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Development and evaluation of a re-sequenced intervention module in learning chemical bonding

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ABSTRACT

In the typical high school chemistry curriculum, chemical bonding precedes the chemical reactions. In this study, the re-sequenced effect of learning chemical bonding when chemical reactions are introduced first among grade 9 learners was investigated. A learning module with re-sequenced intervention in chemical bonding was developed using analysis, design, development, implementation, evaluation (ADDIE) model and validated by eight science education professionals rated as very satisfactory. A quasi-experimental research design was utilized in the implementation phase with 129 respondents selected through cluster random sampling. Pre- and post-tests, formative and summative assessments, and evaluation surveys were administered. Evaluation results revealed that the scores from the re-sequenced intervention group displayed a slightly higher overall satisfaction percentage (99.06%) compared to the control group (94.74%). In addition, the experimental group achieved significantly higher competency levels ($M=49.3$, $SD=19.4$) compared to the control group ($M=41.4$, $SD=15.3$), with $p=0.016$ and $d=0.37$. Furthermore, students reported positive perceptions despite initial misconceptions. These findings highlight that re-sequencing topic order enhances chemistry learning outcomes and student engagement. Hence, the re-sequenced learning module became a valuable tool for enhancing understanding of chemical bonding, independent of baseline competency or attitudes toward the material.

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1. INTRODUCTION

Chemical bonding and chemical reactions serve as fundamental concepts in high school chemistry. The conventional curriculum places emphasis on introducing chemical bonding prior to chemical reactions, under the assumption that comprehension of bonding is vital in order to grasp reaction mechanisms. Additionally, students' challenges with understanding chemical bonding concepts further underscore the significance of acquiring a solid foundation in bonding, as it facilitates the prediction and explanation of chemical properties [1]–[4]. The importance of considering students' conceptions when designing these learning sequences is more effective educational framework that addresses misconceptions and enhances understanding [5], [6]. Furthermore, redesigning learning sequences based on the model of educational reconstruction framework can effectively address students' preconceived notions, enhance comprehension by aligning their conceptions with the scientific understanding of metallic bonding, and overcome difficulties and misconceptions in chemical bonding through suitable learning models and media, ultimately enhancing student comprehension, engagement, and reducing preconceived notions and anxiety [7], [8]. Recent research has explored various instructional strategies to enhance student learning outcomes in chemistry. For instance, studies have investigated the effectiveness of context-based learning and inquiry-based approaches, which have shown promise in increasing student engagement and understanding and the development of the authentic inquiry approach module is effective in improving students' problem-solving abilities [9], [10].

Despite these advancements, there is limited research specifically addressing the sequencing of chemical bonding and reactions in the high school curriculum. Previous studies have primarily focused on isolated topics within chemistry education rather than the integrated sequence of concept presentation. However, the investigative teaching sequence, a proposed didactic transposition for teaching chemical bonds, aims to address this gap in research on sequencing chemical bonding and reactions in high school chemistry curriculum [11], [12]. This research builds on the foundational theories of cognitive load and educational psychology, proposing that an early introduction to chemical reactions might provide a practical context that enhances students' understanding of chemical bonding [13]. Furthermore, it also aimed to address a critical gap in chemistry education, specifically, the impact of re-sequencing the introduction of chemical bonding and chemical reactions on student learning outcomes. Considering previous researches has highlighted the advantages of alternate teaching approaches, there is no empirical data on how shifting the order of topic presentation improves student performance.

The need for addressing competencies related to different types of chemical reactions in grade 9 of the Department of Education curriculum. It also points out that the introduction of these concepts in the curriculum occurs in later years. This delay may pose challenges for Filipino students when they are assessed by the Program for International Student Assessment (PISA) science framework. The Philippines has consistently ranked among the lowest-performing countries in terms of reading comprehension, mathematical and scientific literacy in PISA tests [14], [15]. The lack of instructional materials, textbooks, and science equipment has hindered the conduct of scientific investigations, which has been an ongoing concern since the implementation of the K+12 Curriculum [16], [17]. To address these issues and improve student performance, efforts should be made to provide additional resources for science teachers and promote interest in science among students. As part of this effort, the research aims to develop and evaluate a re-sequenced intervention module to enhance the understanding of chemical reactions and chemical bonding concepts among grade 9 students. Specifically, the study aimed to assess the impact of introducing chemical reactions first on the learning of chemical bonding among grade 9 learners, as perceived by both the respondents and the teachers involved in the implementation of the module in chemical bonding. Thus, the research seeks to address the following questions:

i) What is the evaluation of the respondents in using the re-sequenced intervention module in chemical bonding?
ii) What is the evaluation of the teachers on the re-sequenced intervention module in chemical bonding?
iii) What is the level of competency in using the re-sequenced intervention module in chemical bonding between the control group and experimental group in terms of its pre-tests and post-tests?
iv) Is there a significant difference between the level of competency among the respondents when grouped between the control group and experimental group in using the re-sequenced intervention module?
v) Is there a significant association between the level of competency in chemical bonding and their evaluations of the usefulness using the re-sequenced intervention module among the respondents?

Furthermore, the novelty of this research is on the re-sequencing chemical reactions before chemical bonding, a direct reversal of the conventional sequence of most high school chemistry curriculum topics through a re-sequenced intervention module using the analysis, design, development, implementation, evaluation (ADDIE) model. Moreover, it demonstrates those significant ideas from both content areas while also attempting to determine through which order of concept presentation has more of an impact on student confusion, motivation, and test performance. Its key contribution is that it is one of the first empirical studies to examine the impact of re-sequencing on learning outcomes—a critical gap in chemistry education research. The study also presents a unique curriculum approach grounded in the theories of educational reconstruction and cognitive load and addresses the problem of national education set, paying due attention to particular learning difficulties of Filipino pupils, mostly seen in the reports of PISA.

2. METHOD

The objective of the study is to develop and evaluate a re-sequenced intervention module in the chemical bonding lessons and chemical reactions using the ADDIE model with reference to design-based research. Research respondents were the grade 9 students enrolled in school year 2023-2024 [18]. A total of 129 students grouped in four sections were selected as the respondents of the study for the implementation phase. The two sections were assigned for the control group and the other two for the experimental group.

Cluster random sampling and a randomization tool was used to provide the utmost certainty in the data acquired. These students, distributed across four intact class sections, were selected through total population sampling, as all available learners at the grade level were included to reflect authentic classroom contexts and ensure ecological validity [19]. This strategy is appropriate in school-based research, as it minimizes disruption to normal teaching arrangements while maintaining internal validity in quasi-experimental designs. Also, although variable confounding was not conducted due to practical limitations, the methodological strategies employed are consistent with accepted standards in educational intervention research [20], [21].

In addition, the questionnaires and learning materials used in this study were validated for content and reliability. Experts who validated the module in the design and development phase, including assessment instruments were two university chemistry assistant professors and six experienced science high school teachers. Cronbach's alpha was also computed to assess internal consistency, yielding a high reliability. These results suggest that the questionnaire was both valid and reliable for evaluating students' understanding and perceptions related to chemical bonding and reactions. The first phase began with assessing the need to produce an alternative teaching and learning material for teaching chemical bonding lessons in grade 9 by reviewing existing modules used by the teachers and assessing the needs of grade 9 students in Naawan, Misamis Oriental. After the needs analysis, a re-sequenced intervention module in chemical bonding was designed based salient findings which emerged from the analysis. The development of the module followed the ADDIE model, as shown in Figure 1. This model is a guide through the process of creating effective educational courses and materials for your target audience and it has been used to develop curriculum in diverse fields such as library instruction and programs [22], [23]. It is an instructional design model that has stood the test of time and application and will assist in thinking through the design of the chemistry module. It is an efficient and appropriate five-step method to guide the development and validation of student-based chemistry modules for chemical reactions as well as bonding concepts.

The module development, as described in Figure 1, started with the analysis phase, a review of the existing modules done and uncovered gaps in content using PISA criteria and needs analysis so developers needed to reorder and revise the content. The design phase implemented two main tasks which involved objective alignment with national educational guidelines and the construction of four student-oriented experiential lessons such as chemical reactions and ionic bonding and covalent bonding and metallic bonding. Science professionals evaluated the developed modules in phase 3 followed by feedback-based revising before conducting the pilot test involving grade 9 students who were part of an experimental and control group. During phase 4 (implementation), the developed material was applied to another educational institution whereby adjusted materials were implemented to another group of students. During phase 5 (evaluation), assessments were conducted by survey feedback and test results to determine learning outcomes and student perceptions to reach conclusions about module performance and propose ways to use them in the future. R statistical software was used to determine the difference between the level of competency among the respondents in the pre-test and post-test determined if the students had developed their performance on the subject. Students' evaluations were also obtained through the use of a survey and questionnaire before and after using the module using open-ended questions to collect additional qualitative support findings for the study. Be that the model may look linear, it does not have to be followed rigidly in a linear manner, especially if the module has already been prepared, instead, the module can be refined to tailor the opportunities of the student. To illustrate the process, the phases of development and evaluation is described in Figure 1.

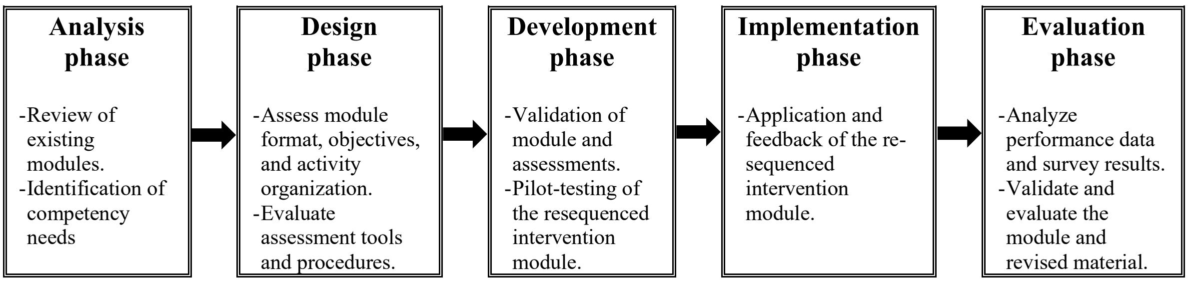

Figure 1. ADDIE model for module development

3. RESULTS AND DISCUSSION

3.1. Respondents' evaluation using the re-sequenced intervention module in chemical bonding

Figure 2 presents an analysis of respondents' views about the re-sequenced chemical bonding intervention module. The results showed positive results through the combination of 18.33% strong agreement and 63.93% agreement demonstrating universal acceptance of its effectiveness. Survey respondents who disagreed with the re-sequenced intervention module reached 16.07% along with 1.67% who strongly disagreed. The analysis revealed that respondents' earlier struggles with science and chemistry explained their negative views more than actual weaknesses found in the module. Chemistry education shows evidence of multiple established misconceptions particularly in abstract subjects since students frequently consider chemistry to be challenging [24], [25]. On the other hand, another data set on the response of the students to negatively phrased statements about the module indicate most students disagreed with negative assertions, which supports the module's effectiveness as described by the responses from the participants, shedding light on the critical perspectives regarding the utilization of re-sequenced intervention module in the context of chemical bonding.

Figure 3 describes the level of agreement in the evaluation of the module. A considerable portion of respondents concur, specifically, 41.46% strongly disagreed and 15.45% expressed disagreement with the negatively phrased statements about the re-sequenced intervention module. Simply because some of the respondents noted that, "*they feel confident about their knowledge about the topic and the teacher after using the module*," some stated that "*the module helped clarified any misconceptions about the topic*," "*the module aided the lessons*," and some said that "*100% helpful in understanding the topic because I want to be a doctor in the future*." This suggests that despite the negative preconceived notion about the subject they find the module useful in learning the lesson. Some find the module useful because of their intrinsic and or extrinsic motivation and mostly how they find the module useful. Indeed, motivation affects respondents' learning and engagement in formal, semi-formal, and informal activities [26].

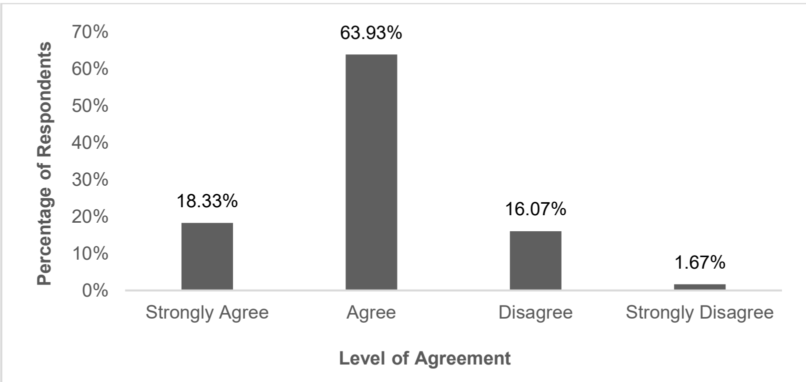

Figure 2. Percentage distribution of the perceptions of the respondents using the re-sequenced intervention module in chemical bonding

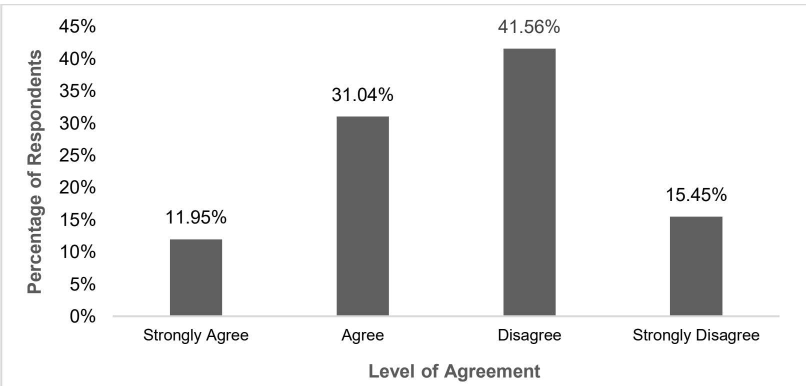

Figure 3. Percentage distribution of the evaluations of the respondents using the re-sequenced intervention module in chemical bonding

However, 11.95% strongly affirmed and 31.04% affirmed the challenges faced in the utilization of the module among the respondents. The registered agreement with the negatively framed statements implies that the respondents' approaches or utilization of the re-sequenced intervention module did help navigate the topic but the negative perceptions about the subject still overwhelm the respondents. Specifically, some of the respondents' feedback was: "*I thought using the module would be hard but it is really easy*" or "*I thought it will be hard for me to understand but I feel interested to know how chemical bonds work*," some respondents also found some of the activities to be "*challenging but they try their best to learn a lot*," some thought that they already "*expected that learning is not possible but they actually have learned*," and others mentioned that "*they can learn faster using the module but still cannot beat their laziness*." Misconceptions about abstract concepts in chemistry, such as chemical bonds, are common among respondents and are difficult to eliminate using traditional methods [27]. This implies that it is possible to overcome negative opinions about the difficulty of the subject when exposed to longer use of the re-sequenced intervention module.

3.2. Science teachers' evaluation on the re-sequenced intervention module in chemical bonding

The evaluation of science high school teachers and science education professors summarized in Figure 4 reflect strong agreement that the module was very satisfactory across all evaluated areas such as content, objectives, and accuracy. This provided a breakdown of data representing the evaluation of teachers on the chapter with four sequenced modules related to chemical bonding. The mean and percentages associated with each category shed light on the overall satisfaction levels of teachers across the modules.

The first module received a high level of satisfaction, with more than 96% of teachers expressing either very satisfactory or satisfactory opinions. The positive reception suggests that module 1 effectively aligns with the expectations and requirements of teaching. Module 2 exhibits a similar trend, with a high percentage of teachers expressing very satisfactory or satisfactory evaluations. The slight increase in the very satisfactory category suggests a potential enhancement or refinement in module 1 compared to module 2. While the third module maintains a high level of satisfaction, there is a slight decrease in the very satisfactory category compared to modules 1 and 2. The reasons for this shift would benefit from further exploration to identify areas for improvement. Module 4 stands out as the module with the highest percentage of very satisfactory evaluations. This suggests that module 4 is particularly well-received by teachers, potentially indicating successful implementation or alignment with instructional objectives.

Altogether, results showed an overall positive evaluation from teachers regarding the re-sequenced intervention modules in chemical bonding. The scope, range, and depth of the re-sequenced intervention module, as content and topics, are evaluated very satisfactorily which implies the appropriateness of the module to the respondents' learning needs. Thus, the material reinforces, enriches, and or leads to mastery of certain learning competencies. Similarly, Medina and Baraquia [27] developed discovery-based modules in chemistry using the same ADDIE model found out that they were valid, acceptable, and well-received by both chemistry teacher experts and criminology student users. This is consistent with one study that shows improvement of learning outcomes using developed material on problem solving skills [28].

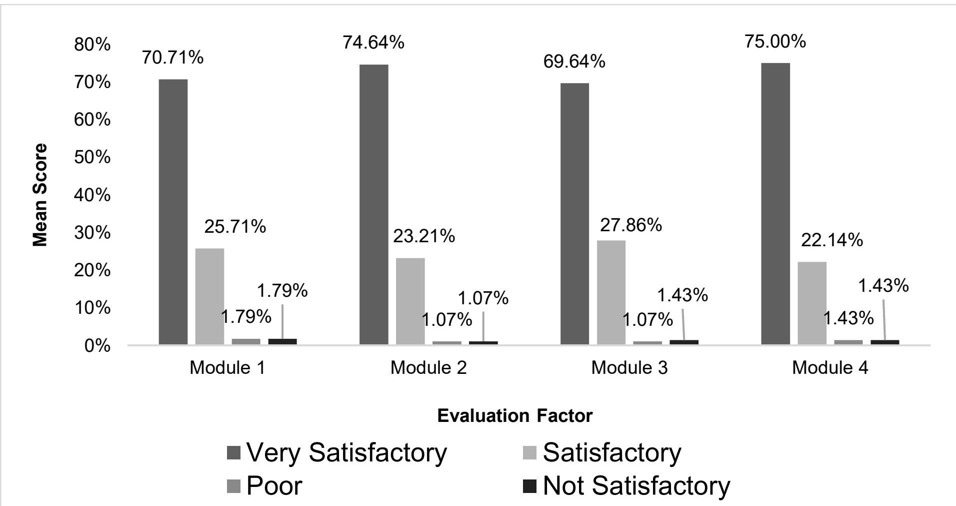

Figure 4. Percentage distribution of the teacher experts' evaluation of the modules

3.3. Level of competency in using the re-sequenced intervention module in chemical bonding between the control group and experimental group

Figure 5 reveals the distribution of participants' competency levels during both pre-test and post-test among control and experimental group. The experimental group who received the re-sequenced intervention module, demonstrated clear learning improvements. The survey results showed most participants from both groups reached the fairly satisfactory and satisfactory performance levels in the pre-test evaluation. Many students in the experimental group rose to satisfactory levels of achievement instead of remaining under performers 1.43% as shown by the control group (3.28%). Moreover, the experimental group showed remarkable post-test advancement since all learners exceeded minimum expectations and 88.41% achieved at least satisfactory results while 37.68% accomplished the very satisfactory benchmark. Students in the control group demonstrated largely satisfactory achievements according to the test results, but none of them achieved levels above very satisfactory. The results are similar to the findings regarding performance improvement through interactive teaching methods while supporting those who observed improved student engagement without consistent top achievement levels. The re-structured educational material proved successful in helping students develop their competencies particularly among students at average and below average levels yet traditional teaching approaches failed to elevate student achievement to higher levels [29], [30].

In general, the re-sequenced intervention module was successful in meeting the needs of the respondents and facilitating a basic level of competency. The moderate percentage in the "fairly satisfactory" category could be indicative of areas where the re-sequenced intervention module might benefit from refinement or additional support to enhance participant understanding and confidence. The performance of respondents using validated modules in chemistry was found to be positive and effective which is supported by multiple studies one in which the developed discovery-based modules were rated as excellent indicating their validity and usefulness. Another study showed that a chemistry learning module based on various redox material representations was considered helpful and received positive responses from respondents [31].

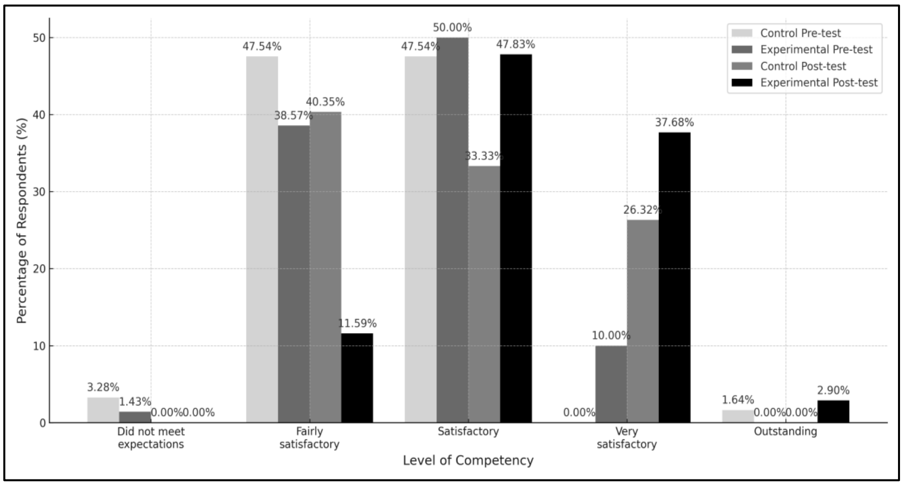

Figure 5. Pre-test and post-test level of competency in the experimental and control group after using the re-sequenced intervention module

3.4. Difference in the level of competency using the re-sequenced intervention module when classified within the control group and the experimental group's pre-tests and post-tests

Table 1 shows the difference between the control group and experimental group test scores on its pre-test and post-test using the re-sequenced intervention module. Pre-test scores to posttest scores improved significantly for both groups according to their p-values indicating that both control and experimental treatments allowed significant improvements. However, the experimental intervention among the second group yielded greater results as their effect size measurement stood at d=0.54 compared to the control group's d=0.39.

In comparison to the control group, the experimental group obtained a superior outcome measure through the implementation of the re-sequenced teaching method. Research has validated that unusual educational methods generate better results while supporting the current study's findings. Simulation-based chemistry laboratory work produced better student outcomes than regular laboratory methods [32], while microscale experiments had better effects on learning than macroscopic experiments [33]. Research cites intervention design as critical for success and learner-controlled environments together with PQ4R and their role in enhancing chemistry learning [34]–[36].

To further test the difference between the level of competency among the respondents when grouped between the control group and experimental group, an independent t-test was used, as shown in Table 2. The results demonstrate mathematical significance between test subjects and control participants. The unpaired t-test (p=0.02) and Mann-Whitney U test (p=0.04) showed results below 0.05 significance. This means that the re-designed sequence added to the intervention curriculum led students to achieve stronger levels of competency in chemical bonding. In addition, the experimental group obtained superior mean performance results than the control group which demonstrates the effectiveness of the intervention. A Cohen's U_3 value of 0.37 indicates moderate effects size between performance distributions which shows a distinguishable separation between groups while keeping portions of their score ranges cross-over. The moderate effect size value of 0.32 demonstrates meaningful practical impact from the implementation of this intervention. The outcome from small educational progress makes substantial differences in student academic advancement [37]. The combination of research findings demonstrates that strategic instructional arrangement delivers worthwhile learning improvements between academic subjects. Hence, the results confirms that treatment produces relevant educational advancement in chemistry therefore demonstrating its potential as an effective approach for classroom use.

Table 1. Difference in the level of competency using re-sequenced intervention module when classified within the control and experimental group's pre-tests and post-tests score

Group/Test		Mean	Mean difference	SD	t-value	p-value	Effect-size	Remarks
Experimental group	Pre-test	38.8		13.7				
			10.47		4.48	2.963e-5	0.54	Significant
	Post-test	49.3		19.4				
Control group	Pre-test	34.1		11.2				
			7.30		2.95	0.005	0.39	Significant
	Post-test	41.4		15.3				

With 0.05 level of significance

Table 2. Difference between the level of competency among the respondents when grouped between the control group and experimental group in using the re-sequenced intervention module

Groups	Mean	Unpaired t-test p-value	W test p-value	Effect-size	Remarks
Experimental post-test	42.50				
		0.016	0.039	0.37	Significant
Control post-test	37.39				

With 0.05 level of significance

3.5. Association between the level of competency in chemical bonding and their perceptions and approaches on the usefulness of the re-sequenced intervention module among the respondents

Table 3 presents the analysis on the association between the level of competency in chemical bonding and their perceptions and approaches on the usefulness of the re-sequenced intervention module. The coefficient for approaches is -0.045 with a standard error of 0.069. The p-value is 0.519, indicating that approaches is also not statistically significant. This suggests that there is no significant association between the respondents' perceptions and approaches of the usefulness of the re-sequenced intervention module and their competency level in chemical bonding. Generally, respondents perceive chemistry as a complex subject resulting in low academic performance [38], but not in this case, which simply means that even in the absence of specific association to the respondents' perceptions or approaches toward the re-sequenced intervention module, the respondents still exhibit a certain level of competency in chemical bonding. This baseline competency could reflect the inherent knowledge or skills possessed by individuals irrespective of their attitudes or behaviors toward the subject, topic, or module. Given that the respondents' learning approach is a multi-factorial construct, investigating the relationship between the two variables in longitudinal time points would also provide better insight into the association between the educational climate and respondents' learning approaches [39].

Table 3. Poisson regression analysis on the relationship between students' chemical bonding competency and their perceptions of the re-sequenced intervention module

Variable	Estimate	Std. Error	z-value	Pr (>|z|)	Remarks
Intercept	2.658	0.329	8.088	6.07e-16	
Perceptions	0.083	0.084	0.984	0.325	Not significant
Approaches	-0.045	0.069	-0.645	0.519	Not significant

4. CONCLUSION

The study evaluated the effectiveness of a re-sequenced intervention module through pre-tests, post-tests, and survey questionnaires based on Learning Resources Management and Development System (LRMDS) Assessment and Evaluation Guidelines. It also explored the relationship between students' competency levels, perceptions, and learning approaches. The experimental group that began their chemical study with reaction content achieved better achievement and competency than the control group because of their re-sequenced intervention module. Moreover, statistical results along with moderate effect sizes prove that the module delivered effective education with meaningful results. The research proves how student-focused instructional designs demonstrated value by advancing learning outcomes in complex subjects especially chemical bonding. The module achieved its educational goals since students from different backgrounds all benefited from its content structure. Resource-constrained school systems throughout the Philippines can benefit from strategic content reordering knowledge as an affordable method to boost teaching effectiveness. The results provide concrete strategies for both curriculum developers and educators to improve the basic education program through innovative educational methods and intervention approaches.

Furthermore, it is recommended to gather qualitative feedback through interviews or open-ended surveys to better understand negative perceptions and refine the module. Comparative analysis of modules could help identify effective instructional strategies for improvement. Small performance differences between groups suggest the need to investigate contextual factors influencing learning outcomes. Future studies should also replicate the module while addressing challenges to optimize its effectiveness. A longitudinal approach across different classroom setups is advised, and exploring additional factors like prior education, study habits, and socio-economic status may offer a deeper understanding of competency development.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state that they have no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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