to 2.50 mL. The same concentrations of the reactants were used for mixing at four concentrations; 0.0010, 0.0020, 0.0030 and 0.0040 M. After mixing the reactants in the cuvettes, the produced red color solution was analyzed by using UV-Visible spectrophotometer at 468 nm. The graph between the absorbance of $FeSCN^{2+}$and KSCN volumes were plotted and compared to select the optimum concentration for the kit development. Under the suitable reactant concentrations, the red color solution of $FeSCN^{2+}$ from the reaction was captured by using the smartphone (Samsung A5). Then, the picture was analyzed with the intensity of red, green and blue color using the Color Grab application in an Android system. The graph between the intensity of RGB color and the volume of KSCN were plotted and analysis the best color correlation. After that we used the suitable reactant concentration and the best correlated color to study the type of smartphone; Samsung A5, Samsung grand prime, Samsung Grand II and Oppo F1, the application programs; Color grab and Color picker, the distance between the sample holder and smartphone camera from 10-50 cm, and the volumetric measurement apparatus; plastic syringe, and glass pipette.

Classroom activity and the efficiency study

After all conditions were optimized, the experimental kit was efficiency tested by ten first year undergraduate students major in chemistry. Brifly, two to three students worked together to do the experiment by using the experimental kit. Firstly, they mixed 1 mL of $Fe(NO_3)_3$ with 0.0, 0.2, 0.5, 1.0 and 1.5 mL of KSCN in each tube. After mixing well, the cuvettes were placed on the foam platform and then photographs were taken using their smartphones. The picture was analyzed for the intensity of the color for three times by the application program; Color picker for iOS and Color grab for Android smartphone. Then, they used the average value of color intensity and the volume of KSCN for graph plotting, which answered the guide questions leading to understanding the meaning of limiting reagent and determining limiting reagent from the graph after finishing their experiment. These graphs could be used for efficiency tested by checking the percentage of graph (X) which showed constantly line at the correct point. The percentage of acceptable graph was calculated by using Equation (2).

$$X = \frac{\text{The number of acceptable graph}}{\text{The total number of all graph}} \times 100 \qquad (2)$$

After first test, the kit was developed and was measured the efficiency (X) again with twenty six of undergraduate students from general science education major. The learning satisfaction of the students as a result of using the developed kit was also tested after the treatment. The level of satisfaction (Yangden, 2017, p. 51-63) was shown as:

0.00 – 1.50 (not at all satisfied)

1.51 – 2.50 (slightly satisfied)

2.51 – 3.50 (moderately satisfied)

3.51– 4.50 (very satisfied)

4.51 – 5.00 (extremely satisfied)

Result and discussion

The smartphone is a useful tool in many studies including chemistry subject learning. Most of the students have their smartphones, therefore, the chemistry activity using this equipment could be engaged by them in chemistry learning. There were many use of smartphone as a laboratory tool in hands-on chemistry experiment for students such as learning element by Element 4D (Yang, Mei, & Yue, 2018, p. 1060–1062), measuring amylase activity (Dangkulwanich, Kongnithigarn, & Aurnoppakhun, 2018, p. 141–145) and quantifying protein concentrations by using a smartphoneas a spectrometer (Gee, Kehoe, Pomerantz, &Penn, 2017, P. 941-945), even for color-blind and visually impaired students, a smartphone also can be used for the sound and feel of titrations (Bandyopadhyay& Rathod, 2017, p. 946–949).In this research, we designed to use a smartphone for stoichiometry learning in the limiting reagent topic though the reaction between $Fe(NO_3)_3$ and KSCN to produce $FeSCN^{2+}$.First of all, we studied the concentration of those two reactants at four concentrations; 0.0010, 0.0020, 0.0030 and 0.0040 M by using the reactants at the same concentration, fix the volume of $Fe(NO_3)_3$constantly at 1.5 mL and vary the volume of KSCN from 0.00 to 2.50 mL so the limiting reagent in this study would be $Fe(NO_3)_3$when used the volume of

KSCN above 1.5 mL. The graph between the absorbance of $FeSCN^{2+}$and KSCN volumes were plotted as in Figure 1. We found that at 0.001 M of reactant presented the lowest absorbance which is difficult to determine the equivalent point of reaction due to the very close of absorbance at various volumes of the reagent and it seemed that the absorbance was constant at 1 mL of KSCN onward which was not the right point of limiting reagent representation. The suitable concentration of reactants is 0.0020 M which the absorbance between 0.00-1.00 and showed constant line at a correct point, i.e., from 1.5 mL of KSCN onward. For the concentration higher than 0.0020 M, the absorbance was more than 1.00 and the intensity of the red color was too saturated that might not be suitable for determining the color of the picture by a smartphone.

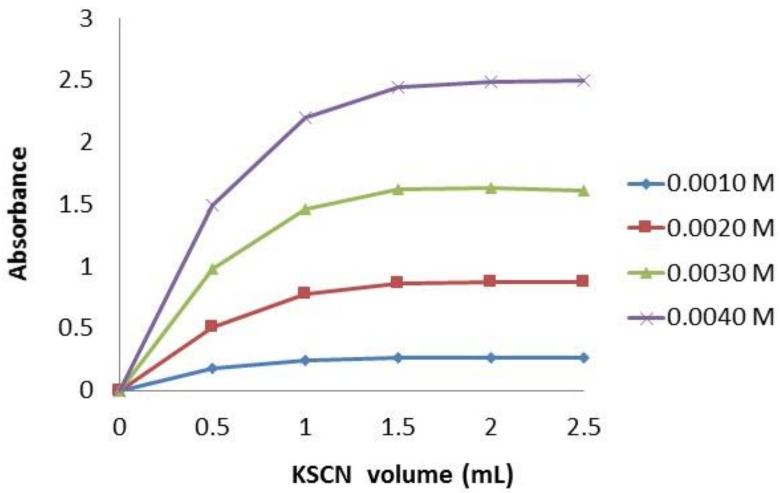
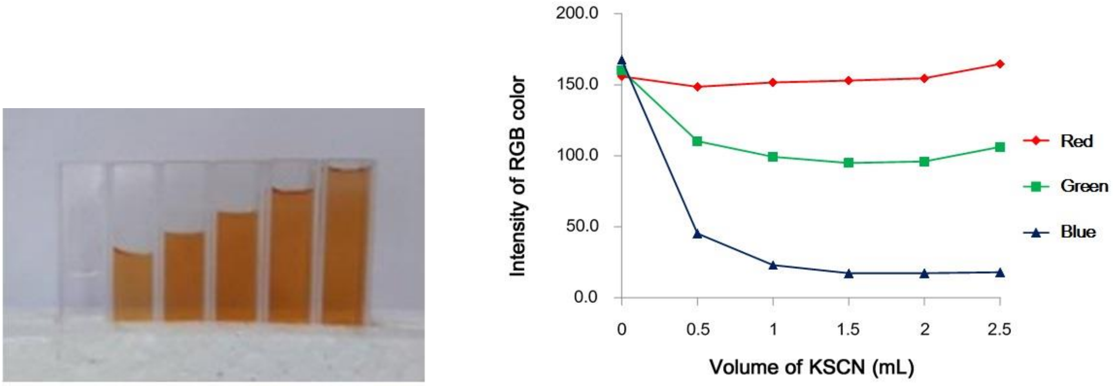


Figure 1. The graph plotting between the absorbance of $FeSCN^{2+}$ and KSCN volume from the reaction between KSCN and $Fe(NO_3)_3$ at four identical molar concentrations of the two reagents.

After we found the suitable reactants concentration, the red color solution of $FeSCN^{2+}$ from the reactants at 0.0020 M was captured by using the smartphone (Samsung A5) as shown in Figure 2a. Then, the picture was analyzed with the intensity of red, green and blue color using the Color Grab application in an Android system. The graph between the intensity of RGB color and the volume of KSCN were plotted as in Figure 2b. From the result, the blue color intensity was the best color intensity for kit development due to the correlation between intensity and volume which is clearly showed the reaction equivalent point. This result was consistent with the complementary color which the blue color from picture was the complementary color with the orange color of the product (Algar, De Jong, Maxwell, & Atkins, 2016, p. 162-165).



(a) **(b)**

Figure 2. (a) The picture of the red color solution from the reaction between KSCN and $Fe(NO_3)_3$
(b) The Graph between the intensity of RGB color and KSCN volume

For the type of smartphone study, four smartphones; Samsung A5, Samsung grand prime, Samsung Grand II, Oppo F1 were used to conduct the study. We did not find anything significantly different because all of them could be used to determine the color intensities of the product reasonably. When we compared the different application programs between Color grab belonging to the Android system, and Color picker belonging to the iOS system, these two programs also used well for color analysis. For the distance study, the smartphone camera was used to capture the picture at 10 cm to 50 cm from smartphone to sample holder and analyzed the B intensity. The graph between the intensity of B color and the volume of KSCN were plotted as in Figure 3. From the result, the graph from each distance had similarly tended which showed constant line from 1.0 mL of KSCN onward and can be used for identify the limiting reagent. However, the best result for good quality picture analysis was the distance between 30 and 40 cm because less than 30 cm the picture would be presented with some shadow of the smartphone in the side and the distance more than 40 cm the picture was too small and hence difficult to determine the color.

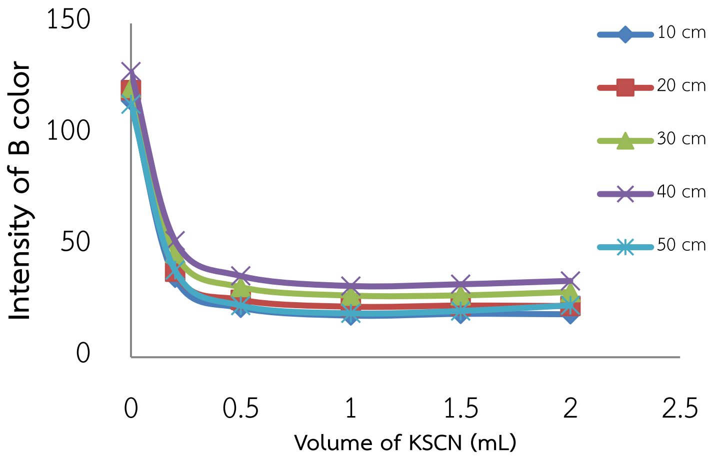


Figure 3. The Graph between KSCN volume and the intensity of B color from the picture captured at 10-50 cm from smartphone to sample holder

The last thing that we compared was the volumetric measurement apparatus; plastic syringe, and glass pipette. We found that the graphs between the intensity of blue color and volume of KSCN from those two apparatus could be used correctly for the limiting reagent determination. So in the deficient scientific equipment school, the plastic syringe can be used instead of the more expensive pipette in this experimental kit. The foam platform made from 15x15 cm foam and covered with the white paper was used for cuvettes holding. The working step of the developed limiting reagent experimental kit using a smartphone was showed in Figure 4.

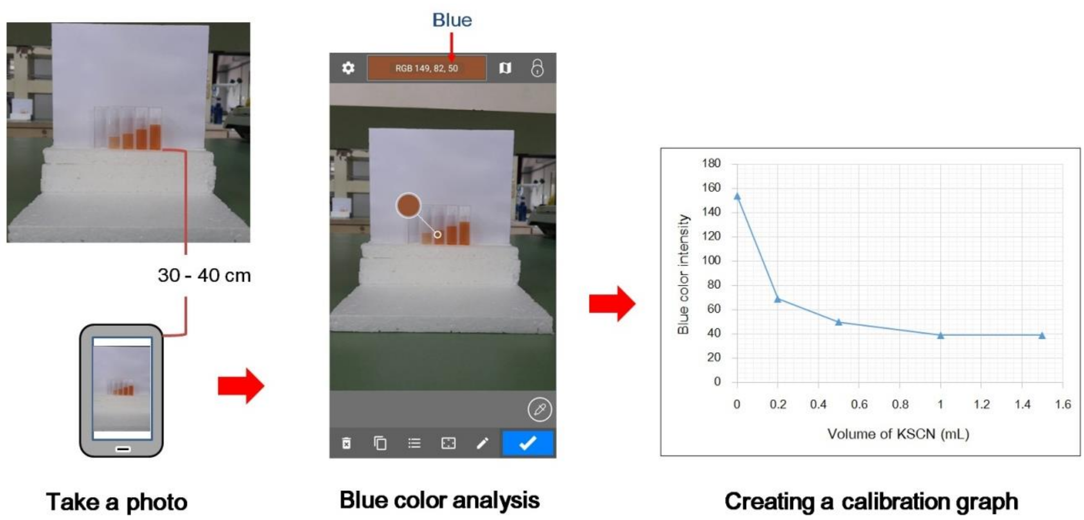
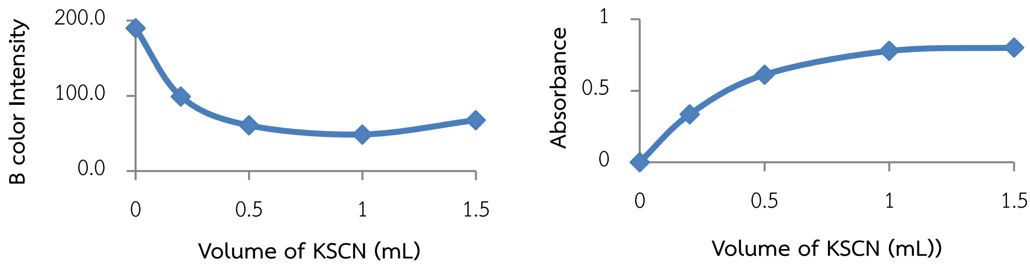


Figure 4. The working step of the developed stoichiometric experimental kit

After all conditions were optimized, the experimental kit was efficiency tested by the first year undergraduate students from chemistry department. Fifty percent of the graphs plotted by the students showed constantly line at a correct point from 1.0 mL of KSCN onward while some of them showed shifted up line at the end volume of KSCN as shown in Figure 5(a).To find out the cause of this problem, we rechecked the absorbance of the $FeSCN^{2+}$ from the same solution by using UV-Visible spectrophotometer at 468 nm. Contrarily, the graph plotted between the absorbance of $FeSCN^{2+}$ and the volume of KSCN showed constant line from 1.0 mL to the end volume as in Figure 5(b). This result presented that the problem was not base on the incorrect amount of reactants solution beceause of the absorbance of $FeSCN^{2+}$ at the end point did not dip down opposite to the blue color. Thus this problem mightdue to the external factor such as the shadow from the picture capture which effect to low quality of the picture and incorrectly indentify the intensity of blue color.We tried to improve this shadow problem by covering two sides with foam that could be control illumination as shown in Figure 6.



(a) (b)

Figure 5.(a) The graph between the intensity of blue color of $FeSCN^{2+}$ and KSCN volume (b) The graph between the absorbance of $FeSCN^{2+}$ and KSCN volume from the same solution

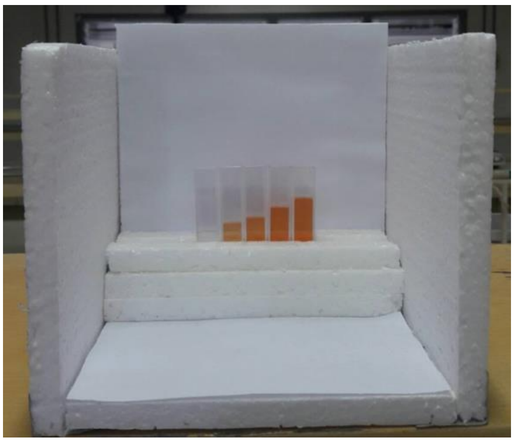


Figure 6. The limitting reagent experimental kit using the new platform

The efficiency of developed kit was measured again with twenty six of undergraduate students from general science education major. The graphs plotted by the second group students (80%) showed higher correctly constant line at a correct point more than the first test group (50%) and those graphs could be used for the limiting determination. Moreover, the overall mean of the student learning satisfaction of the second group was 4.05 ± 0.28 which indicated that students were very satisfied learning with the limiting experimental kit. However, the student learning satisfaction of this limiting reagent experimental kit using a smartphone is lower than the learning satisfaction of the kit using precipitation method that we recently developed (Boonmee, Pachain, & Suwancharoen, 2017, p. 51-63). But to improve the technology skill for the new generation student, this smartphone experimental kit is the one of good choices which can engage the student to enjoy the limiting reagent study.

Recommendation from research finding and for further study

To reduce the error volume from plastic syringe, the air bubble in syringe need to be removed by pushing up and down the syringe several times in the solution before use. The volumetric pipette can be used instead plastic pipette for scientific glass ware skill learning.

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