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Data Pooling of Three Chemistry Experiments: Measuring the Density of Ethanol and Copper, Determining the Molecular Weight of Isopropyl Alcohol and the Chemical Formula of Copper (II) Sulfate Pentahydrate

Dong-Jin Kim

Jowon High School, Suwon-si,
Gyeonggi-do, Republic of Korea
sunjinandsojin@hanmail.net

Kuk-Tae Park

Department of Chemistry Education
Korea National University of Education
Chungcheongbuk-do, Republic of Korea
ktpark@knue.ac.kr

Abstract: *This study was analyzed the data and the results acquired by the gifted science students in three chemistry experiments performed during the 1st semesters of 2005 and 2006. The three chemistry experiments involved measuring the density of ethanol and copper, determining the molecular weight of isopropyl alcohol by ideal gas equation, and determining the chemical formula of copper (II) sulfate pentahydrate. The gifted science students' experimental data pooling from the three chemistry experiments indicate that determining the molecular weight of isopropyl alcohol by ideal gas equation has a higher range of percentage errors than measuring the density of ethanol and copper. The difference in standard deviation for determination of molecular weights of isopropyl alcohol was larger than the other experiments because of diverse variables including temperature, pressure, volume, and weight. These findings led us to conclude that by accumulating the gifted science students' data annually, chemistry teachers can better challenge gifted science students to think logically, analyze errors, create solutions, and interpret their resulting data.*

Keywords: *Chemistry Experiment, Gifted Science Student, Density, Ethanol, Copper, Molecular Weight, Isopropyl Alcohol, Chemical Formula, Copper (II) Sulfate Pentahydrate*

1. INTRODUCTION

Although some question whether chemistry is in fact a laboratory science today, its initial acceptance into college and secondary school curricula owed much to the use of laboratory experimental work (Hawkes, 2004a; Hawkes, 2005; Sheppard and Robbins, 2006). Laboratory-based sciences, such as chemistry, were claimed to be the educational equivalent of more traditional subjects, and they should be included in high school curricula (Sheppard and Robbins, 2006). A well-constructed laboratory course can provide an opportunity to learn how to keep accurate records of results in a research-type notebook; how to write intelligible, cogent reports of the results; and how to practice critical thinking through evaluation of experimental data (Hawkes, 2005).

If the purposes of chemistry laboratory experiments are to calculate the error of experimental results and interpret the results, the well-kept laboratory notebooks provide complete, accurate records of ongoing laboratory experimental work. Many high school students do not know how to prepare adequately for their chemistry laboratory experiments, and so their work in the laboratory is often more time consuming and less rewarding and instructive than it should be. Many laboratory experiments include a pre-laboratory section to make sure that preparations are correctly made (Beall and Trimbur, 2001). Laboratory notebooks are vehicles for organizing and focusing the thinking of the students, as well as being the receptacles for detailed procedural information that might not be available in highly compressed journal articles. Laboratory notebooks are a record of success and failure, a safeguard against error and carelessness in such important areas as the testing of drugs and chemicals (Eisenberg, 1982).

Students believe that the classroom chemistry experiment is fundamentally different from a research or industrial laboratory. This difference is so significant that it carries over into students' perceptions of dishonesty in these two environments (Del Carlo and Bonder, 2004). Many of the students in an introductory chemistry class at their institution manipulated or made up data sometimes, often, or almost always (Lawson *et al*., 1999). This high percentage is attributed to the prevalence of cookbook, or verification, laboratory experiments where the right answer is commonly provided by the experiment and students are rewarded for obtaining it. Chemistry educators suggest that replacing the verification laboratory experiments with inquiry-based laboratory experiments would reduce the manipulation of data because inquiry labs do not provide answers up front. Also, students' perceptions of group laboratory experimental work and written laboratory experimental work influence their decisions of whether to copy another's work or let others copy their work (Del Carlo *et al*., 2006; Kim *et al*., 2014).

“Scientific method” is a course in which an empirical endeavor employs controlled experiments, quantifiable measurements, logical inferences, and testable hypotheses (Giunta, 1998; Giunta, 2001). Data-pooling of chemistry experiments has the advantage of a database that allows the student researchers to examine different aspects of the experiment (Herrick *et al*., 1999). Science high school students in Korea study sciences and mathematics mainly. Two consecutive hours per week of chemistry experiments is devoted to doing the lab, error analysis, interpretation of the results, discussions of the lab’s improvements. The same chemistry experiments are performed every year. Therefore, the chemistry teacher needs to apply the error of chemistry laboratory experimental results, interpretation of the results, and the improvements made for the lab to the annual curriculum of chemistry laboratory experiment. The purpose of this study is to analyze the contents of data-pooled from three chemistry experiments conducted by gifted science students in the first semester of 2005 and 2006 and defines the nature of problems that students encounter in the experiments.

2. EXPERIMENTAL DESIGN

Approximately two hundred 11th grade (age range 16-17) gifted science students attending Gyeonggi Science High School at Suwon, Korea participated in our experiment. The Gyeonggi Science High School is for gifted students especially talented in mathematics and sciences. After graduation, most of them go to engineering schools at Seoul National University, KAIST, Postech and other prestigious universities in Korea and in other countries, and some of them choose medical schools in Korea. Gifted science students thus form a substantial minority of around 1% in the total student population (Um, 2007; Kim *et al*, 2009; Lang *et al*., 2005).

Participants are divided into 2-4 member groups of 11th grade students. All the students enrolled in the chemistry experiment class, which meet two consecutive hours per week, complete four laboratory experimental tasks as part of their semester coursework. The students, working in groups, completed the experiment, and-wrote a group report at the end of the 1st semester of 2005. During the first semester of 2006, however, the students, working in groups, wrote an individual pre-report and post-report in their chemistry experiment laboratory notebook. From several experiments conducted by gifted science students in the first semesters of 2005 and 2006, three chemistry labs that used the same materials were selected. Experimental methods for the measurement of density of a metal, the molecular weight of a volatile liquid, and the chemical formula of copper (II) sulfate were available in most laboratory manuals for general chemistry.

The three chemistry experiments include (1) measuring the density of ethanol (95%) and copper (copper shot of 99.9% purity), (2) determining the molecular weight of isopropyl alcohol (99.9%) by ideal gas equation, and (3) determining the chemical formula of copper (II) sulfate pentahydrate (99%). Reagents were purchased from Duksan Pure Chemical Co. Ltd. Apparatus used in the three chemical experiments are shown in Table 1.

Table1. *Apparatus for chemical experiments*

Physical value	Measuring apparatus
Mass	Electric balance (Adventurer TM OHAUS Corp, USA) Readability: 0.001 g
Volume	Volumetric pipette 10 mL (OMG, KOREA) Readability: 0.1 mL (±0.05) Graduated cylinder 10 mL (OMG, KOREA) Readability: 0.1 mL
Atmospheric pressure	BA116 Digital 4 Line Barometer (USA) Atmospheric pressure mbar, hPa, inch Hg (switchable)

3. Results and Discussion

The data from the three chemistry experiments conducted in the first semesters of 2005 and 2006 by gifted science students were analyzed. The three chemistry experiments measured the density of ethanol and copper, determined the molecular weights of isopropyl alcohol by ideal gas equation, and determined the chemical formula of copper (II) sulfate pentahydrate. Conducted in the 1st semesters of 2005 and 2006, each chemistry experiment was altered to include error counters on each type of error. The theoretical density of ethanol is 0.813 g/mL at 20℃ (Budavari, 2001; Lide, 2006).

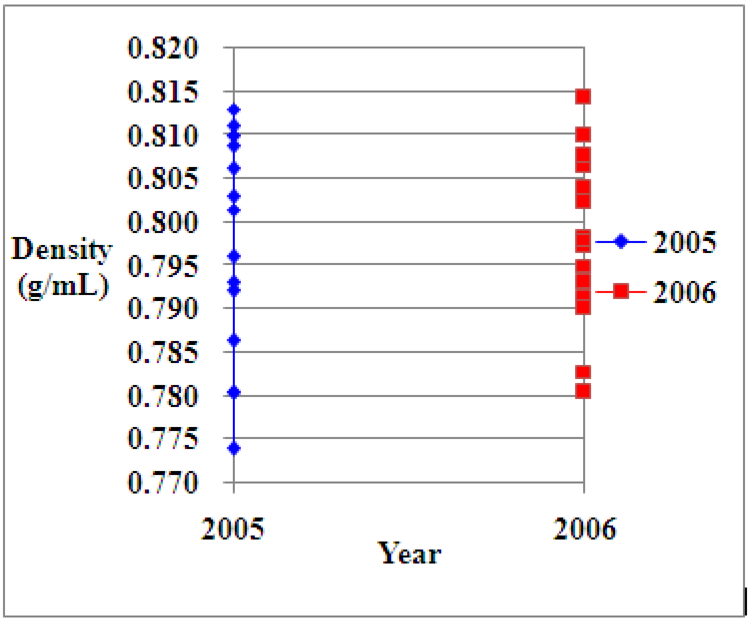

Fig1. *A graph of ethanol density data for 10 mL volumes measured in the 1st semester of the years 2005 (n = 15) and 2006 (n = 15).*

As shown in Figure 1, the experimental value range of ethanol density was 0.714~0.813 g/mL and the range of percentage errors was -0.422~-3.797% in the 1st semester of 2005. Depending on the approach to the laboratory, this experiment asked students at the outset to speculate on which method is expected to be most accurate and which most precise, giving reasons for their speculation. Their experimental results were compared to their expectations and possible explanations were given for any discrepancy (Jordan, 2007).

The experimental value range of ethanol density was 0.783~0.814 g/mL and the range of percentage errors was -0.656~-3.473% in the 1st semester of 2006. The range of percentage errors of ethanol density measured in the 1st semester of 2005 was slightly higher than the values in the 1st semester of 2006. In the data-pooling of the experimental results in measuring the density of ethanol, the range of error did not differ much between 2005 and 2006.

The theoretical density of copper is 8.94 g/cm^3 in the laboratory of measurement of copper density (Budavari, 2001; Lide, 2006). As shown in Figure 2, the experimental value range of copper density was 8.125~9.080 g/cm^3 and the range of percentage errors was -8.209~+0.831% in the 1st semester of

2005. The experimental value range of copper density was 5.241~9.925 g/cm^3 and the range of percentage errors was -22.397~+0.318% in the 1st semester of 2006.

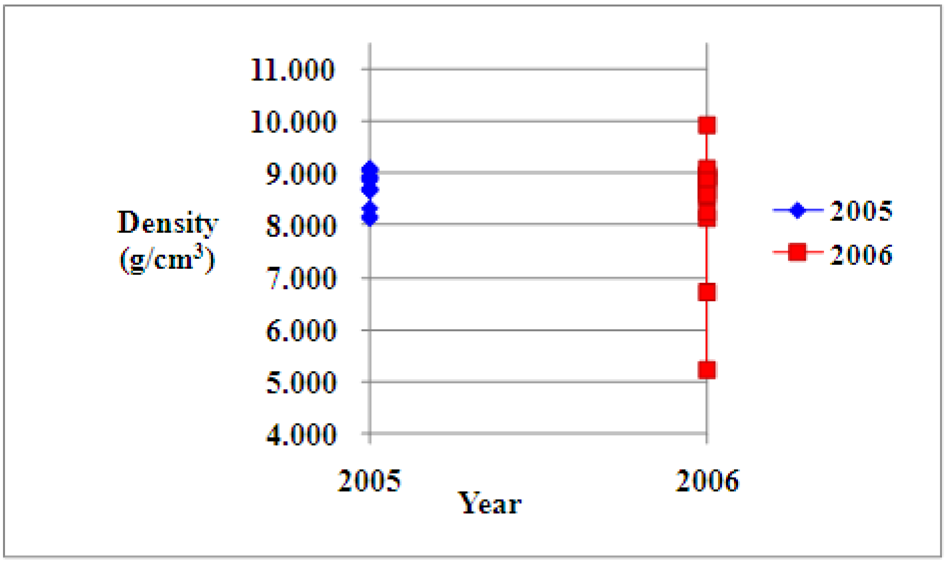

Fig2. *A graph of copper density measured in the 1st semester of the years the years 2005 (n = 15) and 2006 (n = 15).*

The range of percentage errors of copper density measured in the 1st semester of 2006 was broader by a narrow margin than the values in the 1st semester of 2005. The range of percentage errors of copper density measured in the 1st semester of 2006 was higher than the values of 1st semester in 2005. And measurement error range (-22.397~+0.831%) of the copper density experiment is greater than the margin of error range (-0.996~+2.477%) of the density of ethanol experiment of the 1st semester the years 2005 and 2006.

The absolute uncertainty of the electric balance is ±0.001 g and the volumetric pipette of 10 mL to ±0.05 mL and the smallest graduation of the graduated cylinder 10 mL is 0.1 mL. Gifted science students have observed in the copper density experiment one particular case in which a systematic error is revealed. The volume of water should have considered the fact that the systematic error was due to inaccurate recording by graduated cylinder volume and also due to the propagation of error with the determination of the volume of the copper by the displacement of water. In addition, air bubbles tend to cling to the copper metal. Unless the cylinder is tapped until the bubbles rise to the surface, the measured volume will be larger than it should be (Richardson and Teggin 1988). As an aspect of chemistry, the qualitative concept of density is at least as important as its calculation or measurement (Hawkes, 2004b).

The most important aspect of density experiment is that it successfully introduces students to the scientific method while teaching them important concepts and techniques (Herrick *et al.*, 1999). This laboratory exercise of interpretation of results and error analysis give gifted science students an opportunity to use high-level thinking skills in developing a plan to solve a problem. Gifted science students analyzed errors for determination of density (See Table 2).

Table2. *Examples of gifted science student error analyses for determination of density*

Example	Error analyses
1	Density values of the literature are at 20^{0}C of reference temperature. However, our data of density experiment was measured at 16^{0}C.
2	Due to the volatility of ethanol, the error occurs when the volume is measured.
3	When dealing with a piece of copper without using wet hand, the mass of the sample would be increased.
4	Improvements of density experiments, we consider to dealing with a piece of metal tweezers or use a spoon. And we must have removed water of copper sample.

The theoretical molecular weight of isopropyl alcohol is 60.09 g/mol in the laboratory of determination of molecular weights of isopropyl alcohol by ideal gas equation (Budavari, 2001; Lide, 2006).

As shown in Figure 3, the experimental value range of molecular weights of isopropyl alcohol was 56.90~96.66 g/mol and the range of percentage errors was -0.316~+60.859% in the 1st semester of 2005. The experimental value range of molecular weights of isopropyl alcohol was 52.20~64.30 g/mol, and the range of percentage errors was -4.699~+6.618% in the 1st semester of 2006. The range of percentage errors of molecular weights of isopropyl alcohol measured in the 1st semester of 2005 was higher than the values 1st semester in 2006. Two out of three groups of 2005 gifted science students performed the experiment only once, which caused the large range of percentage errors in their random error effects.

On the other hand, the gifted science students could reduce the random error in the first semester of 2006 because they performed the experiment three times. The range of percentage errors was generally higher in the determination of the molar mass of the liquid (Coffin, 1993). Gifted science students with large errors in their data are expected to repeat the experiment to improve the accuracy of their measurements.

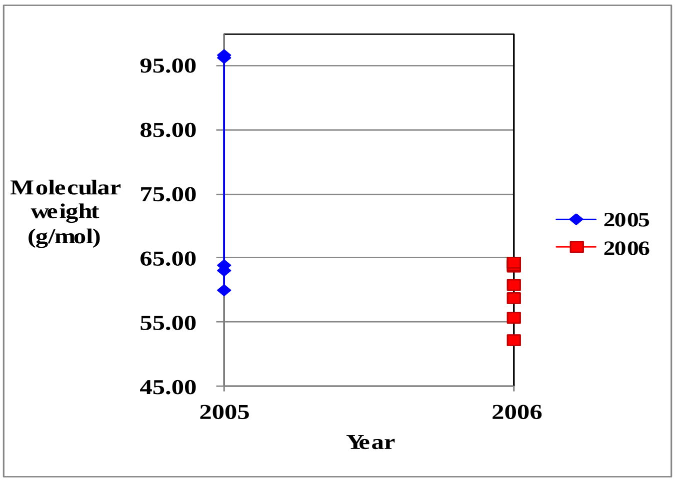

Fig3. *A graph of determination of molecular weights of isopropyl alcohol measured in the 1st semester of the years 2005 (n = 5) and 2006 (n = 8).*

The range of percentage errors of molecular weights calculated in the experiment of determining molecular weights of isopropyl alcohol measured at 1st semester in 2005 and 2006 are somewhat higher than the range -5~+2% (57±2 g/mol) in the determination of molecular weights of butane (Davenport, 1976). In a simple experiment of determining molecular weights gases lighter than air, such as hydrogen, helium, methane, the results were within 1-3% of the true molecular weight of the gas being determined (Lieu and Kalbus, 2002). Because the gas in the butane fueled lighter is not pure, the butane's molecular weight may be as low as 22% (45 g/mol) (Shakhasshiri, 1985). For the investigation of isopropyl alcohol purity, using GC-MS, the volatile liquid was composed of 99.96% of isopropyl alcohol and 0.04% of 1-propanol.

The percentage error in measuring the molecular weights of isopropyl alcohol is attributed to the assumptions used in measuring the volume, pressure, temperature, and mass. The first assumption is that the flask volume is identical to the isopropyl gas's volume, and secondly, the pressure of the vapor is equal to the atmospheric pressure (Shakhasshiri, 1985; Paul *et al*., 2009).

The third assumption is that the temperature in the system of the Erlenmeyer flask is the same as the temperature in the surrounding water bath. Because the flask was not completely immersed in the surrounding water bath, some gifted science student tried to measure the temperature of the gas by inserting a thermometer directly into the system of the Erlenmeyer flask (See Table 3).

The temperature in the surrounding water bath may be conveniently measured by a thermometer in the water bath rather than inserting a temperature probe into the system, which might disturb the system (Paul *et al*., 2009). So, some gifted science students suggested using the Dumas flask that has a small opening at the end of a narrow tubular neck (See Table 3).

Table3. *Examples of gifted science student error analyses for determination of molecular weights of isopropyl alcohol*

Example	Error analyses
1	The temperature of gas in the flask was estimated by inserting a temperature probe into the flask. Because the thermometer probe made large hole in the center of aluminum foil over the mouth of the flask, isopropyl alcohol vapor could escape into large hole and air could still remained.
2	Because the flask entirely did not immersed in the surrounding water bath, the temperature in the system of the Erlenmeyer flask is not the same as the temperature in the surrounding water bath.
3	Since isopropyl alcohol vapor cooled near the neck of the flask, all liquid did not vaporized at water bath temperature above 90℃. Therefore, short-necked flask will be available to vaporize the volatile liquid.

The forth assumption is, in regards to the mass of the gas in the system, that (i) all the gas vaporizes, (ii) all the gas (from the volatile liquid) condenses, and (iii) the container has only the gas from the volatile liquid. If the last two assumptions are invalid, then there would be an underestimation of the amount of gas in the system.

On the other hand, the first assumption may be invalid, for example, the investigator may prematurely begin to condense the gas, which leads to an overestimation of the amount of gas in the system. The potential errors would be an underestimation of the pressure and temperature in the system and an ambiguous situation regarding the mass of the gas in the system; thereby producing an indeterminate error in the determination of the molecular weight of the gas using such assumptions (Paul *et al*., 2009).

Theoretical hydrated moles of copper (II) sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) is 5 moles in the laboratory of determination of chemical formula of copper (II) sulfate pentahydrate (Budavari, 2001). The standard heat of hydration of copper (II) sulfate, $\Delta H^0{}_{hyd,}$ is -78.6 kJ/mol (Shakhasshiri, 1989). It decomposes before melting, losing two water molecules at 30℃, followed by two more at 110℃ and the final water molecule at 250℃. Because copper (II) sulfate pentahydrate slowly effloresces in air, it is required to keep it with other chemicals in a cool and dry storage location (Budavari, 2001; Young, 2002).

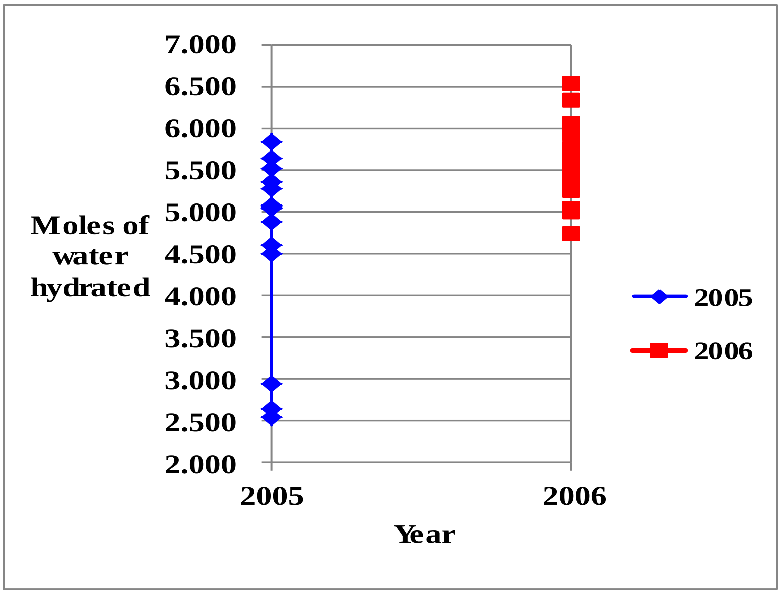

Fig4. *A graph of determination chemical formula of copper (II) sulfate pentahydrate in the 1st semester of the years 2005 (n = 15) and 2006 (n = 15).*

As shown in Figure 4, the experimental value range of hydrated moles of copper (II) sulfate pentahydrate was 5.850~2.550 moles and the range of percentage errors was -45.800~+9.400% in the 1st semester of 2005. The experimental value range of hydrated moles of copper (II) sulfate pentahydrate was 4.747~6.547 moles and the range of percentage errors was +0.513~+24.319% in the 1st semester of 2006. The range of percentage errors of the laboratory of measurement of hydrated moles of copper (II) sulfate pentahydrate was higher than the values of the laboratory of measurement of ethanol and copper density in 2005 and 2006, and it was higher than the values of the laboratory of measurement of molecular weights of isopropyl alcohol in 2006.

The experimental error on hydrated moles of copper (II) sulfate pentahydrate is attributed to its decomposition into copper (II) sulfate (See Table 4). The color of copper (II) sulfate losing five water molecules did not turn grayish-white entirely. Its blue color is due to water of hydration. The ignition temperature of butane gas is 287℃ (Lide, 2006).

Consumer air butane torches are often claimed to develop flame temperatures up to approximately 1400℃, but experimental difficulties arise since little or no control of the heat source (usually an open flame) is maintained. Some of the copper (II) sulfate pentahydrate remained in the light-blue powder. Errors obtained are often due to some decomposition of the anhydrous salt to copper (II) oxide and sulfur trioxide (Harris and Kalbus, 1979).

Table4. *Examples of gifted science students' error analyses for determination of chemical formula of copper (II) sulfate pentahydrate*

Example	Error analyses
1	When the copper (II) sulfate pentahydrate was heated, some of copper (II) sulfate pentahydrate remained into light-blue powder. So, color of copper (II) sulfate losing five water molecules entirely did not turn grayish-white.
2	When the copper (II) sulfate pentahydrate was heated in the crucible, the under layer material could not dehydrated.
3	The heating crucible would be placed in an oven for good dehydration.

The standard deviations of three chemistry experiment are expressed as the resulting range of percentage errors made by the gifted science students in Table 5.

Table5. *Mean and standard deviations measured three chemistry experiments in the 1st semester of the years 2005 and 2006*

Experiment	Theoretical value	Year	Experimental value	
			Average	Standard Deviation
Density of ethanol	0.813 g/mL	2005	0.798 g/mL	0.013 g/mL
		2006	0.798 g/mL	0.01 g/mL
Density of copper	8.94 g/cm^3	2005	8.736 g/cm^3	0.31 g/cm^3
		2006	8.441 g/cm^3	1.115 g/cm^3
Molecular weight of isopropyl alcohol	60.10 g/mol	2005	75.96 g/mol	18.81 g/mol
		2006	61.26 g/mol	5.005 g/mol
Moles of hydrated in $CuSO_4$	5 moles	2005	4.688 moles	1.087 moles
		2006	5.572 moles	0.527 moles

The chemistry experimental procedure given above is a somewhat flexible way to accomplish the stated objective. These three chemistry experiments give students an opportunity to use higher-level thinking skills in developing a plan to solve a problem or to improve the laboratory experiment (Samsa, 1993). In the final column of Table 5, the number of percentage errors per calculation, adjusted as described above, allows the comparisons among different experiments. We used these resulting numbers to analyze the students' progress over the annual semester. The difference of standard deviation for determination of molecular weights of isopropyl alcohol was larger than the other experiments. Therefore, the experiment for determination of molecular weights of isopropyl alcohol must consider procedural assumptions of temperature, mass, volume, and pressure.

4. Conclusion

In the data-pooling of three chemistry experiments, the range of percentage errors of hydrated moles of copper (II) sulfate pentahydrate measured in the 1st semester of 2005 was smaller than the values of the 1st semester in 2006. The range of percentage errors of hydrated moles of copper (II) sulfate pentahydrate was higher than the values in the laboratories measuring ethanol and copper density in 2005 and 2006, and it was also higher than the range of percentage errors of molecular weights of isopropyl alcohol measured in 2006.

The range of percentage errors for the molecular weight of isopropyl alcohol was higher than the values of the other laboratory experiments. The high percentage error obtained may be due to measuring the temperature, pressure, volume, and machines used to obtain the molecular weight of isopropyl alcohol, or it may be due to the inaccurate assumption that the flask volume was identical to the gas's volume. In other words, the high percentage error may be due to many variables and error propagation in the resulting data. Therefore, the chemistry teacher must be aware that the percent error range will vary according to the variables.

Data-pooling of three chemistry experiments has several advantages over traditional laboratory teaching methods in which all the gifted science students perform the same experiments. The gifted science students' experimental data-pooling contributed to the students' understanding of the percent error range and the specific characteristics of the laboratory procedure. The most important advantage is the creation of a database that allows the gifted science students researchers to examine different aspects of the experiment, successfully introducing them to the scientific method while teaching them important concepts and techniques. The data-pooling project examined by this study has made good use of the chemistry experiments.

Note

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AUTHORS' BIOGRAPHY

Dr. Dong-Jin Kim is a Chemistry Teacher at Jowon High School, Republic of Korea. He received a Ph.D. degree in education, majored in integrated science education, Korea National University of Education. His research interest includes the development of teaching-learning program and scientific creativity for the gifted in science, inquiry experiment, experiment applying small-scale chemistry, and STEAM (science, technology, engineering, art, and mathematics) education.

Prof. Kuk-Tae PARK is an Emeritus Professor at Department of Chemistry Education, Korea National University of Education (KNUE). He served as Dean of Graduate School/Graduate School of Education/Graduate School of Educational Policy at KNUE. He joined the faculty at KNUE in 1985. He worked as a postdoctoral scholar at University of Michigan in U.S.A. and Queen's University in Canada. His research as a chemistry education professor focuses on the development of teaching-learning program and scientific creativity for the gifted in science, inquiry experiment, experiment applying small-scale chemistry, and kinetic study of organic reaction.