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Chemistry Students' Mathematics Ability and Their Understanding of Buffer Solution

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Abstract: Mathematics's role in solving chemical phenomena has been well known. Basic mathematical operations such as integral, logarithm and differentiations are the tools for communicating chemistry concepts. This paper describes the effect of chemistry students' mathematical ability on understanding buffer solutions. 56 First-year university chemistry students at a public University in Malang, East Java, taking basic chemistry modules involved in this study. The respondents participated on a voluntary basis after getting a piece of comprehensive information about the study. An equivalent basic mathematical skill test (BMST) and Buffer Solution Test (BST) was implemented for data collection. This study found a positive correlation between students' mathematical ability and success in answering relevant buffer solution questions. The contribution of mathematical knowledge in predicting chemistry students' success in answering relevant buffer solution questions was also essentially high.

Keywords: Calculus for chemistry; Chemical context; Mathematics for chemistry; Mathematics skill

Introduction

The hierarchy of chemistry concepts has been proven in some studies, such as how students' understanding of Lewis Structure, Molecular Geometry and symmetry are positively correlated (Habiddin et al., 2023). Knowledge of other disciplines, including mathematics, biology, physics and other relevant areas, is also essential for helping to understand and explain chemical phenomena. The scope of chemistry education research (CER) is intrinsically interdisciplinary and has traditionally drawn upon concepts, frameworks, and approaches from other disciplines, including anthropology, psychology, cognitive science, and science education in a broader sense (Bain et al., 2019). In order to facilitate the acquisition, comprehension, and application of mathematical and natural scientific concepts among students, educators commonly employ and integrate external knowledge representations (Kokkonen & Schalk, 2021).

Mathematics and chemistry are considered separate disciplines, but their relationship is absolutely significant (Vula & Berisha, 2022). Mathematics plays a crucial role in the physical sciences by providing a means to explain and represent various events. This role leads to the establishment of a distinctive connection between mathematics and disciplines like chemistry and physics (Rodriguez, Bain, et al., 2020). Mathematical concepts, specifically integral and differentiation, are fundamental for chemistry, particularly physical chemistry (Becker & Towns, 2012). Physical chemistry, one of the chemistry branches including chemical kinetics, applies mathematics and physics concepts to establish its principles (Atkins & Paula, 2010).

Mathematical ability is required to understand and apply the subject, specifically calculus. However, Hästö et al. (2019) stated that research focusing on the relationship between students' mathematical flexibility and their understanding of the related areas, including chemistry, has not been explored extensively. In many universities, chemistry students take a maths module

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that includes calculus in the first year. However, many students need help to apply their basic calculus knowledge to a chemical context (Hoban et al., 2013). Chemistry educators agree that many students experience difficulty with mathematics (Hoban et al., 2013). However, there is disagreement as to whether the difficulty is due to inadequate knowledge of mathematics or to an inability to transfer mathematical knowledge into a chemical context (Potgieter et al., 2008). Potgieter et al. (2008) found that the cause is rooted in students' lack of knowledge of mathematics rather than an inability to apply the knowledge. Meanwhile, Hewson (2011) stated that students' failure to translate mathematical knowledge to chemical behaviour is one of the reasons for this difficulty.

Students' proficiency in calculus is one factor that influences their performance in physical chemistry (Hahn & Polik, 2004; Nicoll & Francisco, 2001). However, both groups disagreed about the optimum number of mathematics modules students should take. Nicoll & Francisco (2001) stated that there is no relationship between the number of mathematics modules taken and students' performance in physical chemistry, while Hahn & Polik (2004) reported a positive correlation between the two factors.

Therefore, sufficient mathematics ability is required to learn and understand the subject of physical chemistry. This ability significantly determines students' proficiency in mastering chemical concepts (Hahn & Polik, 2004; Kozma et al., 2000; Kozma & Russell, 1997; Nicoll & Francisco, 2001). The vital role of mathematical knowledge in chemistry, particularly in quantitative methods, grows over time (Witten, 2005). In particular, Justi (2002) emphasises that physical chemistry topics such as chemical kinetics, chemical equilibrium, thermochemistry, thermodynamics and others require students to be skilled in transforming mathematical knowledge into chemical behaviour rather than only having knowledge in mathematics.

Although many chemistry educators have uncovered students' difficulties in implementing mathematical concepts into a chemical context (Hoban et al., 2013), mathematics and chemistry are still often taught as separate disciplines, and the relationship between both is rarely taken into account (Potgieter et al., 2008), particularly in many Indonesian universities. The buffer solution is covered in Basic Chemistry 2 for some Indonesian universities. It is challenging to master the concepts without sufficient mathematics operation skills (Istiana et al., 2015). For example, to carry out correctly a pH calculation of a solution, the ability in basic logarithms is a must (Hewson, 2011).

Chemistry topics with demanding mathematical operations, such as chemical kinetics and thermodynamics, have been an issue for many chemistry students. Our previous studies confirmed that mathematical errors were the source of students' difficulty or even unscientific understanding or misconception of chemical kinetics (Habiddin & Page, 2020, 2021, 2023) and chemistry in general (Williamson et al., 2020). Williamson et al. (2020) supported the idea that students do better in general chemistry classes when they have the knowledge and abilities to do well, including mathematical skills. Therefore, a growing demand is for increased support in facilitating students' practical application of mathematical knowledge and skills to many real-world contexts, including chemistry (Rodriguez, Bain, et al., 2020).

In many Indonesian universities, including Universitas Negeri Malang (UM), chemistry students have to take basic mathematics modules, and they are expected to be able to implement their mathematical knowledge into chemical behaviour. A structured policy regarding how to teach mathematics to chemistry students hasn't been established in Indonesian universities. These results will be used to develop a consideration in teaching mathematics subjects to chemistry students. The results can also be used to design a new policy regarding the interrelation between mathematics and chemistry department UM in teaching mathematical courses for chemistry students.

Method

This correlational study involved 56 chemistry education students of Universitas Negeri Malang from 3 classes, including 2019, 2020, and 2021. Two relevant sets of questions (Basic Mathematical Ability Test, BMAT, and Buffer Solution Test, BST). Knowledge required for answering the BMAT questions is employed for answering the relevant BST questions. Table 1 depicts the example of BMAT and BST questions.

Table 1. Examples of relevant BMAT and BST questions

BMAT	BST
Calculate the following operation: Log (3×10^3) = ……..	Calculate the pH of a buffer solution with CH_3COOH (*aq*) 1.0 M and 1.0 M of CH_3COONa! (Ka $CH_3COOH = 1.8 \times 10^{-5}$)

Students' answers to the BMAT and BST questions represent their basic mathematical ability and understanding of buffer solutions, respectively. The correlation between the two abilities was measured using the correlation product moment with a 95% confidence level. Assumption tests for product-moment correlation, including normality test using Kolmogorov-Smirnov and linearity test, were performed. The significant value for the normality test was 0.077 (> 0.05), confirming that the data are normally distributed. The same trend is also shown for the homogeneity test with a significant value of 0.166, which is also higher than 0.05. the linearity test demonstrated an F value of 1.574, which is < 1.574, inferring the linearity of the data.

The two instruments have also been validated before being applied for data collection. The validity of questions at the two instruments is provided in Table 2. With the degree of freedom (*df*) of 54, the r_{table} for this procedure at α = 0.050 is 0.2681. The table shows that all the questions are valid, with the validity index of each question higher than 0.2681.

Table 2. Validity indices of questions for the BMAT and BST instruments

	No	Validity index	Sig. (2-tailed)	category
BMAT	1	0.282	0.035	Valid
	2	0.294	0.028	Valid
	3	0.328	0.013	Valid
	4	0.326	0.014	Valid
	5	0.580	0.000	Valid
BST	1	0.271	0.043	Valid
	2	0.372	0.005	Valid
	3	0.371	0.005	Valid
	4	0.422	0.001	Valid
	5	0.390	0.003	Valid
	6	0.288	0.031	Valid

Result and Discussion

The product-moment correlation test measured the correlation between students' mathematical ability and their understanding of buffer solutions. With the r_{test} (0.803) > r_{table} (0.268), or the significant values of 0.000 < 0.050, it confirmed that students' ability in basic mathematical operation correlated positively to their understanding of buffer solution. The correlation between students' mathematical knowledge and their ability in chemistry was also uncovered in previous studies (Merdekawati, 2013; Nursa'adah & Nurrahmah, 2019; Scott, 2012; Simanjuntak & Silitonga, 2020; Williamson et al., 2020). In a broader context, Korpershoek et al., 2015) found that Exam scores in mathematics, physics, and chemistry strongly correlated with mathematical and reading ability (the latter only in the pre-university track). In a broader context, Korpershoek et al. (2015) revealed a positive correlation between proficiency in mathematics and reading skills (limited to the pre-university track) and academic performance in mathematics, physics, and chemistry examinations.

Table 3. Linear regression test of students' mathematical ability and understanding of buffer solution

Model	R	R Square	Adjusted R Square	Std. The error in the Estimate
1	0.803[a]	0.645	0.638	2.6354

A linear regression test was performed to measure to what extent the mathematical ability affects the understanding of buffer solution. The outcome of the linear regression test is provided in Table 3. The *R-value* of 0.803 indicates a high degree of correlation between the two variables. The R^2 value of 0.645 represents that their mathematical ability can explain 64.5% of the total variation in students' understanding of buffer solutions. This percentage confirms the large influence of students' mathematical ability towards understanding buffer solutions. This contribution is higher than the one reported by Simanjuntak & Silitonga (2020) on the topic of salt hydrolysis, with 47.49% only.

In addition, the positive correlation between students' mathematical ability and their understanding of buffer solutions can be described from their answers to the relevant pair questions at BMAT and BST instruments.

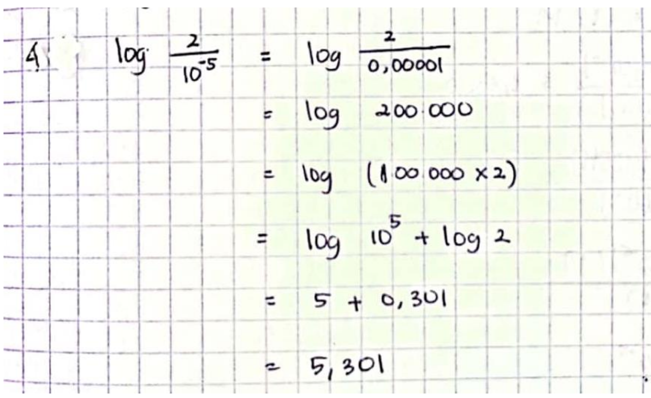

Figure 1. Example of a student's correct answer to BMAT Question

Figure 1 depicts an example of students' correct answers to BMAT questions. The student correctly carried out a basic logarithm question. The student then could also provide a correct answer to a relevant BST question, as presented in Figure 2. The student successfully applied their mathematical knowledge to answer the BST question. The pH of the CH_3COOH solution can be measured using the logarithm operation as required for answering the BMAT question in Figure 1.

A similar trend is also demonstrated when students incorrectly answer the BMAT question. They mostly end up also incorrectly answering the relevant BST questions. The failure of students in answering BST questions was mainly rooted in their inability to work with the required mathematical operation, as shown in Figure 3. The Figure demonstrates how a student failed to answer a simple basic mathematical calculation. A previous study found students' failure in dealing with simple and basic mathematical operations such as division and multiplication (Scott, 2012).

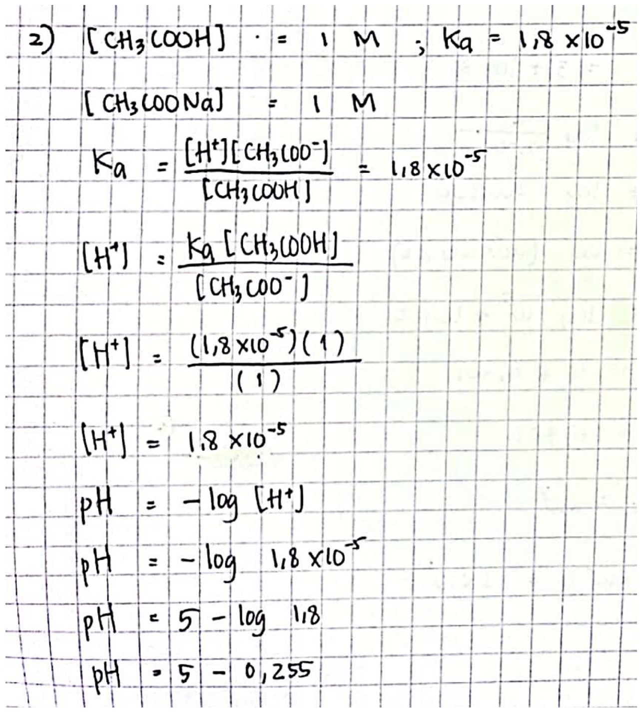

Figure 2. Example of the students' correct answer to BST Question

Another study (Rodriguez, Harrison, et al., 2020) demanded students construct a graphical representation illustrating the temporal variation of a rate. The students expressed that they possess constructive notions for comprehending the context. However, they require additional assistance in integrating these notions, highlighting their struggle in employing mathematical techniques to model chemical behaviours.

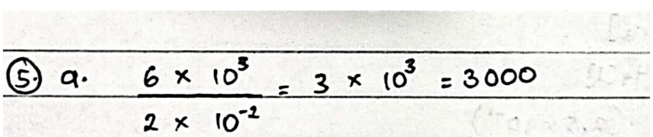

Figure 3. Example of a student's incorrect answer to BMAT Question

The result of this study implies that efforts to provide a novel and efficient approach to teaching mathematical knowledge to chemistry students are essential. Carlson (2022) introduced a novel methodology known as the "scale factor method" for resolving a range of stoichiometry quandaries. They discovered that the proposed method exhibited more extraordinary intuitiveness and achieved a better success rate than students employing the conventional dimension analysis strategy.

Conclusion

This study found a positive correlation between students' mathematical ability and their ability to answer buffer solution questions. Students who correctly answer a mathematical question are more likely to be able to apply the mathematical knowledge for answering a relevant buffer solution question, and vice versa. The contribution of students' mathematical ability towards their success in answering relevant buffer solution questions is relatively high, with 64.5%. This study also uncovered a surprising finding: some students failed to work with a simple mathematical operation. These results imply an increased necessity for the chemistry curriculum in higher education to emphasise the mathematical ability of chemistry students. In particular, how students implement mathematical knowledge in a chemical context is essential. Rodriguez et al. (2020) emphasised the need for more assistance in enabling students to effectively apply mathematical knowledge and skills to various real-world situations, such as chemistry, is steadily increasing. Students need to be able to reason using symbolic and graphical forms in order to successfully integrate chemistry and mathematics in a way that supports their knowledge of the chemical processes in chemical kinetics (Rodriguez et al., 2018).

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Author Contribution

Habiddin Habiddin conceptualised the idea of research, refining the data analysis, finalising the paper, translating, proofreading and submitting the article. Irene Lusita Nagol did data collection, data analysis and writing the initial draft of the article.

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Conflicts of Interest

We declare that there is no conflict of interest regarding of this work.

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