Do Prior Knowledge of Advanced Mathematics Influence Academic Confidence of Students Taking Pre-university Chemistry Courses

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Abstract
The relationship between Chemistry and Mathematics are directly proportional in the perspective of science, technology, engineering, and mathematics (STEM) education. This study investigates the relationship between prior advanced mathematical knowledge attained in high school could predict the outcome of student's overall confidence in studying Pre-University Chemistry courses. Mathematics is often perceived as a subject that bridges and connects scientific concepts including Chemistry. Most students, however, struggle with the transition from mathematics to chemistry due to wide disparities between the two theoretically but a very slim margin in terms of using mathematical applications into learning STEM subjects, particularly chemistry. This paper uses a mixed-method approach that involved quantitative surveys using questionnaires and selected qualitative interviews using Pre-University students as research samplings. Preliminary findings found positive significant correlation between students' mathematics background played indicative confidence levels in Pre-University Chemistry. Most participants agreed that good mathematical skills in high school play major role in shaping their confidence in Pre-University Chemistry including the integration of mathematical equations, algebra and certain calculus application would support their understanding within the chemical concepts and crucial for their overall understanding in the subject. This research findings also suggest that there is a need of a more integrated approach by educators in teaching mathematics and chemistry at high school level with primary emphasizing the interconnections between the two disciplines by providing sufficient support in order to enhance greater confidence and competence level.

Keywords: Chemistry, Confidence, Educational Assessment, Mathematics, Science Education

Introduction

This dissertation explores the importance of prior mathematic units taken by Pre-University students taking Chemistry as their core subject and how advanced mathematical skills can shape academic confidence and build learners' motivation in the build-up of challenging Chemistry program at different type of Pre-University courses offered around the world.

In my capacity as a Chemistry teacher in few International Schools that I have taught at both Upper Secondary and High School levels specialising in the British A-levels and also tutoring chemistry students from different Pre-University programmes background like the International Baccalaureate (IB), American Advance Placement (AP) and the Australian Year 11 and Year 12 High schoolers , I had witnessed many students regardless of curricula struggling to cope with the vast intensity of the subject's requirements; both theoretical and practical. One of it, is the demanding mathematical skills application in Chemistry.

Chemistry involves significant number of mathematical calculations which are important in daily practice of life (Tapia, 1996) particularly in areas such as stoichiometry, thermodynamics, and kinetics. Students having strong foundation in mathematical skills such as algebra, calculus and statistics would have an upper hand in applying such skills into chemistry. While prior mathematical knowledge is essential in doing well in STEM subjects in university, particularly Chemistry, but whether it is a mandatory knowledge remains to be seen in a larger scale.

The focus of this dissertation is to find out do prior advanced mathematical skills have any effect on the academic confidence and motivation of Pre-University students taking Chemistry particularly focusing on their subject strength and to address difficulties students would face during the entire duration of their pre-University programme. At the same time, I would also research on different Pre-University Chemistry curricula with the emphasis on its connection with prior mathematical skills requirements which could indirectly influenced one's confidence in studying Chemistry at Pre-University level. The impact of different Chemistry curricula on student's confidence and motivation has not been widely studied so my aim is to divulge more on this subject. My conceptual framework in this study is to connect the existing knowledge done and examine further on using my research question in this dissertation to explore additional possibilities. Few research findings have found that many students could still proceed to study Chemistry at higher tier without the needs of mathematics while some disagree with the ideology. Several researchers agreed that mathematics is just a tool but not primarily needed in doing great science subjects (Jogalekar, 2013). I aimed to challenge this statement and my research will explore how reliable are these scientific inquiries.

This dissertation also talks about how the evolution of mathematical chemistry and their relationships changed the landscape on how learners cope with the intensity of both subjects. The literature review also studies the vast differences of some popular Pre-University courses offered globally and their roles in preparing students especially on their readiness and confidence when comes to the topic on how the subject mathematics can be blended into learning Chemistry effectively and vice-versa. This is extremely important as one's academic success in the subject relies heavily on how one single subject could overlaps onto another and their jointly progression into one's learning journey. The synchronisations of both mathematics and chemistry are well documented in many research findings and this study is to acknowledge the theory but at the same time, I would challenge some concrete well-

documented inquiry and try to explore other contradictions between the two subjects. This research findings also involved the introduction and how different Pre-University curricula offered globally could differ from each other especially focusing on the research question on how advanced mathematical modules can be blended into students taking Chemistry as their core subject at Pre-University level, with the primary focus on learner's academic confidence.

Research Framework

This project explores the advantages of the utilisation of mixed methods principles by using both quantitative and qualitative techniques. The introduction of triangulation approach were made connection with the current research framework.

Two major Pre-University Chemistry courses were selected out of a few surveyed and a thorough analysis between the two and investigation from the data obtained conduct an overall conclusion from the study.

Academic confidence is one of few major factors needed to be addressed and placed emphasis by academic authorities to ensure students display their maximum potential in their chosen course or modules either at Pre-University or undergraduate level. A thorough connections between some Pre-University Chemistry courses would have a small leverage over some in terms of its teaching syllabus that could predict the outcome of academic confidence faced by learners.

The different Pre-University Chemistry courses taken by majority of students vary in breath, depth, and difficulty levels. Some are more demanding than others while some required sufficient coursework, laboratory work, internal assessments and active presentation hours before students can complete the course and proceed to undergraduate level. Despite the differences between all the curricula, apparently all Pre-University Chemistry courses have one major similarity: the paramount understanding of substantial mathematical knowledge as a pre-requisite to fully comprehend the scientific concepts in higher level Chemistry. The results generated from this study was made to show whether the need of advanced mathematics is required or could benefit wholesomely for students undertaking Pre-University Chemistry courses.

Lastly, this paper summarises and explains how this research can support and contrast research done by others as well as some recommendations that could add more quality for further study. The research question which investigates the relationships between both mathematics and chemistry provide many insights on the factors and major elements that curriculum designers can take considerations and find ways to improve students' overall confidence in studying and learning chemistry at a higher level. The main theoretical framework of this study explores how my research in this dissertation is intrinsically linked and supported by existing literature and my research methodology on the relevance between advanced mathematics and Pre-University chemistry courses on various learners.

In short, my direction of this study is clear. I want to explore the significant impact on students' confidence levels when they study Chemistry as a Pre-University subject with the emphasis on which course provides a higher confidence threshold for high school learners. I have witnessed many students struggle to cope with the intensity and demand of the syllabus due to the requirements of mathematical skills and I aim to delve into this analogy, as well

finding ways to overcome this fear. As a high school Chemistry teacher, I hope I could find ways to provide adequate opportunities for my learners to maximise their potential by strengthening their mathematics skills to enhance their ability in succeeding learning Chemistry eventually.

Methodology

This study involves the experimentation of using questionnaire as my primary research findings. The main objectives mainly involved the research question on how or can prior advance mathematics skills could enhance academic confidence in high school students using different Pre-U Chemistry syllabi as responding variables. I will measure the data and aim to understand the responses from the pre-selected focus group which represents a subset of the general population of high school learners. The experimental methods used in this dissertation involved a random combined sampling method where questionnaire is designed to target a certain age-group population irrespective of genders. The sampling techniques are made to be a mixture of stratified and cluster whereby the ensuring of a particular category is represented in the sampling process (Voxco Insights, 2021) and clustering allowing only individuals in selected geographical locations namely in the Oceanic continent (Australia & New Zealand), North Americas, Asia, and Europe. In this case, this cluster sample are mainly targeting only students pursuing Pre-University Chemistry studies from the listed countries. Data collected in this survey is considered as non-experimental as my observation in the data obtained were merely based on *in-situ* information without an independent variable. As for the focus group of participants, students were selected in the age-group range of between 16-19 years old, and they represent a large majority of students undertaking Pre-University Chemistry courses before embarking in their respective undergraduate courses, mainly STEM modules in university upon graduating from high school. The selected participants came from different ethnic backgrounds at different geographical locations at different continents around the world. The racial profiling issue are strictly excluded in this study and individuals who take part in this questionnaire were not asked to reveal their racial identity to ensure maximum anonymity.

A questionnaire was carefully designed with a series of specific questions to evaluate students' responses over their thoughts and academic confidence in taking prior advance mathematics in high school and the connectivity with their ability in tackling Pre-University chemistry at the same time. My questionnaire has a research question title that was designed to be short but comprehensive. Questions mainly constituted of a series of four-fold Likert Scale modelling so that I could easily gather large amounts of data (Nemoto & Beglar, 2014) which comprised like *strongly agree*, *agree*, *somewhat*, and *do not agree,* ticking boxes and few numerical number choices of design using Semantic differential scales system of *1-5* numbering (The NIHR RDS for East Midlands/Yorkshire & the Humber, 2009) to collect respondents' responses on the specific question asked. There were also few *yes*, *true,* or *false* patterns which represent dichotomous questions type. In all, I kept the questionnaire's questions simple and easy to understand and avoiding ambiguous words are my priority. The use of complicated jargons and acronyms are eliminated (Sauro, 2021), and the questions are made to suit my respondents' vocabulary. Participants do not have to reveal their name to maintain confidentiality but providing an email address was made an option.

Questionnaire was made and distributed via google form application and were sent to participants in three (3) different channels:

a) *Students I am currently tutoring which constitute different Pre-University Chemistry curricula namely, the A-Level, IB, AP, and the Australian ATAR programme.*
b) *Students undertaking Pre-University Chemistry in selected registered member-only certain social media platform like Facebook.*
c) *Through my personal LinkedIn account that has a specific category which only involves individuals with certain engagement in tertiary Chemistry studies that made up of student-researchers as well as passionate Chemistry educators globally.*

Students in the first channel where I am currently tutoring were reminded to take part in the survey by clicking a link provided by the google form application. Meanwhile, for the two other channels which are the Facebook group and LinkedIn Chemistry group, I sent few reminders after asking the post administrator's permission with the intention of getting regular and consistent responses after dissemination and brief explanation of my research objectives in the group forum.

At the same time, few students were also randomly selected from the group for a face-to-face interview via online innovative communication technologies. I have chosen the videoconferencing platform, Zoom, to evaluate, select and provide a coherent data analysis (Archibald, Ambagtsheer, et al., 2019) from the questionnaire and see its correlation with the research question with the emphasis on the respondents' overall academic confidence and educational progress. This interview would be my secondary data source where I get to listen and do calculative observations on my respondents. After that, interpretation will take place from current existing studies. As for the quantitative analysis, my survey questionnaires are mostly made up of fixed and close-ended questions, thereby, using another alternative tool like videoconferencing would be beneficial to some respondents who prefers to reply at certain length. Zoom videoconferencing tool was selected due to its popularity and students' familiarity. The students were carefully chosen with the priority of their identities being made unknown and anonymity labelled. I chose interview as another platform of generation of qualitative research data because it provides rich source of information from a small group of interviewees point of view. Data collection using Interview methodology comprised of both structured and unstructured (Dovetail, 2023) where there is significant difference. The first-hand collection of data directly from primary source is as important as secondary data which relies from previously gathered resources (Clements, 2021). The current research trends have also demonstrated the reliability and convenience of collecting qualitative data using videoconferencing methodology (Archibald et al., 2019b). At the same time, interview provides my respondents their own viewpoint which has an open-ended question style whereby questionnaires are merely strictly closed questions which could inhibit the choices of respondents due to its limited choices (Mather, Fox & Hunn, 2009).

The first method where questionnaire was produced and distributed to the public were selected on random basis. As mentioned in the research design methodology, respondents came from different background and ethnic races. Students currently pursuing a course in Pre-University studies are targeted. The focus of attention here are the 4 major Pre-University courses researched in this study. This *sampling frame* from the earmarked population were adopted (NIHR Research Design for East Midlands, 2007) and carried out systematically. The students are also expected to take Chemistry as one of their core modules and have already finished high school in their respective countries, preferably taken advanced mathematics modules prior studying Chemistry at Pre-University level.

The Australian High School participants are expected to have completed their Year 10 prior to this survey. The IGCSE (International General Certificate of Secondary School Education) is the British Key Stage 3 equivalent and the MYP (Middle Year Programme) are some of the other completed courses from the British GCE A-Level and IB participants respectively. Meanwhile, the AP students taking part in the questionnaire are expected to have either completed their Grade 9 or lower secondary at school prior taking part in this study.

Participants are mainly drawn from the target population which corresponds to their interest in partaking this survey. Their identity will be kept anonymous and confidential with only their email addresses visible to the researcher. I strictly followed the 2018 General Data Protection Regulation (GDPR) where researchers conducting studies involving human participants will have responsibility of protecting the privacy of their respondents (Ryerson University, 2015). In an event where certain qualitative data are needed in my studies, I conducted a Zoom videoconferencing interview with my participants, therefore a letter of consent was generated for the students for their approval so that my respondents are aware of their anonymity rights are preserved in this paper investigation. I also aimed to maintain a researcher's bias-neutrality in my face-to-face interview by eliminating my own preferences and the data generated from the Zoom interview were compiled together with my questionnaire to summarise a final evaluation and conclusion at the end of this study. The main objective of this mixed-method study is to obtain a richer and hopefully, more comprehensive conclusion in this research study. My initial methodology of obtaining a rather larger sampling size is to reduce margin of error as I have expected not all my respondents that take part in my questionnaire will respond sensibly or there will be some form of existence of bias respondents which may provide inaccurate responses.

However, after some brain storming, I have decided to cap my respondent's quotas to a maximum of around 60-70, if desirable. I felt that response rates are a crucial factor that needed to be addressed by researchers. This is to ensure the quality and the outcome of the survey can be analysed accordingly at the end of this dissertation. Several studies have also conducted on the correlation between the number of questionnaires and the number of participants, including the length of the questionnaires. There were studies that found that respondents are more likely to respond to a shorter version of questionnaire compared to a longer one (Koitsalu et al., 2018). Inversely, Bolt (2014) on the other hand found that the length of a long questionnaire played no significant role in improving response rate. And since designing a questionnaire requires time and valid purpose, my studies focused on only 9 major questions with the aim of not making my respondents losing interest during the answering process. Sample sizes are kept at an acceptable region and the topic of interest are maintained throughout the duration of the survey. Faryadi (2019) explores the quality of data and sample size is not directly correlates. A huge sample size need not be necessary to produce good data as less is more. In responding to the researchers who found that the length of the questionnaire plays significant role to the quality of answers provided by respondents, I found that the quality of the questions is more justifiable rather than the quantity of questions. Therefore, my study was designed to ask my respondents only what is related to my dissertation's research question to ensure a straightforward and explicit response from my participants.

Results

	Overall Percentile	Advance Placement (AP)	Australian High School	British A-Levels	International Baccalaureate (IB)
Total number of students/respondents, (N=58)		3	14	36	5
Found Mathematics are essential before taking Pre-U Chemistry	84.5%	66.7%	71.4%	88.9%	100%
Found good grades in Mathematics modules would boost academic confidence in Pre-U Chemistry	48.2%	66.7%	57.1%	66.7%	80%
Found Pre-U Chemistry course rather challenging	41.4%	66.7%	50.0%	41.7%	40%

Table 1: Result findings for four major Pre-University Chemistry courses

	British A- Level	Australian High School ATAR
Total Representation of students, N=50	36	14
High Mathematics Competency	27.8%	50%
High Chemistry Competency	13.9%	7.1%
Overall High Confidence Level for Mathematics but not Chemistry	27.8%	35.7%
Overall High Confidence Level for Chemistry but not Mathematics	5.6%	28.6%
Overall High Confidence Level for both Mathematics & Chemistry	52.8%	42.9%

Table 2: Two main Pre-University Chemistry courses were compared

	British A-Level	Australian High School ATAR
Number of Participants, N= 50	36	14
Number of students have intention of dropping Pre-U Chemistry	8	5
Overall Percentage Value	22.2%	35.7%

Table 3: Attrition rates for two major Pre-University Chemistry courses

Figure 1:

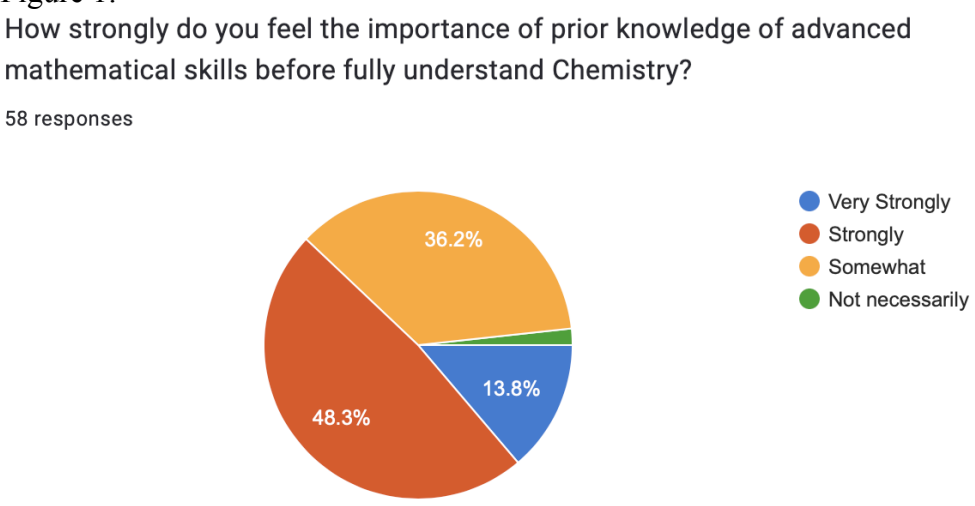


Figure 2:

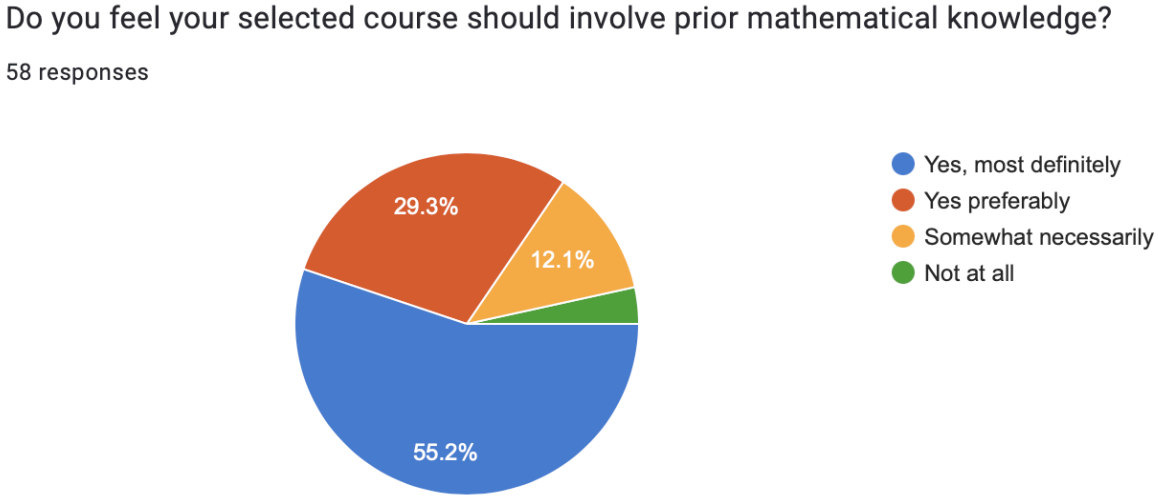


Figure 3:

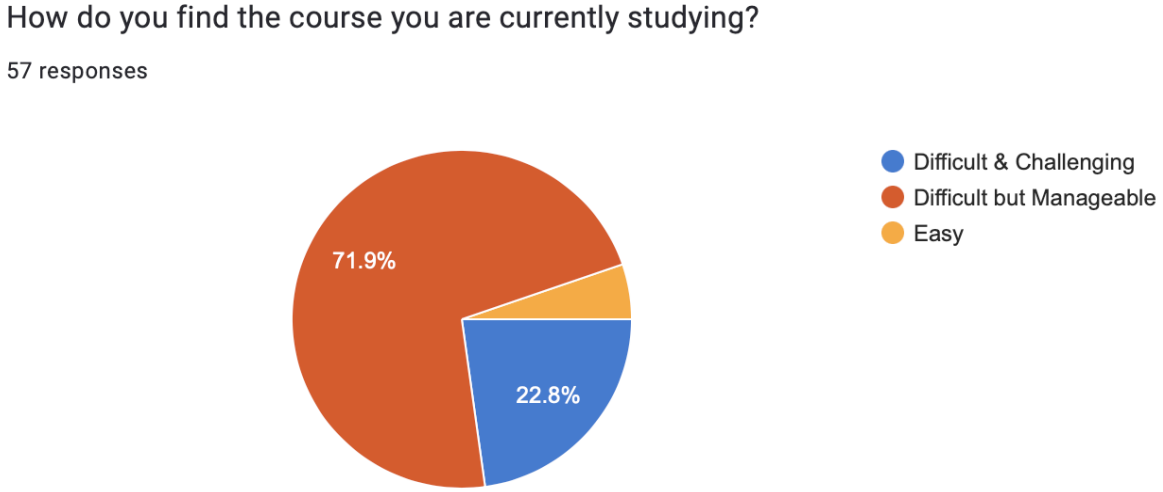
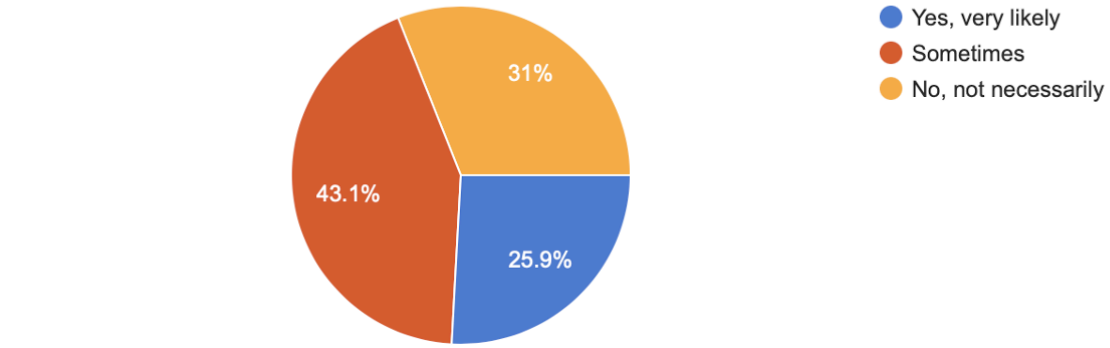


Figure 4:



Data Analysis

There is a total of 58 respondents took part in this study which comprises 4 major Pre-University Chemistry courses. Random sampling found that from most of the Pre-University courses, the British A-level appeared to be the most popular amongst all Pre-University students that took part in this survey and Advanced Placement (AP) the least, with both registering a total of 36 and 3 respectively.

The result from this questionnaire found that all International Baccalaureate (IB) students found mathematics modules are important at high school prior taking higher level Chemistry at Pre-University level. Overall, the result found that a whopping 84.5% of the respondents agreed that mathematics is essential but only 48.2% found that obtaining good grades in mathematics do not necessarily guarantee a good academic performance or overall academic confidence in Chemistry at Pre-University level. At the same time, most A-Level students surprisingly do not find Chemistry as daunting as it seems with only 41.7% of participants found their courses challenging. AP Chemistry students registered highest percentage for finding its syllabus rather difficult.

Pie charts were generated from the questionnaire and demonstrated extremely diversified data giving researcher different dimensions and angles and opportunity of more intensive analysis. Each category was analysed and reflection of the overall idea of each question asked in the questionnaire were summarised accordingly.

Most students agreed that the mathematical components are important where 55.2% concurred that prior advanced mathematical knowledge is necessary and another 29.3% agreed taking mathematics modules at high school is a preferable option before taking Pre-University Chemistry. However, there were slight disagreements between some respondents who felt that prior mathematical knowledge may or may not contribute to overall confidence whatsoever. The 3.4% representation might be insignificant but this also showed that some respondents do not fully agree that the correlation of mathematics and chemistry must be parallel to each other.

Most Chemistry students somewhat agreed that advanced mathematics plays significant role in fully understanding the in-depth theoretical concepts of Chemistry. A combined proportion of 62.1% of the population felt strongly on the importance of advanced mathematical skills prior to fully understand Chemistry. This is worthy of attention as for students to do well academically in STEM, chemistry in particular, the ability of one in mathematics does play a convincing role. On the other hand, there were also a rather large number of respondents in this study (36.2%), that felt that only 'somewhat' important for mathematics in relation to fully understand any chemical concepts.

Conclusion & Future Recommendations

After thorough analysis of this study, there is an indeed some common connections between mathematics and chemistry and its outcome of student's academic performances. We cannot disagree that the integration of advanced mathematics into the academic curriculum of chemistry students has a profound impact on their overall academic confidence. Advanced mathematics equips chemistry learners with the tools to approach complex chemical phenomena with precision and rigor. Both questionnaire and interview results shown students would develop better understanding in theoretical Pre-University Chemistry if they have prior advanced mathematics knowledge in high school. However, there are also conflicting responses from respondents from various Pre-University Chemistry courses studied in this research that do not agree with the original hypothesis. Nevertheless, students studying the British A-level programme yielded the highest confidence level in this study compared with 3 other courses, which indirectly answered the hypothesis of my research question in this study. Regardless of these circumstances, I still felt that both educators and relevant school management policy administrators should play crucial role in introducing effective bridging programs for students at secondary and high school level to minimise academic deficiencies between both mathematics and chemistry. Teachers must be able to disseminate key skills like confidence and resilience to students for our learners to develop greater motivation in both well-being as well as academic proficiency. The incorporation of advanced mathematics into the education of chemistry students is not merely a means to an end; it is actually a transformative experience that empowers students to explore the intricate realms of chemistry with more confidence and enthusiasm.

Further and more elaborate research methodology is needed to draw a more accurate conclusion judging from the data obtained from the respondents. Perhaps, a narrowed down Pre-University Chemistry course could be used rather than 4 other courses which are simply

different in their curricula and course expectations on students. At the same time, the sample size could be increased to a larger pool to minimise percentage error. A targeted demographic can be used as well rather than a random selection which may cause confusion at some point. A more detailed, specific, and more inclusive questions can be created in the questionnaire for easier interpreting of results. At the same time, I felt a more accurate triangulation research survey should also include researchers' methods of gathering information at the same time (concurrent design methodology) rather than sequential design (Molina-Azorin, 2016) where time lapse occurs. In addition, the objective of a research study also depends on how the interviews and surveys are done where one can precedes another. This has implications for curriculum development and educational strategies, emphasising the importance of mathematics education in chemistry programs to foster a positive collaboration and competence among future chemistry researchers.

Further research should explore the mechanisms underlying this relationship and investigate potential interventions to improve advance mathematical skills among Pre-University chemistry students.

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