

Influence of Problem Based Learning on Lower Secondary Students' Performance in Chemical Reactions in Nyarugenge District Rwanda

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Abstract

This study examined the influence of Problem-Based Learning (PBL) on lower secondary students' academic performance in chemical reactions in Nyarugenge District, Rwanda. Despite the importance of chemistry in science education, students often experience difficulties in understanding chemical reactions due to the abstract nature of the subject and the continued use of teacher-centered instructional approaches. The study aimed to compare the pre-test performance of students in experimental and control groups and to determine the effect of PBL on students' achievement in chemical reactions. The study employed a quasi-experimental pre-test–post-test non-equivalent control group design involving 227 Senior Two and Senior Three students selected from four secondary schools. Students in the experimental group were taught using PBL, while those in the control group received conventional lecture-based instruction. Data were collected using a Chemistry Achievement Test and analyzed using descriptive statistics and an independent samples t-test. The findings revealed no statistically significant difference between the experimental group ($M = 23.87$, $SD = 9.60$) and the control group ($M = 17.70$, $SD = 8.78$) in the pre-test, indicating baseline equivalence. However, post-test results showed that the experimental group achieved a higher mean score ($M = 29.34$, $SD = 7.75$) than the control group ($M = 17.78$, $SD = 7.91$). The independent samples t-test confirmed a statistically significant difference between the groups, $t(225) = 3.28$, $p = 0.002$. The study concludes that Problem-Based Learning significantly improves students' academic performance in chemical reactions compared to traditional lecture-based instruction. It recommends the integration of PBL into chemistry teaching to enhance learner engagement, conceptual understanding, and academic achievement.

1. Background to the Study

Chemistry is a fundamental science that plays a vital role in technological advancement, healthcare, agriculture, environmental sustainability, and everyday life. It also serves as a foundation for many scientific disciplines, including biology, medicine, engineering, and physics, while fostering critical thinking, creativity, and scientific literacy among learners (Zhang & Jiang, 2026). Despite its importance, chemistry is widely perceived by secondary school students as difficult and abstract, which often results in low motivation, negative attitudes, and poor academic performance (Renvall & Kurtén, 2024).

One of the major challenges in learning chemistry is its highly abstract nature. Many chemical concepts exist at microscopic and symbolic levels that cannot be directly observed in everyday life. Learners are expected to integrate three levels of understanding macroscopic phenomena, submicroscopic particle behavior, and symbolic representations-yet many students struggle to connect these levels meaningfully (Diani et al., 2024). This difficulty frequently leads to misconceptions and weak conceptual understanding, particularly in complex topics such as chemical reactions.

Chemical reactions are considered one of the most challenging areas in secondary school chemistry. This topic requires students to interpret observable changes in matter using particle-level explanations and chemical equations. However, many learners experience difficulties in balancing chemical equations,

identifying types of reactions, and understanding molecular interactions, especially when instruction emphasizes memorization rather than conceptual understanding (Pöllöth et al., 2023; Wu & Yeziarski, 2022).

Globally, persistent low achievement in chemistry has encouraged educators to adopt learner-centered instructional approaches such as Problem-Based Learning (PBL). PBL promotes active engagement, collaboration, critical thinking, and real-life problem-solving, enabling learners to construct knowledge meaningfully rather than passively receiving information (Zhao & Wang, 2022). Empirical studies further show that PBL enhances students' academic performance in science by encouraging inquiry and deeper conceptual understanding (Hidayah et al., 2022).

In Rwanda, although the Competence-Based Curriculum emphasizes learner-centered pedagogies (Ndiokubwayo & Habiaremye, 2018), students' performance in chemistry remains low, particularly in chemical reactions (NESA, 2023). This situation is partly attributed to continued reliance on lecture-based instruction, large class sizes, and limited instructional resources (Renzaho & Kampire, 2022). While some local studies have reported positive outcomes of learner-centered strategies such as task-based and practice-based learning, limited empirical evidence exists on the effectiveness of Problem-Based Learning in chemistry education at the lower secondary level.

More specifically, no study has investigated the impact of PBL on students' performance in chemical reactions in Nyarugenge District. Therefore, this study seeks to address this gap by examining the influence of Problem-Based Learning on lower secondary students' academic performance in chemical reactions through a comparison of pre-test and post-test results between experimental and control groups, and by determining the statistical significance of the observed differences.

2.Objectives

General Objective

To examine the influence of Problem-Based Learning on lower secondary students' academic performance in chemical reactions compared to lecture-based instruction

Specific objectives

- i.To compare the pre-test academic performance of students in the experimental (PBL) group and the control (lecture-based) group in chemical reactions in order to establish baseline equivalency.
- ii.To determine the effect of Problem-Based Learning on students' post-test academic performance in chemical reactions compared to conventional lecture-based instruction.

3.Literature Review

Existing literature consistently shows that learning chemistry remains a major challenge for many secondary school students due to its abstract and complex nature. Chemistry requires learners to understand and integrate three interconnected levels of representation: the macroscopic level (observable phenomena), the submicroscopic level (particle behavior), and the symbolic level (chemical equations and formulas). However, many students struggle to make meaningful connections between these levels, particularly in topics such as chemical reactions, leading to fragmented understanding and persistent misconceptions (Diani et al., 2024; Salame & Khalil, 2023). As a result, learners often rely on rote memorization rather than conceptual understanding, which contributes to weak academic performance and low retention of chemistry concepts.

To address these persistent challenges, educational researchers and practitioners have increasingly recommended learner-centered instructional approaches. Among these, Problem-Based Learning (PBL) has gained significant attention due to its emphasis on active learning, collaboration, inquiry, and real-world problem-solving. PBL engages students in authentic problems that require them to investigate, discuss, and construct knowledge collaboratively, thereby promoting deeper conceptual understanding and critical thinking skills (Hidayah et al., 2022; Zhao & Wang, 2022). Unlike traditional lecture-based instruction, PBL shifts the learning process from teacher-centered transmission to student-centered exploration, allowing learners to take responsibility for their own learning.

Despite the growing global evidence supporting PBL, most studies have been conducted in higher education contexts or in developed countries, where learning environments, resources, and student preparedness may differ significantly from those in developing countries. This limits the generalizability of findings to lower secondary school settings. In Rwanda, existing research has mainly focused on general science achievement and alternative instructional strategies such as task-based learning, practice-based learning, and technology-assisted instruction. However, empirical studies specifically examining the effectiveness of Problem-Based Learning in chemistry education, particularly in the topic of chemical reactions at the lower secondary level, remain very limited. This indicates a clear research gap regarding the impact of PBL on students' conceptual understanding and academic performance within this specific context.

This study is grounded in constructivist learning theory as proposed by Piaget (1970) and Vygotsky (1978), which emphasizes that learners actively construct knowledge through interaction with their environment and social collaboration. From this perspective, learning is not a passive process but an active reconstruction of knowledge based on prior understanding and new experiences. Problem-Based Learning aligns strongly with constructivist principles by engaging learners in meaningful problem-solving tasks that promote cognitive conflict, discussion, and reflection. Furthermore, Vygotsky's concept of the Zone of Proximal Development highlights the importance of social interaction and scaffolding, which are central features of PBL, as learners work collaboratively to solve problems slightly beyond their individual capability.

The conceptual framework

This study is based on a conceptual framework that explores the effect of Problem-Based Learning (PBL) on students' academic performance in chemical reactions. PBL is the independent variable, while academic performance is the dependent variable. The framework suggests that PBL improves learning outcomes through four mediating factors: conceptual understanding, learner engagement, collaboration, and problem-solving skills. By actively engaging students in authentic problem-solving tasks, PBL enhances these skills, leading to better academic achievement. The framework also considers contextual factors, such as traditional teaching methods and the

Below is summary in diagram:

4.Methodology

This study adopted a quasi-experimental pre-test–post-test non-equivalent control group design. Random assignment of individual students was not possible due to the school-based setting; therefore, intact classes were used. The design enabled comparison between an experimental group taught using Problem-Based Learning (PBL) and a control group taught using the traditional lecture method. Pre-test and post-test measures were used to determine students' prior knowledge and measure the effect of the intervention on performance in chemical reactions. This design is widely used in educational research to evaluate instructional effectiveness in real classroom environments.

Population and Sampling

The target population comprised approximately 2,750 lower secondary students from four selected schools (School A, B, C, and D) in Nyarugenge District. Yamane's (1967) formula was used to determine a sample size of 349, which was adjusted to 348 for equal distribution across four schools. Stratified random sampling ensured proportional representation of gender and class streams. However, after excluding Senior 1 students (due to limited prior chemistry knowledge), the final sample consisted of 227 students (S2 and S3 only). Schools A and B formed the experimental group (PBL), while Schools C and D formed the control group (lecture method).

Research Instruments

Data were collected using a Chemistry Achievement Test (CAT) focusing on chemical reactions, including reaction types, equation balancing, and problem-solving. The CAT was administered as both pre-test and post-test. Content validity was ensured through alignment with the national curriculum, and reliability was enhanced through standardized administration.

Data Collection Procedure

A pre-test was administered to both groups to establish baseline equivalence. The experimental group was then taught using PBL, while the control group received lecture-based instruction over four weeks. After the intervention, both groups completed the same post-test.

Data Analysis

Data were analyzed using descriptive statistics (means and standard deviations) and inferential statistics. An independent samples t-test was used to determine whether there was a significant difference between the two groups’ post-test performance in chemical reactions.

5. Results Presentation

This section presents the findings of the study in line with the specific objectives. The analysis focuses on comparing the performance of students in the experimental and control groups before and after the instructional intervention, as well as examining the effect of Problem-Based Learning (PBL) on students’ academic achievement in chemical reactions.

Objective 1: Comparison of Pre-Test Performance between Experimental and Control Groups

Table 1
Pre-test Comparison

Group	Mean	SD
Control	17.70	8.78
Experimental	23.87	9.60

The pre-test results revealed that there was no statistically significant difference in academic performance between the experimental and control groups prior to the intervention. The experimental group obtained a mean score of 23.87 (SD = 9.60), while the control group recorded a mean score of 17.70 (SD = 8.78). Considering that the Chemistry Achievement Test was marked out of 50, both groups performed below average, indicating generally weak prior knowledge of chemical reactions.

These findings confirm that the two groups were comparable at baseline. Therefore, any differences observed in the post-test results can be attributed to the instructional intervention rather than pre-existing differences in students’ abilities. Overall, the results establish a strong baseline equivalency between the experimental and control groups before the implementation of the teaching intervention.

Objective 2: Effect of Problem-Based Learning on Post-Test Performance

Table 2
Post-Test Performance

Group	Mean	SD
Control	17.78	7.91
Experimental	29.34	7.75

The post-test results revealed a clear difference in academic performance between the experimental and control groups after the intervention. The experimental group taught through Problem-Based Learning (PBL) obtained a higher mean score of 29.34 (SD = 7.75) compared to the control group, which recorded a mean score of 17.78 (SD = 7.91). These findings indicate that students exposed to PBL demonstrated a stronger ability to understand and apply concepts of chemical reactions than those taught using the traditional lecture-based approach. This suggests that Problem-Based Learning had a positive effect on students' academic achievement in chemistry.

Further analysis using an independent samples T-test showed that the difference between the two groups was statistically significant, $t(225) = 3.28$, $p = 0.002$. Since the p-value was below the 0.05 significance level, the null hypothesis was rejected. This confirms that the observed improvement in the experimental group was not due to chance but can be attributed to the PBL intervention.

In short, the statistical results provide strong evidence of a significant difference between the experimental and control groups, confirming the effectiveness of Problem-Based Learning in improving students' performance.

6. Discussion of the results

This study examined the influence of Problem-Based Learning (PBL) on students' academic performance in chemical reactions in lower secondary schools in Nyarugenge District. The discussion is organized according to the study objectives and integrates statistical evidence with relevant literature and constructivist theory.

For the first objective, the pre-test results revealed no statistically significant difference between the experimental group ($M = 23.87$, $SD = 9.60$) and the control group ($M = 17.70$, $SD = 8.78$). Although the experimental group obtained a slightly higher mean score, both groups scored below the average mark of 50, indicating limited prior knowledge of chemical reactions. This finding suggests that the two groups were comparable before the intervention, thereby providing a fair basis for evaluating the effectiveness of the instructional approach.

The results are consistent with previous studies by Akinoglu and Tandogan (2007) and Tarhan and Acar-Sesen (2013), which similarly found no significant differences between experimental and control groups at the pre-test stage in Problem-Based Learning (PBL) research. They also support the observations of Yew and Goh (2016), who noted that students often begin chemistry instruction with limited conceptual understanding. Therefore, the baseline equivalence of the two groups strengthens the internal validity of the study and provides confidence that any differences observed in the post-test results can be attributed to the teaching method rather than pre-existing differences in students' abilities.

Regarding the second objective, the post-test results revealed a substantial improvement in the experimental group ($M = 29.34$, $SD = 7.75$) compared to the control group ($M = 17.78$, $SD = 7.91$). The difference in mean scores (approximately 11.56 marks) indicates that students exposed to PBL

significantly outperformed those taught using the lecture method. This suggests that PBL enhanced students' understanding and application of chemical reaction concepts by promoting active engagement, collaboration, and problem-solving. These findings are consistent with constructivist theory (Piaget, 1970; Vygotsky, 1978), which emphasizes knowledge construction through active learning and social interaction, as well as previous studies reporting improved achievement through learner-centered approaches (Hidayah et al., 2022; Zhao & Wang, 2022).

For the third objective, the independent samples t-test revealed a statistically significant difference in post-test performance between the experimental and control groups, $t(225) = 3.28$, $p = 0.002$. Since the p-value was less than the 0.05 significance level, the null hypothesis was rejected, indicating that the observed difference was unlikely to have occurred by chance. These findings provide strong evidence that Problem-Based Learning (PBL) had a positive effect on students' academic performance in chemical reactions.

The results are consistent with previous studies that have demonstrated the effectiveness of PBL in science education. For example, Akinoglu and Tandogan (2007) found that students taught through PBL achieved significantly higher academic outcomes than those taught using traditional methods. Similarly, Tarhan and Acar-Sesen (2013) reported that PBL enhanced students' understanding of chemistry concepts and improved achievement levels. The findings also support those of Yew and Goh (2016), who argued that PBL promotes deeper learning by engaging students in active problem-solving and collaborative learning processes. Therefore, the present study confirms that PBL is more effective than traditional lecture-based instruction in improving students' achievement in chemistry.

7. Conclusion

This study investigated the influence of Problem-Based Learning (PBL) on lower secondary students' academic performance in chemical reactions in Nyarugenge District, Rwanda. Based on the findings, it is concluded that there was no significant difference between the experimental and control groups at pre-test stage ($M = 23.87$, $SD = 9.60$; $M = 17.70$, $SD = 8.78$), confirming that the groups were academically comparable before the intervention.

After the intervention, the results showed a clear improvement in the experimental group taught using PBL ($M = 29.34$, $SD = 7.75$) compared to the control group taught using the lecture method ($M = 17.78$, $SD = 7.91$). Furthermore, the independent samples t-test confirmed that this difference was statistically significant, $t(225) = 3.28$, $p = 0.002$.

Therefore, the study concludes that Problem-Based Learning significantly improves students' academic performance in chemical reactions compared to traditional lecture-based instruction. This improvement is attributed to the learner-centered nature of PBL, which promotes active engagement, collaboration, critical thinking, and meaningful learning.

8. Recommendations

Based on the findings, the following recommendations are made:

For chemistry teachers

Teachers should integrate Problem-Based Learning strategies into the teaching of chemical reactions to enhance students' understanding, engagement, and academic performance.

For school administrators

School leaders should support teachers through professional development programs and provide teaching resources that facilitate the effective implementation of PBL in science classrooms.

For curriculum developers (REB)

The curriculum should include structured problem-based activities and real-life chemistry problems to strengthen the implementation of Competence-Based Curriculum goals.

For education policymakers: Policies should promote learner-centered pedagogies such as PBL through training, monitoring, and continuous teacher support to improve science outcomes nationally.

For future researchers

Further studies should explore the long-term effects of PBL on students' retention of chemistry concepts and its effectiveness across other topics and education levels in Rwanda.

Declarations

Ethics approval and consent to participate

Ethical approval for this study was obtained from the **University of Rwanda, College of Education Research and Innovation Unit**, which served as the institutional research ethics committee responsible for reviewing and approving the study **DRI-CE/052(a)/MT/gi/2026**. The study was conducted in accordance with the ethical standards of the institutional research ethics committee and applicable national research ethics requirements.

Informed consent

was obtained from all participants before their participation in the study. For participants under 16 years of age, written informed consent was obtained from their parents or legal guardians, and the students provided assent before participating. Participants aged 16 years and above provided their own informed consent. Teachers and school leaders who participated in the study also provided informed consent.

Participation was voluntary, and participants were informed about the purpose and procedures of the study and their right to withdraw without penalty.

Consent for publication

Not applicable. The manuscript does not contain personally identifiable information, images, or other information that could identify individual participants.

Competing interests

The authors declare that they have no competing interests.

Consent for Publication

Not applicable.

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Author Contribution

P.D.B. conceived the study, collected and analyzed the data, interpreted the results, and drafted the manuscript. J.K. supervised the research, contributed to the study design, reviewed the analysis, and critically revised the manuscript. Both authors reviewed and approved the final manuscript.

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Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Figures

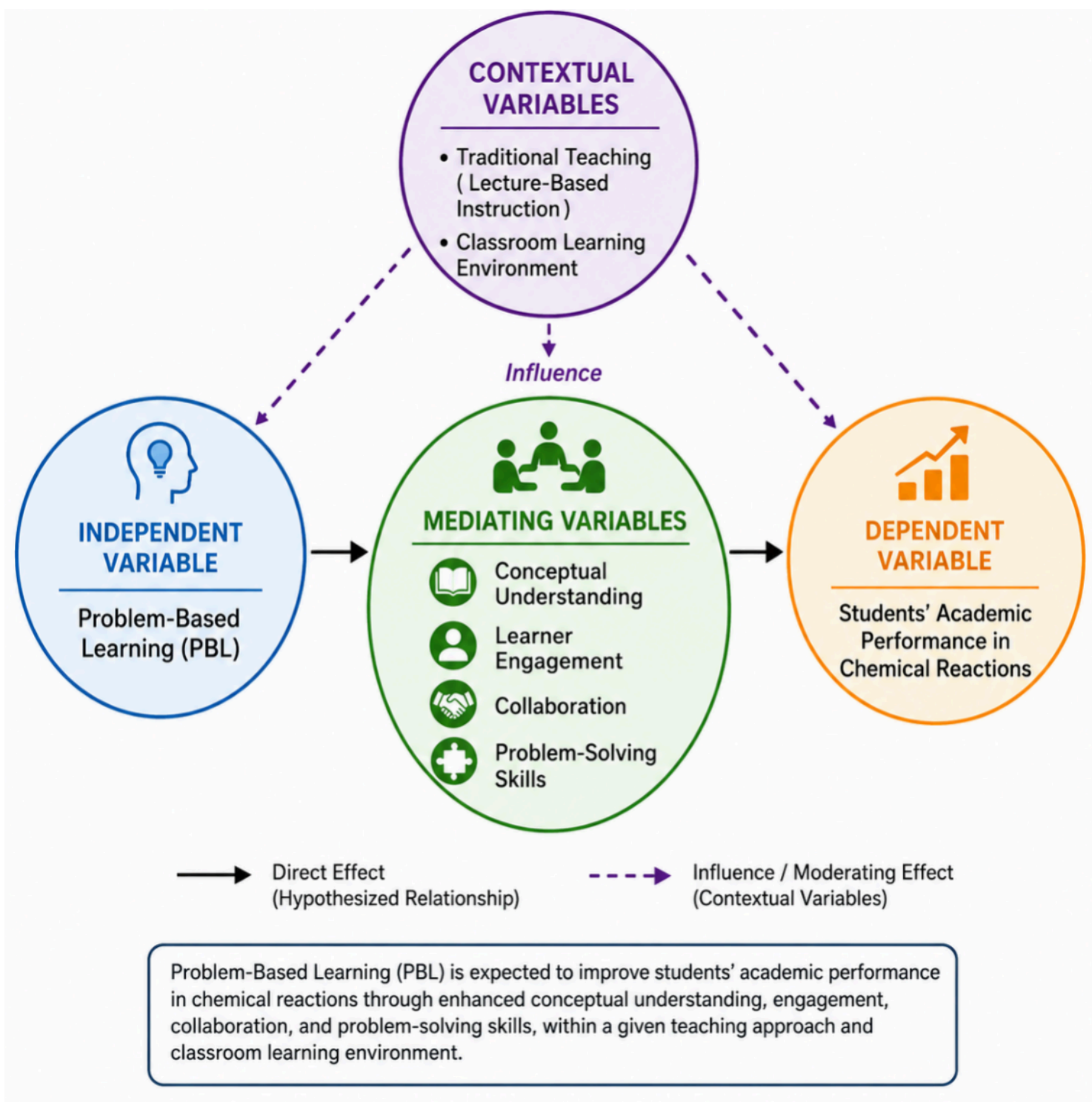


Figure 1

Diagram of Problem-Based Learning Framework

Supplementary Files

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- [APPENDICES.docx](#)