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Enhancing Learning Outcomes and Motivation of Grade 9 Learners in Chemical Bonding Utilizing Contextualized 3D Manipulatives

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ABSTRACT

Chemical bonding is one of the abstract topics in Chemistry. Students find it hard to imagine how bonding between two or more atoms occurs. Failure to do so leads to low performance and motivation, especially for those who are struggling to understand the lessons due to poor prior knowledge. This study aims to enhance learning outcomes and motivation of grade 9 learners in chemical bonding by utilizing contextualized 3D manipulatives. It used a quantitative, one-group pretest–posttest action research design. Purposive sampling was employed to select learners who met the inclusion criteria, a Science grade of 74 and below during the previous quarter. The participants were 16 Grade 9 challenged learners from Mindanao State University – University Training Center (MSU-UTC), Marawi City. The results demonstrate a statistically significant improvement in students' performance from the pretest to the posttest. Findings suggest that the contextualized 3D manipulatives had a positive effect on students' motivation, supporting research that emphasizes the role of hands-on, concrete learning tools in enhancing learners' engagement and interest in science. The absence of a significant relationship before the intervention underscores the need for instructional strategies, such as contextualized 3D manipulatives, that can simultaneously support conceptual learning and provide conditions under which motivation and achievement may become more closely aligned. Overall, although a positive trend between postintervention motivation and achievement was observed, there is insufficient evidence to conclude that increased motivation directly contributed to higher posttest performance in this study. These results only suggest that integrating contextualized 3D manipulatives into instruction can be an effective strategy for fostering both achievement and motivation among learners of challenging content.

Keywords: Contextualized 3D Manipulatives, Students' Performance, Learning Motivation, Challenged Learners

INTRODUCTION

Chemical bonding is a foundational concept in secondary chemistry that underpins students' understanding of molecular structure, properties of matter, and chemical reactions. However, research consistently indicates that learners at the lower secondary level experience substantial difficulty in mastering this topic due to its abstract and multilevel nature, which requires coordination between macroscopic phenomena, sub-microscopic representations, and symbolic notation (Gilbert & Treagust, 2009; Taber, 2013). For Grade 9 challenged learners—particularly those who have demonstrated low academic performance—these conceptual demands are often compounded by limited spatial visualization skills, weak prior knowledge, and low academic motivation, resulting in persistent misconceptions about valence electrons, the octet rule, Lewis structures, and ionic and covalent bonding (Cooper et al., 2017; Çalik et al., 2015).

Contemporary science education literature emphasizes the need for instructional approaches that make abstract chemical concepts more concrete, meaningful, and accessible to diverse learners. One widely supported approach is the use of physical manipulatives, especially three-dimensional (3D) models, which allow learners to externalize and visualize invisible entities such as electrons and atomic interactions (Stull et al., 2018). Grounded in constructivist learning theory, manipulatives enable students to construct knowledge through hands-on engagement actively, promoting deeper conceptual understanding rather than rote memorization (Piaget, 1972; Bruner, 1966). Empirical studies have shown that students who interact with tangible models demonstrate improved conceptual accuracy and reduced misconceptions in chemistry compared to those taught using purely symbolic or lecture-based methods (Chittleborough & Treagust, 2007; Stull & Hegarty, 2016).

In addition to cognitive outcomes, motivation is a critical factor influencing students' engagement and achievement in science. Self-determination theory posits that learning environments that support autonomy, competence, and relatedness enhance intrinsic motivation and persistence, particularly among low-performing learners (Ryan & Deci, 2020). Several studies in science education report that the use of manipulatives and interactive learning materials positively affects students' interest, confidence, and willingness to participate in class activities (Ainsworth et al., 2016; Srisawasdi & Panjaburee, 2019). For challenged learners, concrete and contextualized instructional materials may reduce anxiety toward chemistry and foster a sense of competence, thereby improving both motivation and performance.

Contextualization further strengthens the effectiveness of manipulatives by linking scientific concepts to familiar materials and real-world experiences. In developing contexts and inclusive classrooms, low-cost, locally available materials—such as Styrofoam and push pins—can serve as effective representations of abstract chemical structures while remaining sustainable and accessible (Millar, 2014; Kibirige & Tsamago, 2019). When students recognize instructional materials as relevant and understandable, learning becomes more meaningful, which is particularly important for learners who struggle in conventional academic settings.

Despite growing evidence supporting the use of manipulatives in chemistry instruction, there remains a need for focused action research examining their combined effects on both learning outcomes and motivation among challenged learners in real classroom contexts. Moreover, limited studies have explored the relationship between students' motivation and performance before and after manipulative-based interventions, particularly using nonparametric statistical approaches appropriate for small and non-normally distributed samples (Field, 2018). Addressing this gap is especially relevant in the Philippine K–12 context, where inclusive education and learner-centered pedagogies are strongly advocated.

Therefore, this action research explores the efficacy of contextualized 3D manipulatives in enhancing both learning outcomes and motivation in chemical bonding among Grade 9 challenged learners at Mindanao State University – University Training Center in Marawi City, Lanao del Sur, Philippines. Specifically, the study examines differences in performance and motivation before and after the intervention and investigates the relationship between these two variables. By integrating hands-on, low-cost 3D models into instruction on valence electrons, the octet rule, Lewis structures, and ionic and covalent bonding. This study seeks to provide empirical evidence to inform inclusive chemistry teaching practices and support struggling learners in developing meaningful and motivating learning experiences.

Research Objectives

This study aims to determine the effectiveness of utilizing contextualized 3D manipulatives in improving the performance and motivation of Grade 9 challenged learners in Chemical Bonding. The following are the specific objectives of this study:

1. To compare the performance level of Grade 9 challenged learners in Chemical Bonding before and after utilizing the contextualized 3D manipulatives.
2. To compare the motivational level of Grade 9 challenged learners in Chemical Bonding before and after utilizing the contextualized 3D manipulatives.
3. To determine if there is a significant relationship between the pretest and motivation level of the Grade 9 challenged learners in learning chemical bonding before utilizing the contextualized 3D manipulatives.
4. To determine if there is a significant relationship between the posttest and the motivation level of the Grade 9 challenged learners in learning chemical bonding after utilizing the contextualized 3D manipulatives.

Significance of the Study

This action research highlights the effectiveness of contextualized 3D manipulatives in enhancing both learning outcomes and motivation in Chemical Bonding among Grade 9 challenged learners. By using concrete, low-cost, and locally available materials, the study demonstrates how abstract concepts—such as valence electrons, the octet rule, Lewis structures, and ionic and covalent bonding—can be made more accessible, particularly for students who struggle in traditional classrooms. The findings offer practical insights for science teachers seeking inclusive, manipulative-based strategies, guide school administrators and curriculum planners in designing learner-centered and remedial approaches, and support students in building engagement, confidence, and motivation in Chemistry. Additionally, the study provides a foundation for future research on instructional interventions that integrate both performance and motivational outcomes in science education.

Limitations of the Study

This study has several limitations that should be considered in interpreting the findings. First, the research utilized a one-group pretest–posttest design without a control or comparison group; therefore, improvements in performance and motivation cannot be attributed solely to the intervention with absolute certainty, as other external factors may have influenced the results. Second, the small sample size of 16 participants, selected through purposive sampling, limits the generalizability of the findings to other Grade 9 populations or educational contexts. Third, the intervention was implemented over a short duration of seven (7) days, which may not be sufficient to capture long-term retention of chemical bonding concepts or sustained changes in learners' motivation. Fourth, the use of self-reported motivation questionnaire may be subject to response bias, as learners may provide socially desirable answers. Lastly, the study focused only on selected topics in Chemical Bonding and did not examine other chemistry concepts or higher-order learning outcomes. Despite these limitations, the study provides valuable insights into short-term, classroom-based instructional innovations for challenged learners.

METHODOLOGY

This study utilized a quantitative, one-group pretest–posttest action research design to evaluate the effectiveness of contextualized three-dimensional (3D) manipulatives in teaching Chemical Bonding and their impact on learners' motivation. The participants were 16 Grade 9 challenged learners (identified based on Science grades of 74 and below) at Mindanao State University – University Training Center (MSU-UTC), Marawi City. Purposive sampling was employed to select learners who met the inclusion criteria.

Learners' performance was assessed using a 30-item researcher-made Chemical Bonding Achievement Test covering valence electrons, octet rule, Lewis structures, ionic bonding, and covalent bonding, with a reliability coefficient of 0.720. Motivation was measured through a 15-item Likert-scale Motivation in Chemistry Questionnaire ($\alpha = 0.792$), evaluating interest, engagement, confidence, and persistence. Pretest was administered to establish baseline data.

The intervention, conducted over seven 50-minute sessions, involved using Styrofoam rings, sticky notes and colored push pins to model electron arrangement and bond formation. Posttest was administered to measure changes in performance and motivation. Due to the small sample size and non-normal data distribution, nonparametric tests were used: the Wilcoxon Signed-Rank Test to examine pre-post differences and Spearman's rank-order correlation to analyze relationships between performance and motivation, with significance set at $\alpha = 0.05$.

Ethical Considerations

Permission to conduct the study was obtained from the school administration. Informed consent was secured from the participants and their parents or guardians. Confidentiality and anonymity of participants were strictly maintained, and the data collected were used solely for academic and research purposes.

RESULTS AND DISCUSSIONs

This section presents the findings on utilizing contextualized 3D manipulatives in improving Grade 9 challenged learners' performance and motivation in learning Chemical Bonding. Results are shown for pre- and post-intervention performance and motivation, followed by analysis of the relationship between the two. Interpretations are discussed in light of the study's objectives and relevant literature, highlighting the impact of 3D manipulatives on learners' understanding and engagement.

Table 1. Descriptive statistics of students' performance in a 30-item multiple-choice test

Test	Mean	Standard Deviation	Qualitative Interpretation
Pre	7.19	2.738	Beginning
Post	12.63	3.181	Developing

The results demonstrate the descriptive statistics of students' performance in a 30-item multiple-choice test administered before (pretest) and after (posttest) the intervention. The pre-test results show a mean score of 7.19 with a standard deviation of 2.738, which was qualitatively interpreted as "Beginning". This indicates that, prior to the intervention, students demonstrated limited mastery of the assessed competencies, with generally low performance across the test items. In contrast, the post-test results reveal an increased mean score of 12.63 and a standard deviation of 3.181, corresponding to a "Developing" level of performance. The increase in the mean score suggests an overall improvement in students' test performance after the intervention. Although variability among students slightly increased, the higher mean indicates that more students were able to answer a greater number of items correctly, reflecting progress in their understanding of the subject matter. According to student S3, *"I am really thankful that you made this 3D manipulatives for us to understand how to identify the energy level and valence electrons. We are able to visualize what is a valence shell and how to locate the valence electrons. Though I am not so good, I can say that my conceptual understanding has improved."* Overall, this statement from student S3 has supported the comparison of pretest and posttest results, which implies that students' performance improved from the "Beginning" to the "Developing" level, suggesting a positive effect of the instructional intervention on students' learning outcomes.

This finding is consistent with prior research indicating that instructional interventions incorporating concrete and interactive learning materials can lead to substantial gains in academic performance, particularly when addressing abstract scientific concepts. Studies have shown that hands-on and manipulative-based approaches enhance conceptual understanding and promote deeper cognitive processing, which in turn results in improved post-intervention achievement (Padalkar & Hegarty, 2015; Stull et al., 2012). Furthermore, empirical evidence in science and mathematics education suggests that learners exposed to structured, activity-based interventions demonstrate significantly higher posttest performance compared to their pre-intervention levels, supporting the effectiveness of such instructional strategies in improving learning outcomes (Uribe-Flórez & Wilkins, 2016).

Table 2. Wilcoxon Signed-Rank Test of pretest and posttest

Ranks	**N**	**Mean Rank**	***Z*-value**	***p*-value at 0.05 level of significance**	**Qualitative Interpretation**
Negative	2	4.25	-3.080	0.02	Significant
Positive	14	9.11			

The Wilcoxon Signed-Rank Test further supports this finding, with 14 students obtaining higher scores in the posttest compared to the pretest and only 2 students showing a decrease. Moreover, the mean rank of positive changes (9.11) substantially exceeded that of negative changes (4.25), indicating that the gains were generally larger than the declines. The test statistics revealed a Z value of −3.080 with a two-tailed p-value of .02, which is below the 0.05 level of significance. Therefore, there is a statistically significant difference between pretest and posttest scores, suggesting that the intervention implemented between the tests was effective in improving students' performance. This pattern of results is consistent with previous studies demonstrating that instructional interventions utilizing concrete and model-based learning tools yield statistically significant improvements in achievement by enhancing conceptual understanding and representational competence (Padalkar & Hegarty, 2015; Stull et al., 2012). Meta-analytic evidence further supports the conclusion that manipulative-supported instruction produces reliable and meaningful learning gains across learners, reinforcing the effectiveness of the intervention used in this study (Carbonneau et al., 2013).

Table 3. Descriptive statistics of students' learning motivation before and after utilizing the contextualized 3D manipulatives

Contextualized 3D Manipulatives Intervention	**Mean**	**Standard Deviation**	**Qualitative Interpretation**
Pre	2.56	0.512	Moderately Motivated
Post	3.88	0.500	Highly Motivated

The table above shows the descriptive statistics of students' learning motivation before and after the utilization of contextualized 3D manipulatives. Prior to the intervention, the mean motivation score was 2.56 (SD = 0.512), which corresponds to a "Moderately Motivated level." This indicates that students initially demonstrated an average level of motivation toward learning before exposure to the instructional strategy. After the intervention, students' mean motivation score increased to 3.88 (SD = 0.500), interpreted as "Highly Motivated." The increase in the mean score reflects a marked improvement in students' motivation following the use of contextualized 3D manipulatives. The relatively similar standard deviations across pre- and post-intervention suggest that students responded consistently to the instructional approach. Overall, the shift from moderately motivated to highly motivated indicates that contextualized 3D manipulatives positively influenced students' engagement and interest in learning.

Moreover, learner-centered interventions that incorporate physical models have been found to promote positive motivational outcomes alongside academic gains, particularly among students who struggle with abstract content (Uribe-Flórez & Wilkins, 2016). As student S6 has said, *"I enjoyed the use of 3D manipulatives in our lesson on chemical bonding. It makes our lesson clearer. We learn, at the same time we are having fun."* These findings are supported by research showing that active and hands-on learning approaches significantly enhance students' motivation and engagement. Freeman et al. (2014) reported that instructional strategies emphasizing active participation and interaction with learning materials lead to improved student engagement and affective outcomes in science education. By allowing students to physically interact with learning materials in meaningful contexts, contextualized 3D manipulatives align with active learning principles that promote higher motivation and sustained interest.

Table 4. Wilcoxon Signed-Rank Test of students' learning motivation during pre-intervention and post-intervention of contextualized 3D manipulatives

Ranks	**N**	**Mean Rank**	**Sum of Ranks**	***Z*-value**	***p*-value at 0.05 level of significance**	**Qualitative Interpretation**
Negative	0	0	0	-3.666	0.000	Significant
Positive	16	8.5	136			

Table 4 presents the results of the Wilcoxon Signed-Rank Test comparing students' learning motivation before and after the implementation of contextualized 3D manipulatives. The analysis shows that all observed differences were positive (N = 16), with a mean rank of 8.50 and a sum of ranks of 136, while no negative ranks were recorded. This indicates that all participating students demonstrated higher motivation levels following the intervention. The Wilcoxon test yielded a Z-value of −3.666 with a corresponding p-value of 0.000, which is lower than the 0.05 level of significance. This result indicates a statistically significant increase in students' learning motivation after exposure to the contextualized 3D manipulatives. The absence of negative ranks further suggests a consistent improvement in motivation across participants rather than isolated gains among a few students. The magnitude of the observed effect, the effect size (r) using the obtained Z-value and a sample size of 16, the resulting effect size was $r = 0.92$, which is interpreted as a large effect based on conventional benchmarks. This indicates that the intervention had a substantial practical impact on students' learning motivation, not merely a statistically detectable change.

According to student S13, "*I can say that I have learned from these 3D manipulatives in our topic on chemical bonding. It is very hard to imagine how electrons could be in energy levels. Through the manipulatives, I was able to grasp the idea in a better way."* This student's statement is just an example of the significant and large motivational gains observed in this study align with constructivist and motivational theories emphasizing the role of active, hands-on learning environments in fostering student engagement. Contextualized 3D manipulatives provide learners with concrete representations of abstract concepts, which enhance perceived competence and task value—two critical components of intrinsic motivation (Ryan & Deci, 2020). Empirical studies have consistently shown that manipulative-based instruction promotes higher levels of interest, persistence, and engagement, particularly in science and mathematics education (Fyfe et al., 2014). By allowing learners to interact physically with instructional materials that are relevant to real-life contexts, such tools help bridge the gap between abstract content and students' everyday experiences, thereby increasing motivation (Hidi & Renninger, 2006). Furthermore, the large effect size supports findings from prior research indicating that motivational outcomes are especially sensitive to instructional strategies that emphasize autonomy, exploration, and experiential learning (Lombardi et al., 2021). While motivation does not always translate immediately into

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measurable cognitive gains, improvements in learning motivation are widely recognized as a critical precursor to sustained academic engagement and long-term achievement.

In classroom practice, these findings suggest that integrating contextualized 3D manipulatives can be an effective strategy for enhancing student motivation, particularly in settings where traditional lecture-based instruction may limit active participation. Teachers are encouraged to pair manipulative-based activities with reflective discussions and guided inquiry to maximize both motivational and cognitive benefits.

Table 5. Descriptive statistics of the relationship between students' pretest and posttest scores and their level of motivation before and after utilizing the contextualized 3D manipulatives using Spearman's rank-order correlation.

Test	Spearman's rho (ρ) value	p-value at 0.05 level of significance	Qualitative Interpretation
Pretest	-0.145	0.593	Not Significant
Posttest	0.220	0.413	Not Significant

The table above presents the relationship between students' academic performance and motivation as measured during the pretest and posttest using Spearman's rho. For the pretest, the correlation coefficient ($\rho = -0.145$) indicates a very weak negative relationship between students' motivation and their initial academic performance. This suggests that prior to the intervention, students who reported slightly higher levels of motivation did not necessarily demonstrate higher test scores, and vice versa. However, this association was not statistically significant ($p = 0.593 > 0.05$), indicating insufficient evidence to support a meaningful relationship between motivation and academic performance at baseline.

Similarly, the posttest results yielded a weak positive correlation ($\rho = 0.220$) between motivation and academic performance following the intervention, but this relationship also failed to reach statistical significance ($p = 0.413 > 0.05$). While the direction of the relationship changed after the intervention, the magnitude of the correlation remained low, suggesting that improvements in academic performance were not strongly associated with changes in students' motivational levels within the duration of the study.

These null findings should be interpreted with caution. Correlation analyses are sensitive to sample size and measurement conditions; the relatively small number of participants and the short duration of the intervention may have limited the ability to detect statistically significant relationships. Moreover, existing literature emphasizes that the relationship between affective factors such as motivation and cognitive outcomes is complex, often mediated by variables such as instructional design, prior knowledge, classroom environment, and time-on-task. Motivation may influence learning indirectly and over longer periods, rather than producing immediate, linear effects on test performance. This is consistent with previous research showing that initial motivation does not always translate into higher achievement, particularly when learners are confronted with abstract and cognitively demanding concepts such as chemical bonding (Glynn et al., 2015; Potvin & Hasni, 2014). Studies suggest that without appropriate instructional support, motivated students may still struggle to demonstrate strong performance due to limited conceptual understanding (Padalkar & Hegarty, 2015). Thus, the absence of a significant relationship before the intervention underscores the need for instructional strategies, such as contextualized 3D manipulatives, that can simultaneously support conceptual learning and provide conditions under which motivation and achievement may become more closely aligned.

From a classroom perspective, the results suggest that while contextualized 3D manipulatives may support learning outcomes, improvements in academic performance should not be assumed to automatically translate into measurable changes in student motivation, or vice versa. Teachers in similar contexts are encouraged to combine hands-on instructional strategies with explicit motivational supports—such as goal-setting, feedback, and reflective activities—to more effectively address both cognitive and affective dimensions of learning.

CONCLUSION

The pattern of findings aligns with research showing that concrete, model-based instructional tools support deeper conceptual understanding by helping learners translate between representations and reduce cognitive load during complex reasoning tasks (Padalkar & Hegarty, 2015; Stull, Hegarty, Dixon, & Stieff, 2012). In addition, the consistent increase in motivation across participants is consistent with literature indicating that hands-on and activity-rich instructional experiences can enhance student engagement and situational interest in science learning (Swarat, Ortony, & Revelle, 2012). Taken together with meta-analytic evidence supporting the general effectiveness of manipulatives in improving learning outcomes (Carbonneau, Marley, & Selig, 2013), these results suggest that integrating contextualized 3D manipulatives into instruction can be an effective strategy for fostering both achievement and motivation among learners of challenging content.

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