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# INTEGRATING MICRO PROJECT-BASED LEARNING TO IMPROVE CONCEPTUAL UNDERSTANDING AND CRUCIAL LEARNING SKILLS IN CHEMISTRY

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**Abstract.** *Active participation in project-based learning (PBL) could develop students` knowledge and crucial learning skills across various disciplines. However, the implementation of PBL in the K-12 classroom is usually impeded by the step-by-step PBL cycle. Micro project-based learning (MPBL), which advocates and adheres to the learning principles and mechanisms of PBL with constraining the learning cycle in shorter periods, has been considered as a lightweight alternative to PBL process. As an exploration, this study explored the impact of MPBL on the conceptual understanding of sodium bicarbonate and the crucial learning skills in chemistry class at upper-secondary schools. The quasi-experimental research was implemented for 125 students, with an experimental group receiving MPBL teaching and a control group receiving conventional teaching. In the study, data including knowledge tests, crucial learning skills survey, and student interview were collected and analysed. The results indicated that MPBL was effective in the development of students' conceptual understanding and crucial learning skills (i.e., communication and collaboration, information integration, independent learning, and problem-solving). The study will inform the pedagogical innovation in chemistry education and teaching practices in chemistry class.*

**Keywords:** *chemistry education, upper-secondary schools, pedagogical approach, sodium bicarbonate*

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### Introduction

The purpose of education is to cultivate students with a distinct sense of social responsibility, a sound personality, the spirit of innovation, the desire and ability for lifelong learning, good information literacy, etc., so that the new generations will have the skills necessary to adapt to the social, scientific and technological and economic development of the 21st century (Care, et al., 2017; Friesen & Anderson, 2004; Luo, et al., 2021; Walsh et al., 2022). However, in China, upper-secondary schools, teachers, parents, and students are still biased toward the pursuit of academic excellence and somewhat neglect the development of these learning skills (Cui et al., 2022; Xu & Liu, 2010). Being aware of such inadequacies, innovative pedagogical approaches, such as project-based learning (PBL), which foster competencies required in the 21st century, are suggested (Desnelita et al., 2021; Fiore et al., 2018). PBL is a learner-centred instructional approach that emphasizes learner-autonomy, productive inquiry, goal setting, collaboration, interaction, and feedback in the context of practical applications (Baser et al., 2017; Kokotsaki et al., 2016). It has been integrated into the teaching of different subjects. The research has demonstrated that PBL is effective in developing students' conceptual understanding and crucial learning skills (Chen & Yang, 2019; Krajcik, et al., 2021). Besides, some research also identified several challenges which hinder the implementation of PBL in actual classrooms, especially in upper-secondary schools (Chen et al., 2021). The most prominent challenge lies in the conflict between the long time spent on a PBL cycle and the limited time available in a class (Habók & Nagy, 2016). Following the PBL approach, teachers usually find it difficult to complete the planned lessons. Moreover, studies found that students' engagement may decline in a prolonged learning cycle (Oteyza, 2012).

In school-based learning, a lightweight form of PBL approach is more feasible. Micro project-based learning (MPBL), which shares the same core principles and mechanisms with PBL but features a shorter learning cycle, is recognized as a lightweight alternative in a regular classroom (Díaz Redondo et al., 2021; McDonnell et al., 2007). With the desirable characteristics of be-



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ing "short, precise, and highly applicable", MPBL attaches importance to core concepts and can be adopted across different subjects, grades, and schools (Külahçı, 1994; Lombardo, 2006). In comparison with PBL, it is easy to design and implement in addition to helping achieve multiple learning objectives including the improvement in knowledge, skills, motivation, and enthusiasm for learning (Dowis & Schloss, 1992; Maleki & Verrett, 2018; Zhang, 2021).

The chemistry class calls for the integration of MPBL in teaching and learning to provide students with assistance in the development of conceptual knowledge and the application of concepts to interpret the phenomena in daily life and solve problems in real life (Aksela & Haatainen, 2019; Gutwill-Wise, 2001). Yet, little discussion and practice are available in this regard. In chemistry education, the textbook introduces the concept of sodium carbonate in the module named Sodium Metals & Sodium Compounds, and it emphasizes the stimulation of comparative thinking by elaborating on the properties and experimental investigation of sodium bicarbonates, as well as the similarities and differences between it and sodium carbonate (MoE of China, 2019). Sodium bicarbonate enjoys a wide application in scenarios in daily life, from food production to medicine manufacturing (Babinčáková, 2020). However, the textbook provides an explanation of the extensive applications of sodium bicarbonate in a limited space. They mostly describe their application using static representations in the form of texts or images and fail to emphasize a core principle of the discipline— the properties of a chemical determine its use (Wright, 2021). Therefore, there is a lack of process-based demonstration and the rationale behind it, which makes it difficult for students to understand the relationship between chemistry knowledge and real-life experience, and the social value of chemistry (Krajcik, & Czerniak, 2018).

In this study, the incompatibility between PBL and the reality of upper-secondary school classroom teaching was addressed by leveraging MPBL. The effectiveness of an MPBL-integrated intervention on students' conceptual understanding of sodium bicarbonate and the development of crucial learning skills in chemistry class at an upper-secondary school was explored. In our study, communication and collaboration, information integration, independent learning, and problem-solving skills which have been emphasized in the curriculum and syllabus were adopted as crucial learning skills. In the MPBL lessons, the practical activities of making steamed buns were designed for connecting students' knowledge of sodium bicarbonate as an ingredient of a leavening food agent. Through participation in and interaction with the familiar, real-life scenario, we expected that students would improve their comprehension of the chemical concept and develop crucial learning skills including communication and collaboration, independent learning, information integration, and problem-solving.

## Literature Review

### *Project-Based Learning*

Project-based learning (PBL) is a pedagogical approach with a focus on the completion of projects through cooperating with each other (Krajcik & Blumenfeld, 2006). Specifically, it features the learning composed of procedures including searching for solutions, asking questions, arguing ideas, designing plans, and communicating with others (Choi et al., 2019). Many researchers and practitioners have conducted studies on integrating PBL into teaching and learning practices. The topics include the development of PBL (Ansarian & Teoh, 2018; Priemer et al., 2020); the framework of PBL assessment (Lin, 2018); comparative studies of PBL and other pedagogies (Chairuddin & Farman, 2022; Jatmiko et al., 2018); the revisions of PBL by integrating other approaches or contexts (e.g., scaffolded learning, STEM, Internet of things, cooperative learning, peer learning) (Ernawati et al., 2022; Musalamani et al., 2021; Siew & Ambo, 2018; Tsybulsky & Sinai, 2022; Veale et al., 2018), and the learning outcomes of PBL implementation (Alrajeh, 2021; Syakur et al., 2020; Zhang, & Hwang, 2022). Recently, the implementation of online PBL also attracts a great deal of attention due to the current disruptions to formal schooling resulting from the Covid-19 pandemic (Charania, et al., 2021). Chemistry educators lay emphasis on online PBL as it involves students in projects unfeasible in classroom settings due to the reasons of safety with the assistance from technologies of virtual and augmented reality (Kumar, 2010; Li et al., 2022; UZ et al., 2019).

Researchers generally agree with the idea that in the PBL process students learn actively and have a good master of knowledge and skills (Meilon et al., 2019; Putranta & Kuswanto, 2018; Qomariyah, 2019; Weng et al., 2022). PBL synthesizes communicative interaction and imaginative thinking, promotes collaboration (Greenier, 2020), develops the skills of problem-solving and crucial thinking, and stimulates affective and cognitive skills which contribute to intellectual and creative development (Barak & Yuan, 2021; Fauzia & Kelana, 2021).


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*Micro Project Based Learning (MPBL)*

Along with the accumulation of experience from theoretical and empirical studies of PBL, its deficiencies are increasingly apparent. The time spent on the implementation of PBL cycles is usually too much to deliver all the learning content of designed lessons on time (Wang et al., 2019). The issue also increases teachers' workloads and affects the learning effectiveness of PBL (Aldabbus, 2018). To mitigate this issue of incompatibility displayed by PBL in the classroom, researchers propose MPBL approach as an alternative, which is an innovative pedagogical approach that combines project learning and micro course (McDonnell et al., 2007). In comparison with PBL, MPBL is efficient, flexible, and practical. MPBL retains the advantages of PBL and could get students engaged in authentic problems, allowing them to develop skills covering collaboration, communication, and problem-solving in collective exploration (Bell, 2010; Frank et al., 2003); meanwhile, due to its characteristic of "micro", an MPBL cycle can be completed within one or two class periods. Therefore, it functions as a lightweight alternative to PBL (McDonnell et al., 2007). It was revealed by literature that there is limited research and application of MPBL in teaching and learning practices, with only a few studies on vocational education and higher education (Ji, 2020). In K-12 education, MPBL is a comparatively new topic, and the publications available are confined to miniaturizing PBL in laboratory instruction (McDonnell et al., 2007). The learning processes of MPBL, such as how to design a mini project which can include the core concept and involve task introduction, implementation, presentation, evaluation and reflection, feedback and adjustment, and effectiveness shown by MPBL are not explored sufficiently.

*The Teaching for Sodium Bicarbonate*

Sodium and its main compounds (e.g., sodium carbonate and sodium bicarbonate) are essential concepts in the chemistry curriculum at upper-secondary schools in China. Related learning objectives stated by the curriculum standard include: 1) understanding the main properties of sodium and its important compounds through explorations of experiments or paying attention to their applications in real-life situations, and 2) comprehending the applications of sodium compounds in life and production (MoE of China, 2020). Students of the 1$^{st}$ grade at upper secondary schools are expected to be able to compare and contrast the chemical properties of sodium carbonate and sodium bicarbonate and understand and apply the core principle of chemistry discipline.

When sodium bicarbonate, an important sodium compound, is heated, it decomposes into carbon dioxide, water, and sodium carbonate; it reacts with acetic acid to generate sodium acetate, water, and carbon dioxide (Greenwood & Earnshaw, 1997). These properties make it as an ideal ingredient for the leavening agent, due to the process that increases gases such as carbon dioxide to improve the volume and taste of essential foods, steamed buns for instance, in our daily life (Arranz-Otaegui et al., 2018). Sodium bicarbonate produces carbon dioxide in thermal decomposition and interacts with acid, both of which are essential mechanisms in leavening (Rask, 1932).

Using food leavening agents as an example of the application of sodium bicarbonate in daily life is one of the common strategies to teach the properties of sodium bicarbonate (Babinčáková, 2020; Lanni, 2014), but they are more positioned as fun activities, rather than a systematically organized learning project which can deepen understanding of the concept through the exploration of the principles related to fermentation and leavening. In addition, there is a lack of coherence among various activities and knowledge points. To resolve all these issues, it is expected that there will be a project-based approach providing connected, consistent, and systemic experiences.

*Research Purpose and Questions*

Stimulated by the potential of MPBL in science education, this study explored the impact of an MPBL pedagogical approach on students' conceptual understanding and the development of related crucial learning skills in chemistry class. The following research questions were answered:

1. What were the specific strategies for integrating the MPBL pedagogical approach into the teaching of chemistry concepts and crucial learning skills at upper-secondary schools?
2. Could the MPBL pedagogical approach improve students' conceptual understanding of sodium bicarbonate in chemistry class?
3. Could the MPBL pedagogical approach develop students' crucial learning skills including communication and collaboration, information integration, independent learning, and problem-solving?
4. What were students' perceptions and attitudes toward MPBL integrated chemistry class after experiencing intervention?


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## Research Methodology

*Research Design*

The study was conducted in the fall term of the academic year of 2021/2022 at a local public upper-secondary school in mainland China. In this study, a quasi-experimental research design was implemented. The design consisted of one experiment group receiving the MPBL approach, and one control group receiving conventional teaching. Both qualitative and quantitative methods were used in the data analysis.

*Participants*

Two classes with the same knowledge level from Grade 1 at an upper-secondary school (A total of 18 classes) were selected as an experimental group ($n$ = 63), and a control group ($n$ = 62). The sampling method adopted in this study was purposive sampling, i.e., the two classes with the closest levels in their grade were selected to participate in the intervention based on their midterm exam results. The school was located in the north of Henan, China. Since the study was conducted based on a class, the aim—an equal number of participants between two groups—was not achieved. Besides, the two sexes in the experimental and control group classes were roughly equal because the school assigned each class equally between boys and girls as much as possible when they enrolled. It can be seen from Table 1 that in both groups, over 45% of the participants are female, with a mean age of 15 and a standard deviation of 0.47 and 0.51. According to the participant's demographic information on socioeconomic status (Hair, et al., 2015), they were generally from middle-class families, and in both groups, most of the students' parents had high school diplomas.

The two classes were comparable in terms of academic performance obtained from the mid-term exam. A teacher with more than five years of teaching experience was recruited to teach the students from the control and experimental groups in a separate class. Students' natural learning environment did not change during the study period. Consent from the participants, parents, and the school was obtained before the intervention.

**Table 1**
*Demographic Characteristics of the Participants*

| Groups | $N$ | Male-female ratio | $M_{Age}$ | Family socioeconomic status | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Parents' education level | | | Family income level | | |
| | | | | Elementary school diploma | High School Diploma | College diploma | Upper class | Middle class | Poor Class |
| Control group | 62 | 28:34 | 15 | 9 | 42 | 11 | 5 | 51 | 6 |
| Experimental group | 63 | 30:33 | 15 | 10 | 45 | 8 | 2 | 53 | 8 |

*MPBL Pedagogical Approach and Process*

Through the integration of the principles with the mechanisms of PBL and micro course, a process-based model for the design and implementation of MPBL in chemistry class was developed. The process was divided into 6 phases (Figure 1), task design and introduction, implementation, presentation and review, evaluation, and summary and reflection, and feedback and adjustment (Krajcik & Blumenfeld 2006; Lombardo, 2006). Take the teaching of the leavening agent as a case, the MPBL in the teaching of the leavening agent contained an integration of in-class and out-of-class sessions which takes about 1-2 class hours (40 mins in one session). In the first phase, teachers and students prepared for the project (out-of-class activities). Teachers analysed the curriculum, determined the learning content, divided students into 9 groups in advance, and then provided a report on food

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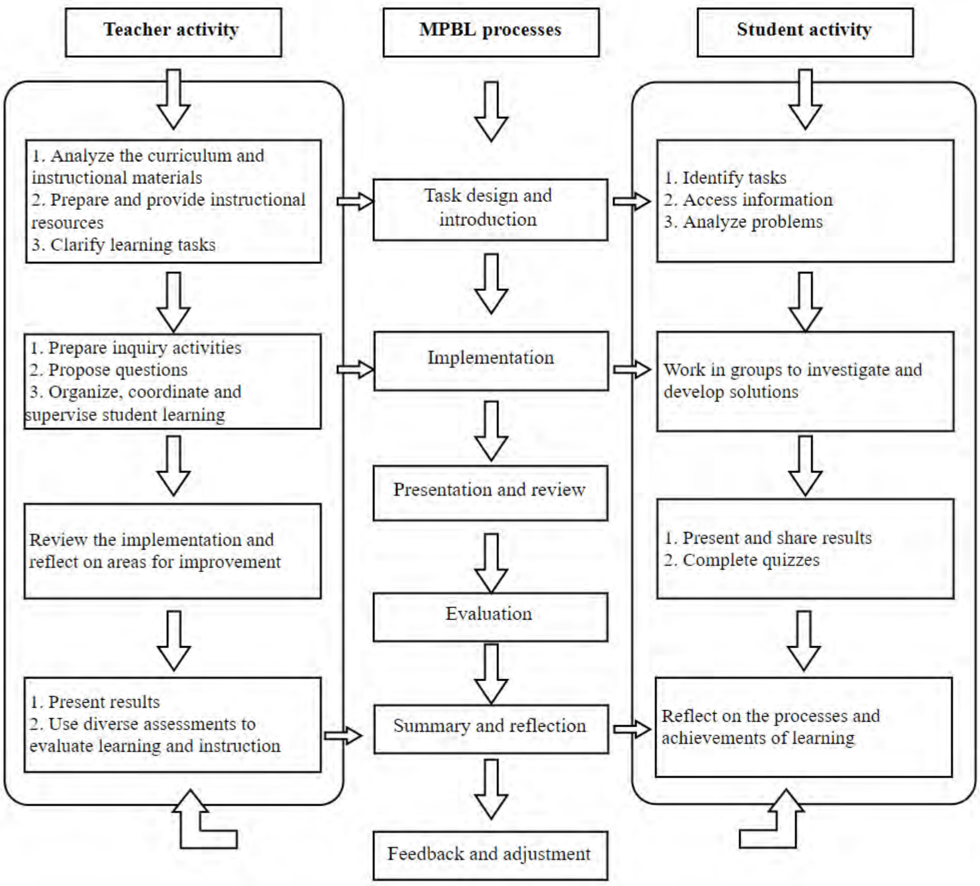
additives to students as a preview. Students were required to search and gather relevant information online and offline by themselves to make better preparation for the lesson. Through completing the tasks, students developed their information integration skills and independent learning skills (Ayaz & Söylemez, 2015). In the second phase, students conducted inquiry activities in groups. Each of the 7 students in every group played the specific role of the Leader, Experimenter, Observer, Recorder, and Reporter. The inquiry activities contained exploring the working principle of sodium bicarbonate as a leavening agent, the chemical properties of sodium bicarbonate, and the comparison of sodium bicarbonate and sodium carbonate. Most of the inquiry activities need collaboration so that students could develop their collaborative learning skills and problem-solving skills (Chiang & Lee, 2016). After the exploration phase of task understanding (5min), hypotheses forming (5 min), experimentation (10 min), analysis and discussion (10 min), and elaboration and extension (10 min), students had to apply conceptual knowledge and creative thinking to the settlement of practical problems, making their products (out-of-class activities) and sharing their product and result (10 min). In this phase, they deepened their understanding of the concept and experienced the joy obtained from problem-solving (Nainggolan et al., 2020; Song, 2018). After the presentation phase, the teacher, peers, and themselves evaluated the students' presentation (5 min). At the end of the lesson, the teacher guided their students to make a summary and reflection for the project learning (5 min). After the implementation, teachers collected feedback from peers and students, and made an adjustment for the projects further improved. The specific lesson design can be seen in Appendix A.

**Figure 1**
*Flowchart of the MPBL Process and Activities*





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*Procedures and Instrument*

This study was implemented for about 3 weeks after the mid-term exam. In the first week, students from both the control and experimental group completed the crucial learning skill survey and the data of their responses were analysed. Then, the micro project was implemented in the second week. For the last week, students from both groups completed the knowledge test, and the post-survey of crucial learning skills, and the experimental group students attended the interview.

To evaluate the effectiveness of MPBL integrated lessons on students' understanding of conceptual knowledge and the development of crucial learning skills, data in multiple forms including the results from the knowledge test, responses to the survey questionnaire, and interview responses were collected and analysed. Knowledge tests were composed of the mid-term chemistry exam, which was treated as the pre-test, and a specifically designed test on "sodium bicarbonate", which was regarded as the post-test. The post-test contained the classification, main components of leavening agents, and the principle of its action (sodium bicarbonate easily decomposed by heat, sodium carbonate does not decompose by heat, sodium bicarbonate and sodium carbonate acid-base comparison, the reaction of sodium bicarbonate with acid). The post-test adopted and adapted the questions used in the academic-level tests carried out in previous years. It included a total of 10 one-option questions (5 points each) and 10 blank-filling questions (2 points for each blank). Before the implementation, the tests were distributed on a small scale. The collected data's Cronbach's Alpha coefficient based on the standardized term and the KMO (Kaiser-Meyer-Olkin) sampling relevance measure were ensured to be higher than 0.7, indicating that the tests were valid and credible.

The survey questionnaire (Appendix B) was developed for the evaluation of the crucial learning skills development before and after the intervention. It was designed to refer to the General High School Chemistry Curriculum Standards and precious research, encompassing 4 sets of learning skills covering communication and collaboration, information integration, independent learning, and problem-solving (Gok, 2012; MoE of China, 2020; van Laar et al., 2019). For each skill set, there were 4 items. A 5-point Likert scale, ranging from Strongly Agree to Strongly Disagree, was applied for the collection of responses. Later on, a small-scale pilot test was conducted and the reliability of the collected data Cronbach's $\alpha = .815$ ($> .8$) and the KMO value = .848 ($> .8$). It indicated that the survey was credible and valid. The survey was implemented in both the control and experimental groups before and after the intervention.

Besides, in the experimental group, a semi-structured interview was conducted for the selected students to probe their perceptions and attitudes toward the MPBL integrated class after the intervention. The interview contained 4 questions (Appendix C), which asked students' view towards the MPBL compared with the traditional learning approach, whether and how MPBL helped their learning, if MPBL was an extra burden for their study and their suggestions about the MPBL further improving. Regarding the summary of the data collection process, please refer to Figure 2.


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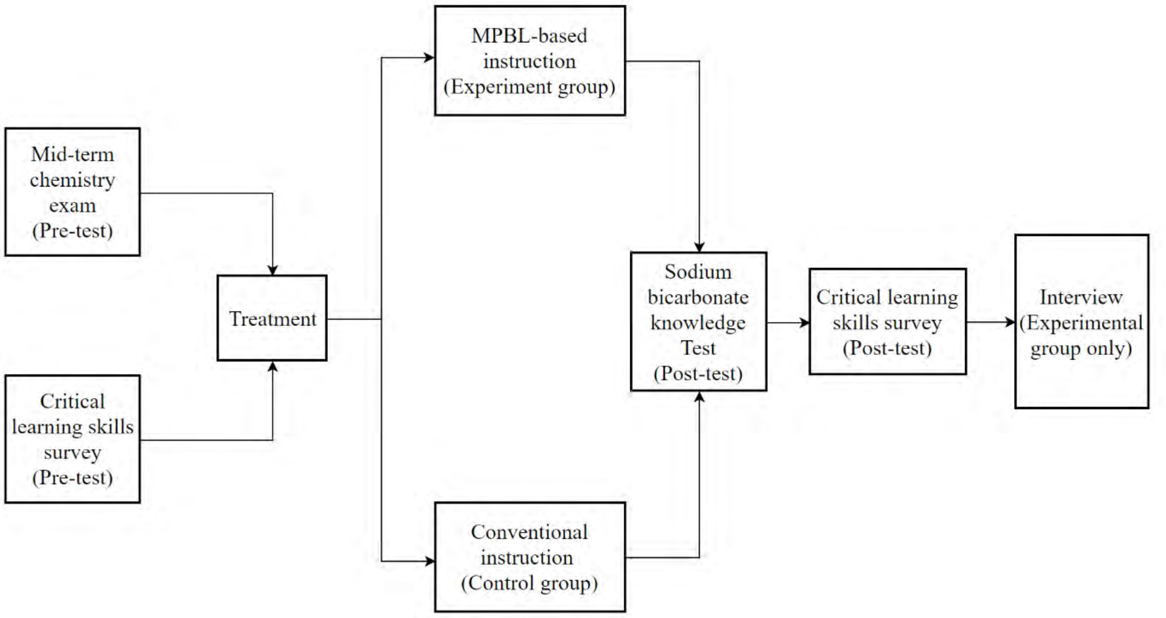
**Figure 2**
*Data Collection Methods and Processes*




*Data Analysis*

Data collected were analysed qualitatively and quantitatively. The application of quantitative analysis was carried out for the knowledge tests and the survey using the SPSS 22.0 software. Single-sample Kolmogorov-Smirnov (K-S) tests and independent samples *t*-tests were adopted to uncover group-based differences in conceptual understanding, which were reflected in the knowledge test. Descriptive analysis was adopted to investigate students' responses to the survey to explore group-based differences existing in the development of each learning skill set. Qualitative analysis of the semi-structured interview transcripts was conducted, with a focus on students' perceptions of and attitudes toward MPBL approach.

## Research Results

*Performance on Conceptual Understanding*

One-sample K-S test and independent sample *t*-test of both the pre-test and post-test of the two groups were performed. As Table 2 shows, the asymptotic significance values of pre-test scores in both groups are greater than .05, indicating that the scores obtained from the pre-test of both groups are normally distributed. The mean scores obtained from the control group and the experimental group are 42.90 points and 42.44 points, respectively. The post-test scores of both groups are also normally distributed ($p > .05$). The mean scores obtained from the control group and the experimental group were 46.87 points and 49.95 points, respectively. There was a difference of 3.08 points on average between the two groups, suggesting the positive impact of MPBL instruction on the development of conceptual knowledge in comparison with the conventional method.


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**Table 2**
*One-sample Kolmogorov-Smirnov Test Results*

| | Group | Control group | | Experimental group | |
|---|---|---|---|---|---|
| | *N* | 62 | | 63 | |
| Normal Parameters (a, b) | *M* | 42.90 | 46.87 | 42.44 | 49.95 |
| | *SD* | 15.212 | 12.235 | 16.549 | 14.613 |
| Most extreme differences | Absolute | .067 | .060 | .076 | .101 |
| | Positive | .060 | .060 | .076 | .060 |
| | Negative | -.067 | -.052 | -.052 | -.101 |
| | Kolmogorov-Smirnov Z | .067 | .060 | .076 | .101 |
| | *p* | .200 | .200 | .200 | .178 |

The test distribution was normally distributed b. It is calculated from the data

The group difference of the pre-test was not significant in accordance with the results from the independent sample t-test ($p = .872$) (Table 3), indicating the homogeneity of the two groups in terms of overall chemistry level before the intervention. The post-test Levene variance equality test in Table 3 shows that $p = .092$ (> .05). Then, assume equal variance and the $p = .204$ (> .05), indicating that the post-test scores of the two groups are not significantly different. This insignificance may be ascribed to the limited time spent on the implementation of MPBL.

**Table 3**
*Independent Sample t-Test Results*

| | | Levene Variance Equality Test | | Mean *t*-test | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | **95% confidence intervals for differences** | |
| | | *F* | *p* | *t* | *df* | *p* (2-tailed) | *MD* | *SD* error | Lower | Upper |
| Pre-test | Assume equal variance | .425 | .515 | -.161 | 123 | .872 | .459 | 2.844 | -5.171 | 6.089 |
| | Assume unequal variance | | | -.161 | 122.434 | .872 | .459 | 2.842 | -5.168 | 6.085 |
| Post-test | Assume equal variance | 2.885 | .092 | -1.277 | 123 | .204 | -3.081 | 2.413 | -7.857 | 1.694 |
| | Assume unequal variance | | | -1.279 | 119.934 | .203 | -3.081 | 2.409 | -7.851 | 1.688 |

*Students Responses to Crucial Learning Skills Survey*

All 125 participants in both groups completed the pre-test survey about crucial learning skills, with a completion rate of 100%. A descriptive analysis of the percentage of students' choice of each option on each item was conducted, with the result displayed in Figure 3.

The pre-test questionnaire analysis was divided into 4 groups, including communication and collaboration (as reflected in Item 3/4/7/9 in Figure 3a), information integration (as reflected in Item 1/8/11/14 in Figure 3b), independent learning (as reflected in Item 6/10/12/15 in Figure 3c), and problem-solving (as reflected in Item 2/5/13/16 in Figure 3d). In every Item, the E represents the experimental group and C represents the control group.


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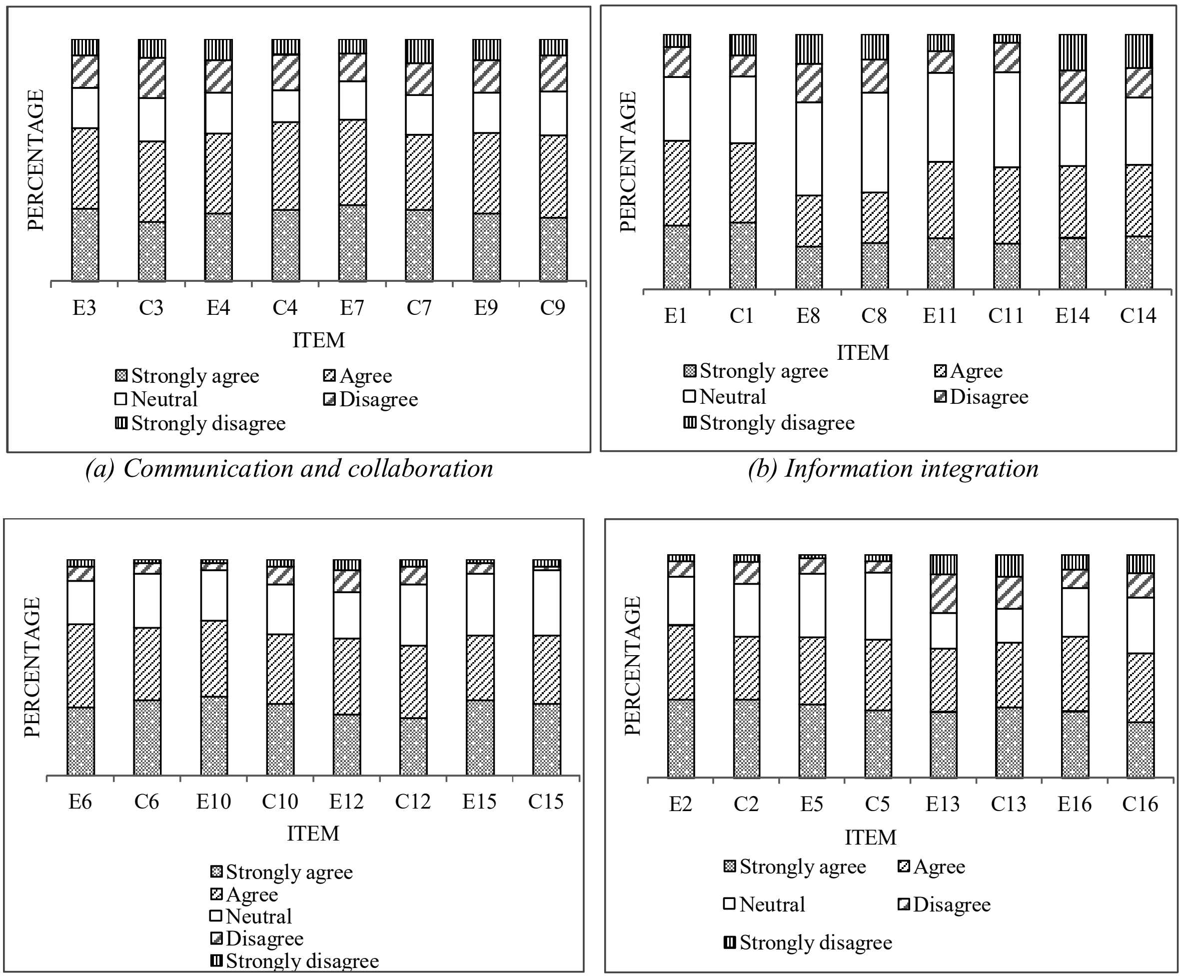
**Figure 3**
*Descriptive Analysis of Crucial Learning Skills Survey Responses in the Pre-Test*




*(a) Communication and collaboration* *(b) Information integration*

*(c) Independent learning* *(d) Problem-solving*

** E indicates the experimental group and C indicates the control group.*

According to observation (Figure 3), the distribution of the responses of different types is consistent between the two groups. The experimental group and the control group were equal in the area of skills including communication and collaboration, information integration, independent learning, and problem-solving before the intervention.

To assess the effectiveness shown by the MPBL approach for the development of important learning skills, the same survey was adopted again after its implementation, and a comparison between the experimental group results and those of the control group was conducted using the same method. The descriptive analysis results, as displayed in Figure 4, are in favour of the MPBL teaching. The ratio occupied by positive responses of "Strongly agree" and "Agree" in the experiment group is greater than that of the control group across different items. In general, it was reported that the students in the experimental group were equipped with better skills in the four foci areas.


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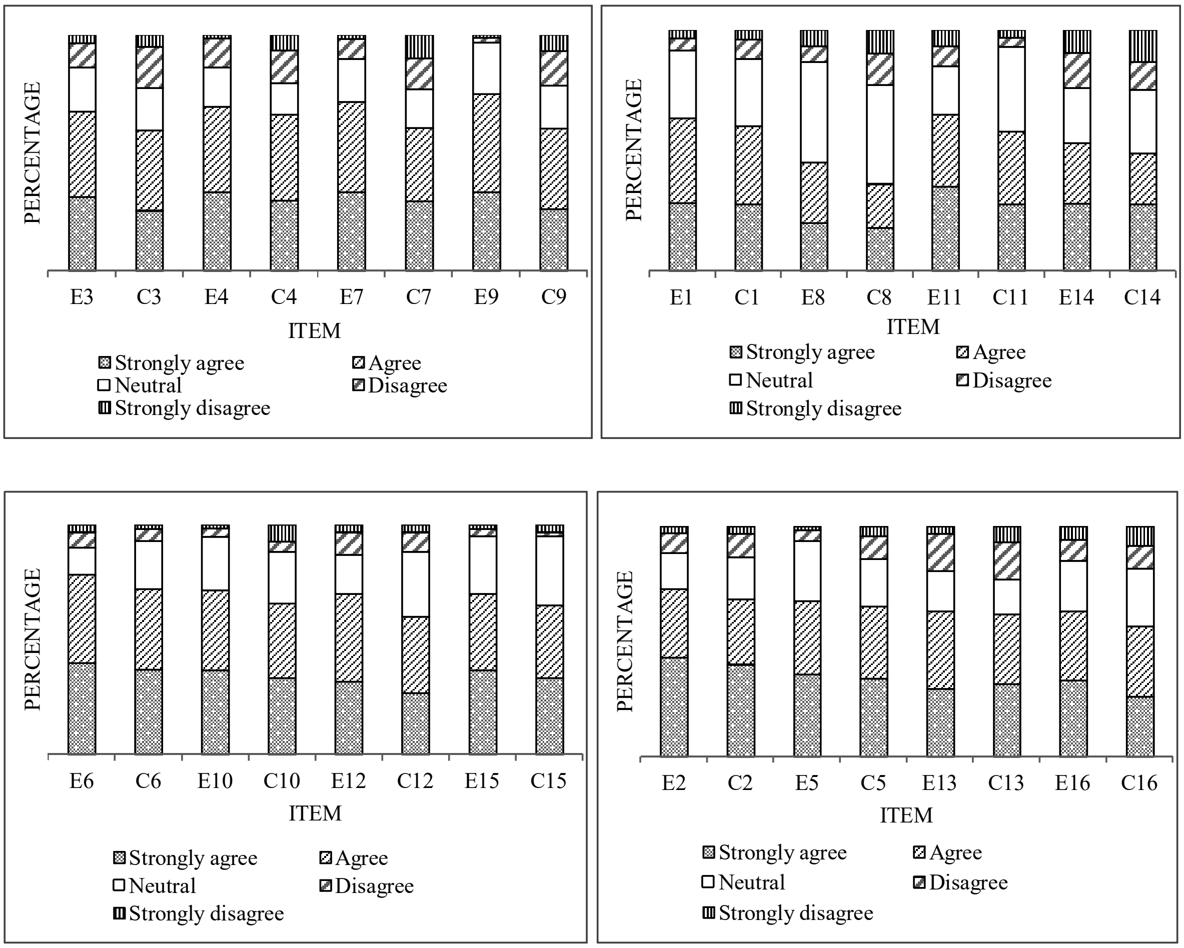
**Figure 4**
*Descriptive Analysis of Crucial Learning Skills Survey Responses in the Post-Test*




*(c) Independent learning* *(d) Problem-solving*

To delve into and explain how the two groups get improved in each learning skill set after the intervention, every option was assigned points (1 for Strongly agree, 2 for Agree, 3 for Neutral, 4 for Disagree, and 5 for Strongly disagree). The differences in mean scores between the pre-test and post-test of the two groups obtained on each survey item were calculated using the following formula. [Main difference between post and pre-test for every item = $\sum_{\text{post-test}}$(Assigned point for each option × Percentage of people who select this option) – $\sum_{\text{pre-test}}$(Assigned point for each option × Percentage of people who select this option)].

Items 3, 4, 7, and 9 of the survey explored the communication and collaboration skill of the respondents, and it was indicated by the overall results that MPBL improved students' communication and collaboration skills successfully in this regard. As shown in Figure 5, the average score obtained by the control group stays almost unchanged in the post-test, with a minor increase on Item 3. In contrast, it is an apparent increase in the mean score in the experiment group, with improvement on all items, especially in Item 9. The 3$^{rd}$ item had a close connection with group discussion and negotiation (*I3: I persuade others when I disagree with them*). In conventional teaching, there were also opportunities for students, though not frequent, to get engaged in group work. Such experience might lead to the development of this specific skill. Nevertheless, group work functioned as a major component of MPBL, and students in the experimental group, in comparison with their peers, achieved considerable progress after the instruction. The group-based inquiry activities in MPBL also got students involved in communication and collaboration with the members from the same group frequently to solve problems. That was probably the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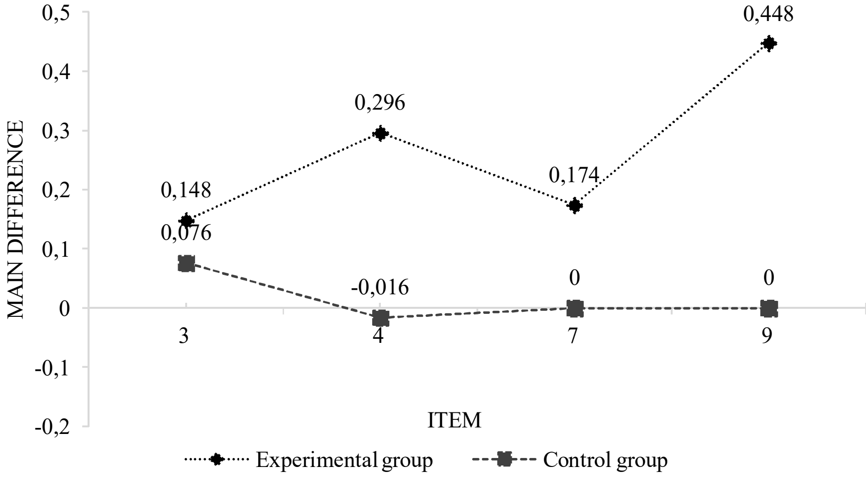
reason why the experimental group got improved to such a great extent on the 9th item *(I9: I communicate with group members to complete the task).*

**Figure 5**

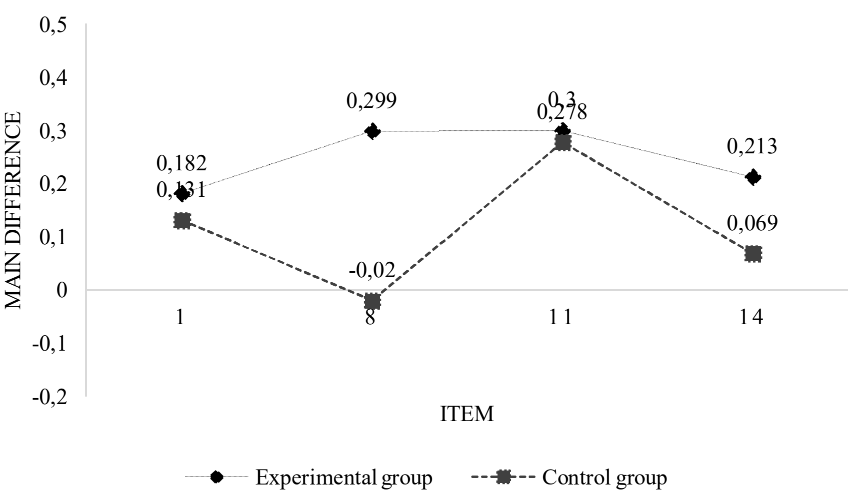
*Mean Score Differences between Groups of Communication and Collaboration*




Items 1, 8, 11, and 14 were relevant to the skill of information integration. As shown in Figure 6, both the control and the experimental groups get improved in this skill set on the whole after the instruction, but the performance of the experimental group is slightly better than that of the control group. It is worth noting that for Item 8 *(I8: I know how to find chemistry-related websites and information*), group difference is much evident. In terms of the experimental group, the mean score obtained is 0.3 points greater than that of the pre-test survey. Nevertheless, the control group witnessed a decrease in the mean score obtained from the post-test. Such discrepancy may be explained by whether students got engaged in actual application and practice regarding the skill of information collection and consolidation in instruction. In MPBL teaching, it was required that students should search for and compile relevant information before the lesson, whereas in the conventional classroom, there was no existence of such experiences. As a consequence, in comparison with their counterparts, the experimental group reported better in the skill of information integration on the whole.

**Figure 6**

*Mean Score Differences between Groups of Information Integration*





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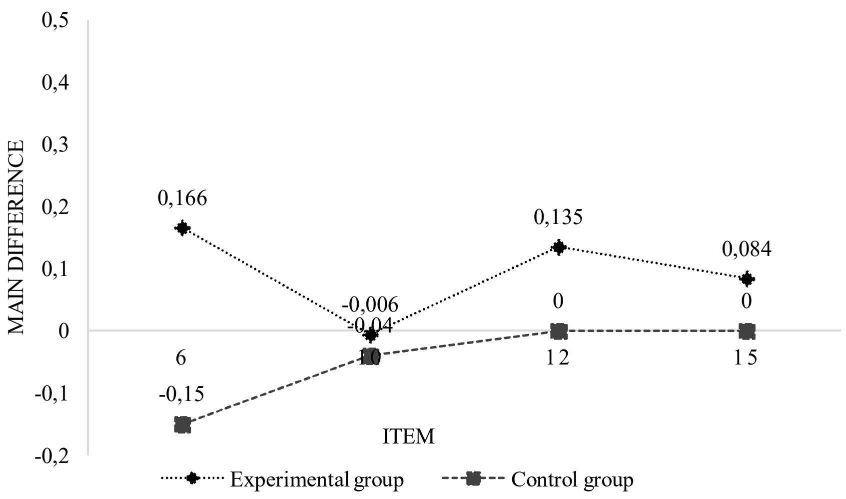
In comparison with the first two skill sets discussed above, not much growth is available in the mean score for the independent thinking skills in the post-test. As shown in Figure 7, there is a minor increase in the mean score regarding Items 6, 12, 15 in the post-test survey of the experimental group. Thanks to the MPBL approach, students were able to get engaged in self-regulated learning sessions frequently. It required that students could do previews, complete application-related tasks, and reflect and retrospect on their own. These experiences were useful and necessary for the development of independent learners. However, the cultivation of autonomy in learning is a long-term process, and the implementation of this exploratory study was far from sufficient, with minor effects generated.

On the contrary, in the control group, no growth is available across all four items. For Item 6 and 10, the mean score even decreases in the post-test process concerning the control group. Following the conventional method, the teacher assigned many tasks to students for completion before the class, so she could attach greater importance to the target concepts in the time during the class. Some of the tasks were too complex to finish, and the students were somewhat discouraged, which probably led to the control group reporting more negative responses for Item 6 in the post-test (*I6: I can complete the tasks assigned by the teacher before the lesson*). Correspondingly, they did not think they managed the time to study effectively outside of the classroom and responded negatively to Item 10 (*I10: I manage my study time effectively outside of the class*).

**Figure 7**

*Mean Score Differences between Groups of Independent Learning*




Items 2, 5, 12, and 16 were about the problem-solving skill. Similarly, the enhancement of this skill set was more prominent in the experimental group. As shown in Figure 8, there was an increase in the mean score across all four items in the post-test of the experimental group, and the increase is much greater than that of the control group, indicating the superiority shown by MPBL over the traditional method of instruction. In MPBL, students solved authentic problems by connecting chemistry with real-life situations. During the process, they developed both the mindset and skill for problem-solving. On the contrary, students in the control group were deprived of these experiences, and therefore they failed to be equipped with the confidence and capability for problem-solving which was reflected in their responses to the post-test survey, especially for Item 5 *(I5: I can use my knowledge of chemistry to solve problems).*


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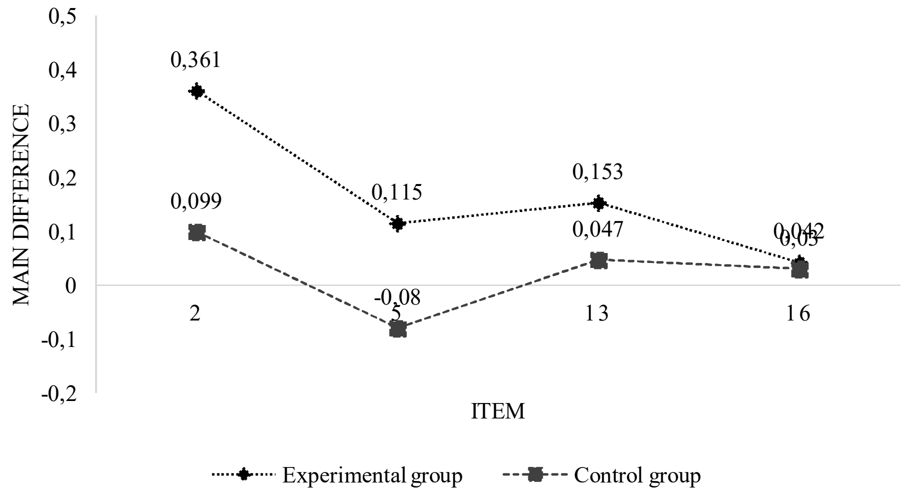
**Figure 8**

*Mean Score Differences between Groups of Problem-Solving*




It was demonstrated by the overall analysis of the survey questionnaire that MPBL could function as an effective pedagogical approach for the development of crucial learning skills including communication and collaboration, information integration, independent learning, and problem-solving. Moreover, the effect was more evident in the promotion of collaborative skills.

*Student Interview Results*

To better understand student experiences and perceptions of MBPL, 8 students from the experimental group were randomly selected for a semi-structured interview. Some representative responses from the interviewees were presented below:

***Question 1:*** *Which teaching method do you prefer, MPBL or the conventional method? Why?*

***Answer 1:*** *I prefer MPBL, because in the conventional method, teachers talk more in most of the time, while in MPBL, we read materials before the class, did hands-on practice, and displayed and shared our results. These activities significantly enhanced my interests in learning chemistry, so I prefer the former one.*

***Answer 2:*** *I like the way of learning with micro-projects. The questions in MPBL were exciting and required constant thinking, so we paid close attention in class and did not get distracted. In the MPBL class, we could also speak freely.*

***Answer 3:*** *I...how to say? I feel that the MPBL method is relatively new. However, the teacher asked too many questions, and I had to move from one question to the next before I completely understood and solved it first. Given the current situation that focuses on tests and examinations, I still prefer the conventional method where teachers emphasize and elaborate key knowledge points, making it easier for me to grasp them.*

***Question 2:*** *Was MPBL helpful? if yes, how did it help you?*

***Answer 1:*** *MPBL was helpful, especially in improving important learning skills such as problem-solving and collaboration.*

***Answer 2:*** *It helped me experience the connection between chemistry and life, the value of knowledge, and the joy of applying knowledge. In addition, we had the opportunity to do experiments by ourselves and have more exchanges with classmates.*

***Question 3:*** *Has MPBL added an extra burden to your study?*

***Answer:*** *Most students believe there was no added burden because the information collection and production activities of micro-projects were completed at home. However, one of them felt collecting information and completing the product shortened his rest time. He felt some pressure.*

***Question 4:*** *How do you view MPBL? Any suggestions?*

***Answer 1:*** *Generally speaking, I feel this pedagogical approach is okay, but there were some minor problems. For example, the group work was not well organized or supervised. Some students were lazy and idle in collaborative activities. If the teacher had helped us divide the work within the group in advance, our group would have been more efficient. I hope the teacher will facilitate and supervise every student in the classroom in the future.*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**Answer 2:** *(I hope) the teacher can give us a little more time to solve the problem. By the time the teacher asked us to make a report, our group had not reached an agreement yet. Then we just asked one group member to share her individual opinion. So hopefully, the teacher can give us a little more time to explore and discuss.*

Overall, students interviewed were optimistic about MPBL teaching. MPBL engaged them in class activities more than the traditional method did. The activities of experimentation and inquiry promoted their interest, activated thinking, and deepened learning. MPBL also provided them with more opportunities to communicate with classmates. Most students thought the MPBL approach was fresh and fun, and they hoped teachers to use it more often in the future.

A small number of students expressed their concern that they might be unable to grasp the key points in MPBL. A deeper look into such negative responses unveiled the influence of their knowledge foundation and learning style. This finding highlights the significance of student analysis and preparation to improve the acceptance and adaptability to MPBL. During implementation, teachers also need to engage these students in successful experiences to improve their attitude, confidence, and sense of personal value in the long run.

## Discussion

As a lightweight alternative to PBL, MPBL utilizes the key mechanisms of PBL while mitigating its incompatibility with the classroom, shortening the learning cycle, and activating students' interest and motivation to focus on classroom projects (McDonnell et al., 2007). For the specific strategies of integrating the MPBL pedagogical approach into the teaching of chemistry concepts and crucial learning skills at upper-secondary schools, it is noteworthy that the previous papers, although they mentioned the benefits of PBL and its impact on students' study, did not specifically address the improvement of certain problems in the implementation of PBL in the classroom at this stage (Ayaz & Söylemez, 2015). Besides, some studies have established some PBL design processes, but most of them are rough and lack a refined design process and specific cases of lesson plan integrating implementation (Zhao & Wang, 2022). In this study, the PBL pedological approach was revised into MPBL to make it more compatible with the upper-secondary science classroom.

In this study, the specific MPBL design process was divided into 6 steps, which contained task design and introduction, implementation, presentation and review, evaluation, summary and reflection, and feedback and adjustment (Barron et al., 1998). Based on these key elements of MPBL design, the concept that students need to understand during the lesson according to the curriculum standard, and the skills that they shall develop through the activities, the micro project for teaching sodium bicarbonate was developed and implemented in a local upper-secondary school (Krajcik et al., 1994; Krajcik et al., 2013).

The MPBL lesson plan for teaching sodium bicarbonate contained preparation and introduction, understanding the task, forming hypotheses, experimentation, analysis and discussion, elaboration and extension, summary, application, and presentation. The preparation, introduction, and task understanding part need students to collect and exact information by themselves so that they could develop information integration skill and independent learning skill. The designed driving questions in inquiry activities (forming hypotheses, experimentation, analysis and discussion, elaboration and extension, and summary) guided students to explore the working principles of sodium bicarbonate as a leavening agent step by step which mainly developed their problem-solving skill (Krajcik & Blumenfeld, 2006). Besides, most exploring activities need students' group work so that they could develop communication and collaboration skill. The application and presentation contained a making project which could inspire students' sense of satisfaction and achievement and help them deepen their understanding of the chemical properties of sodium bicarbonate (Hanif et al., 2019)

Regarding students' conceptual understanding of sodium bicarbonate, the MPBL experimental group achieved comparatively better performance than that of the control group in the knowledge understanding of the chemical properties of sodium bicarbonate from the result of the post-test. It has been confirmed by established research that the benefits of PBL to students' knowledge improvement were available (Günter & Alpat, 2017; Hakim et al., 2016; Musengimana et al., 2022). Sharing the same principles of PBL, MPBL was also proved to be effective in the enhancement of conceptual understanding in this study. Students designed and conducted chemical experiments, observed phenomena, and gained insights into the composition and working mechanisms of chemical leavening agents, by solving the encountered problems in the activity of making steamed buns which were common in daily life (National Research Council, 2012). Meanwhile, through the strengthened connection between chemistry


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knowledge and daily life experience, students developed an in-depth comprehension of the properties and applications of the target concept and a core principle of the chemistry discipline (Blumenfeld et al., 1991; Krajcik & Czerniak, 2013). However, although this study demonstrated that the experimental group, i.e., the class using the MPBL approach, had higher learning scores than the students in the control class in the post-test, the results were not significantly different statistically. This may be due to the limitation of experimental time and selection of teaching contents, the lack of relevant experience of the teachers, and the small sample size.

Regarding crucial learning skills, MPBL proved to be effective. It has been confirmed by previous research that the effect of PBL is available in nurturing communication, presentation, and independent learning (English & Kitsantas, 2013; Isik-Ercan, 2020; Situmorang et al., 2018; Tosun & Taskesenligil, 2013). However, most relevant studies focused on the university level (Belt et al., 2002; Overton & Randles, 2015). As a lightweight alternative to PBL, MPBL applied the affordances of scientific inquiry projects to the chemistry classes at the upper-secondary level to improve crucial learning skills including communication and collaboration, information integration, independent learning, and problem-solving, as reflected in the surveys. After participating in MPBL, students in the experimental group generally provided more positive responses concerning the survey items probing into their confidence in and application of the target skill sets. However, in the classroom with the traditional type, such improvement, if any, was less evident. For some items, even a decrease was available in the mean score obtained by the control group, which consequently suggests that conventional instruction is not supportive of or may even hinder the development of learners. Following the traditional approach, students relied too much on the teachers, and thus the opportunities for them to participate in scientific inquiry and problem-solving were somewhat deprived so they were seldomly engaged in collaborative learning experiences. Their motivation and interest in learning would be affected, and so did their self-efficacy (McParland et al., 2004; Vlassi & Karaliota, 2013).

For students' perceptions and attitudes toward MPBL integrated chemistry class, most of the students interviewed recalled that they had a sense of being involved and engaged deeply in the MPBL class. They were required to verify their hypotheses through the design of relevant experiments, which made them feel that learning knowledge was interesting. For the experimental group, learning was investigative rather than dictated. The experimental and investigative processes in MPBL, as discussed by McDonnell et al. (2007) and Mataka and Kowalske (2015), enhanced interest, activated thinking, and contributed to more in-depth learning. Moreover, MPBL provided students with more opportunities to interact with their classmates, and having perceived such benefits, students in the experimental group generally held a positive attitude towards MPBL. There were several students mentioned that they might be unable to grasp the key points in MPBL. A deeper look into such responses unveiled the influence of their knowledge foundation and learning style. This finding highlights the significance of teachers' lesson design and student analysis and preparation to improve the acceptance and adaptability to MPBL implementation.

## Conclusions and Implications

This study developed a specific strategy for integrating the MPBL pedagogical approach into the teaching of chemistry concepts and crucial learning skills at upper-secondary schools. Based on the MPBL design strategy, an intervention of MPBL integrated lessons was implemented in chemistry class. Through the collection and analysis of multiple data sources including knowledge tests and survey questions, the results of the quasi-experimental study demonstrated the learning effectiveness of the MPBL approach in improving students' conceptual understanding of sodium bicarbonate, and crucial learning skills (communication and collaboration, information integration, independent learning, and problem-solving) in chemistry education. Besides, student interviews showed most of the students who had received MPBL teaching approach had positive perceptions and attitudes toward MPBL integrated chemistry class. MPBL is largely effective in teaching chemistry and can have some positive effects on students' conceptual understanding and skills development. Therefore, teachers are suggested to design micro-projects with PBL principle in teaching practices, especially in the teaching of the physical and chemical properties of some materials and chemical reactions in chemistry classes. Using a project to link all knowledge organically as a whole can stimulate students' interest in learning, enhance their confidence in learning, and give them a sense of achievement in problem-solving. Teachers can set driving questions in the microprojects that are close to students' "nearest developmental zone" to avoid confusing students after the questions are asked, which will affect the project and reduce the sense of efficacy. In addition, teachers may assign some small tasks outside the classroom and focus on guiding students to cooperate in solving problems and making products to develop


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the ability to analyse and solve real-life problems. In addition, teacher professional development is necessary and will facilitate them to design and conduct MPBL lessons more effectively.

Based on the current study, there are several recommendations that can be carried out in further research. Although the MPBL approach achieved better results in knowledge development than the traditional approach, this difference was not significant. This may be due to the limited time spent on implementation and the lack of experience of teachers in guiding MPBL. In addition, as an exploratory study, the implementation process involved only a few participants with limited data. Moreover, due to some limitations, only one particular school and grade were selected for the implementation. Participants of different study levels and schools of different areas were not included. Therefore, the generalization of the study results should be done with caution. The insights gained and limitations found in this study can inspire and inform future research that aims to develop models, principles, implementation, assessment, and professional development for teachers to enhance MPBL capacity across disciplines, levels, and schools.

**Declaration of Interest**

The authors declare no competing interest.

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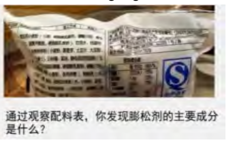
**Appendix A MPBL lesson design for the instruction of sodium bicarbonate**

| MPBL processes | Teacher activity | Student activity | Design rationale |
|---|---|---|---|
| Preparation<br>(Out-of-class activity) | Distribute the report on food additives for a preview. | Go to the market or search online to learn about different types of additives and conduct research on and collation of relevant information. | Develop skills in independent collection and integration of information. |
| Introduction<br>(In-class activity) | Instruct students to read the list of ingredients for a leavening agent and propose guiding Question 1.<br>*Q1: What is the main ingredient of the leavening agent?*<br> | 1) Read the ingredient list and identify sodium bicarbonate as the main ingredient.<br>2) Think over the role played by sodium bicarbonate. | Get students engaged in the process and encourage them to explore. |
| Understanding the task<br>(In class activity) | Guide students to read the materials and propose Guiding Question 2 & 3.<br>*Q2:* What problems occur in the bun-making process?<br>*Q3:* What are the causes? | 1) Read the material and launch a discussion on the processes of Lu and his mother's steam-bun-making.<br>*- Lu's mother added yeast to the flour and the steamed buns tasted alkaline and looked unshaped.*<br>*- Lu found that sodium bicarbonate could be used to leaven buns, but it may affect the taste and colour. The addition of vinegar would be a solution, which Lu and her mother tried and verified.*<br>2) Speculate on the mechanisms involved. | Guide students to pay attention to the properties and applications of the chemical using a real-life situation. |
| Forming hypotheses<br>(In class activity) | Propose Guiding Question 4 & 5, before guiding and facilitating students to generate solutions by working in groups.<br>*Q4:* Sodium bicarbonate is the ingredient for chemical leavening agents which are most commonly adopted. Why is it? What's the working principle of it?<br>*Q5:* What properties does sodium bicarbonate, as an important ingredient of chemical leavening agents have? | Discuss in small groups and put forward hypotheses about the properties of sodium bicarbonate.<br>*- The phenomenon that the steamed buns puffed up suggests that sodium bicarbonate generates gas upon being heated.*<br>*- The alkaline smell of the steamed buns indicates that sodium bicarbonate, after being heated, generates an alkaline residue.*<br>*- The phenomenon that the addition of vinegar changed the colour of the steamed buns suggests that sodium bicarbonate reacts with acetic acid in the vinegar.* | 1) Get students further engaged and connect chemistry to daily life using real-life situations.<br>2) Develop skills in information extraction. |
| Experimentation<br>(In class activity) | Guide students to design and conduct experiments to verify the hypotheses proposed. | 1) Design and conduct experiments for the verification of the properties shown by sodium bicarbonate hypothesized.<br>*Experiment 1: Verify the property about the easy decomposition of sodium bicarbonate upon being heated.*<br>*Experiment 2: Verify the property that sodium bicarbonate reacts with acetic acid.*<br>2) Observe and record. | Develop the mindset and skills for scientific inquiry. |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| MPBL processes | Teacher activity | Student activity | Design rationale |
|---|---|---|---|
| Analysis and discussion<br>(In class activity) | Propose Guiding Question 6, 7 & 8, and guide students to analyse and discuss the phenomena observed by them.<br>*Q6: How do you test whether the white solid produced during the heating of sodium bicarbonate is sodium carbonate or not?*<br>Q7: *Can soda be used to make a leavening agent?*<br>Q8: *Are all salt solutions have been studied by us neutral? How about the solution of sodium bicarbonate?* | Discuss and analyse the phenomena observed in the experiments.<br>*- In Experiment 1, we observed the solid change from crystal clear to white, at the same time of producing some gas, the lime water becoming unclear. The phenolphthalein can be used to test whether the white solid generated was sodium carbonate or not.*<br>*- As observed, sodium carbonate did not decompose after being heated, and therefore it cannot be used to make a leavening agent.* | Develop an in-depth comprehension of the target and related concepts (i.e., sodium bicarbonate, sodium carbonate, and salt solutions). |
| Elaboration and extension<br>(In class activity) | Propose Guiding Question 9 to further deepen students' thinking.<br>*Q9: What is the role of each ingredient in a compound leavening agent?* | 1) Read the materials about compound leavening agents.<br>2) Recognize respective roles played by carbonates, acids and additives in compound leavening agents. | 1) Discover and deepen the understanding of compound leavening agents and respective roles played by each ingredient.<br>3) Appreciate the value shown by chemistry in the improvement of human life. |
| Summary<br>(In class activity) | Guide students to make a summary of the working mechanisms of leavening agents, analyse the pros and cons for making leavening agents using sodium bicarbonate as the key ingredient, and compare the chemical properties shown by sodium bicarbonate and sodium carbonate, respectively. | 1) Make a summary of the working mechanisms of leavening agents.<br>*- Upon being heated, the chemical for the creation of leavening agents will decompose and produce non-toxic, odourless gas to puff up the bun.*<br>2) Make a summary of the pros and cons for making leavening agents using sodium bicarbonate as the key ingredient.<br>3) List a table in which the chemical properties of sodium carbonate and sodium bicarbonate are displayed. | Deepen the comprehension of leavening agents in food production and sodium bicarbonate via a comparative approach. |
| Application and presentation<br>(in-class and out-of-class activities) | Propose Guiding Question 10, and guide students to apply what they have learned to real-life scenarios.<br>*Q10: How would you choose the compound baking agent if you were the owner of a cake shop? Please design a baking compound which can be used to make your own pastry.* | Design and make a leavening agent using the materials available.<br>*- Add lemon juice to sodium bicarbonate to reduce alkalinity, but too much of it may affect the taste of the bun.*<br>*- Cultivate yeast to leaven buns.* | Apply conceptual knowledge and creative thinking to the settlement of practical problems. |
| | Display, evaluate and feedback to students' work. | Present and introduce their own works.<br> | Deepen the understanding and experience the joy obtained from application and problem solving. |


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**Appendix B Crucial learning skills survey questionnaire**

Dear Student,

Thank you for participating in this survey. The survey will take you about 20 minutes. It is anonymous and we will keep the information you provide confidential. Your honest response is appreciated. Thanks for your cooperation.

1. I think chemistry-related information is very common in our daily life.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

2. I like to work together with others to solve problems.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

3. I persuade others when I disagree with them.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

4. I can express my ideas in a structured way when I speak on behalf of the group.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

5. I can use my knowledge of chemistry to solve problems.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

6. I can complete the tasks assigned by the teacher before the lesson.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

7. I like to share my ideas with others.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

8. I know how to find chemistry-related websites and information.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

9. I communicate with group members to complete the task.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

10. I manage my study time effectively outside of the class.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

11. I ask others for advice on difficult topics.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

12. I sometimes do things that I have never done before on a whim.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

13. I have a clear mind for problem-solving.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

14. I know a variety of ways to find chemistry-related information.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

15. I summarize the areas for improvement in my learning.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

16. I come up with more solutions to a problem than others do.
A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree


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**Appendix C Student interview outline**

I. Purpose of the interview
To explore students' actual learning experiences in and attitudes toward the MPBL lesson.

II. Interviewees
Students from the Experimental group.

III. Interview questions
**Question 1:** Which method of instruction do you prefer, MPBL or the conventional method? Why?
**Question 2:** Was MPBL helpful to you? How did it help you?
**Question 3:** Have MPBL added an extra burden to your study?
**Question 4:** How do you view MPBL? Any suggestions?

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