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Research Article

Practical problem-solving tasks for meaningful learning and retention in college chemistry for pre-service teachers

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ABSTRACT

This study investigated the influence of practical problem-solving tasks (PPST) in promoting meaningful learning (ML) and retention in a nonlaboratory chemistry component of a physical science course for pre-service teachers (PSTs). It utilized a mixed-methods research using a modified quasi-experimental design followed by a detailed analysis of change in the conceptual understanding of case participants. The researcher employed mechanical and statistical matching to select 80 participants in two intact groups. The study's findings revealed that using PPST as a mode of instruction significantly promoted ML and meaningful retention of chemistry concepts. The study generated patterns of explanation, patterns of change in the level of conceptual understanding, and patterns of regression in understanding. The study further argued that PSTs exposed to PPST experienced ML as evidenced by (1) the outcome–significant differences in performances in ML and meaningful retention tests, (2) the process–qualitative evidence of positive change in conceptual understanding, and (3) the context–use of PPST designed for PSTs to engage in a learning process meaningfully. This study called for further research on the inclusion of PPST in other nonlaboratory classes in chemistry and other science subjects, both at secondary and tertiary level.

Keywords: practical problem-solving tasks, meaningful learning, meaningful retention, teacher content knowledge, chemistry education

INTRODUCTION

At the dawn of the 21st century, science education faces multiple challenges. An urgent problem facing science education today is the growing belief that students no longer view education as meaningful to their lives. Many students believe that schools hold no meaning and/or purpose (La'Keisha, 2018; Rice & Sianjina, 1997). This view is alarming; hence, there is a need to emphasize meaning-oriented teaching and learning, particularly in preparing prospective science teachers (Kostiainen et al., 2018; Rivera & Pérez, 2023).

What is meaningful learning (ML)? Novak (1993, 2002) traces the evolution of ML from the '30s onwards through the writings of Skinner, Piaget, and Kelly. According to Novak (2002), these three educational psychologists identify meaning as an essential factor in learning. A detailed conceptual understanding of ML was only uncovered through theoretical and empirical evidence in the '60s and '70s. While Novak (2002) credits Ausubel (1960) for his extensive contribution to the topic, recent publications include the study of ML in the context of video episodes and action cameras (Galloway & Bretz, 2015, 2016), concept mapping (Bressington et al., 2018), teaching laboratories (George-Williams et al., 2019), fourth-generation assessment tools (Ligabo et al., 2023), local research integrated into a chemistry class (States et al., 2023), writing-to-learn activities (Gupte et al., 2021) among others.

Given current advances in ML research in science education brought about by advances in qualitative research (e.g., Blackie, 2022; Raven & Wenner, 2022; Vergara et al., 2019)–this study has captured the whole spectrum of ML–as a process, context, and outcome. It revisits Ausubel's (1967, 2012) notion of ML as opposed to rote learning, emphasizing the salient role of a learner's prior knowledge in defining conditions, determinants, and outcomes of the acquisition and retention of concepts and conceptual understanding through a constructive, active, intentional, relational, and authentic construction of meanings (Kostiainen et al., 2018).

ML as a context has been linked to practical problem-solving (Rivera & Pérez, 2023; Toh, 1993). In fact, Novak (1985, 1993, 2002) considers practical problem-solving as a special case of ML. Initially limited to verbal materials as learning modes (Ausubel, 1960, 1961, 2012), ML has expanded to include all factors and conditions, including ML tasks, relevant prior knowledge, and ML set (Cavallo, 1996; Ferreira et al., 2019; Gupte et al., 2021). Both a process and an outcome, ML is best depicted as a form of conceptual change, a view of changing existing ideas to more scientifically sound conceptions (Li et al., 2023). As an outcome, ML is characterized by a change in conceptual understanding, a product of a mental process that establishes relationships between what would otherwise be isolated facts (Berlinger, 1987; Britz, 2001; Cavalcante et al., 1997), and by the meaningful retention of conceptual understanding (Driscol, 1994), emphasizing the stability in resisting the eroding effect of rote learning.

There are plenty of studies built on the Ausubelian psychology of ML (e.g., Chauke & Goosen, 2022; Dods, 1997; ElJishi, 2023; Haloun, 1996; He et al., 2023; Healy, 1989; Imam et al., 2022; Monereo & Perez, 1986; Okebukola, 1990; Okebukola & Jegede, 1988; Oladejo et al., 2022; Onowugbeda et al., 2022). However, they are limited to an aspect of indicators or conditions of ML. Most of these studies deal with conceptual understanding or meaningful retention of conceptual understanding, which partly indicates ML.

There are few attempts to expand ML across the affective domain in science education such as the creation of joyful experiences in a science class (Jeet & Pant, 2023), dispositional strategies (Durte-Herrera et al., 2019), and creative engagements (Anderson, 2020), and the psychomotor domain such as problem-based learning through citizen science projects (Cavas et al., 2023) and problem-based learning (Dods, 1987; Rizaldi & Fatimah, 2023). Despite these attempts, very little has been done to explore the entire spectrum of Ausubel's (2002) ML in the research design and across domains of stability and clarity of pre-service science teachers' knowledge in the context of task-based variables. This current study is significant because it captures ML conditions in the design of tasks, including its indicators in the process and outcome of learning.

REVIEW OF LITERATURE AND THEORETICAL UNDERPINNINGS

This study is located at the intersection of theoretical frameworks and/or conceptions surrounding pre-service science teachers' content knowledge (CK), meaningful retention (ML), and practical problem-solving tasks (PPST) in college chemistry.

Pre-Service Science Teachers' Content Knowledge

CK is critical to pre-service science teacher preparation (Mishra & Koehler, 2006; Shulman, 1986; Turan-Oluk, 2023). According to Koehler and Mishra (2009), CK is the "knowledge of concepts, theories, ideas, organizational frameworks, knowledge of evidence and proof, as well as established practices and approaches toward developing such knowledge" (p. 63). In line with chemistry education, this includes "knowledge of scientific facts and theories, the scientific method, and evidence-based reasoning" (p. 63). It is crucial for prospective chemistry teachers to meaningfully acquire a sound conceptual understanding of chemistry concepts, apply them to solve real-life problems and access them for future use in related problematic situations and settings.

Meaningful Learning

For CK to help solve problematic real-life situations, it must be meaningfully learned and assimilated into the overall cognitive structure of the learner (Ausubel, 2012; Britz, 2001). ML is the opposite of rote learning, which is an arbitrary and verbatim memorization of a learning material (Ausubel, 1978). Rote learning does not make sense to the learner. It is a futile kind of learning because concepts are retained only for a short period, interfere with previously known similar materials, and inhibit the application of new knowledge to other situations (Baptiste & Martins, 2023; Galili, 2022; Gil-Doménech & Berbegal-Mirabent, 2020; Gupte et al., 2021; Okebukola, 1990).

It is, therefore, a challenge among chemistry teachers to discourage rote learning and encourage ML. This is a challenge since using rote learning in the chemistry classroom downplays a meaningful educational experience among learners. Consequently, learners will have difficulty conceptualizing key topics related to the chemistry syllabus. This has a negative knock-on effect on the learning process of learners.

Meaningful Retention

Meaningful retention (MR) is defined as maintaining the availability of acquired information that may be accessed for use later (Ausubel, 1962, 1968; Driscoll, 2000; Healy, 1989; Zohar, 1996). It is also defined as the ability to recall, rediscover, or reconstruct the rule. Retention is closely related to the stability of the meaningfully learned material (Mayer, 2002). According to Driscoll (2000), the stability of the retained material is initially anchored to the relevant conceptual foci in the learner's cognitive structure. Such learned material is gradually subjected to the erosive influence of the reductionist trend in the cognitive organization. In our study, it refers to the regression of conceptual understanding. According to Ausubel (1968), meaningful retention effectively indicates ML. If meaningfully learned material is mastered better, to begin with, more incorporated meanings are available at any subsequent time when retention is tested. The superiority of the ML process can be reflected in a higher score on a retention test.

Practical Problem-Solving Tasks

PPST are defined as hands-on investigations with no prescriptive instructions for solving problems at hand (Cavas et al., 2023; Denney et al., 1982; Gallagher, 1997; Toh, 1993). Competing conceptions of PPST, such as challenged-based learning (CBL) exist. While PPST and CBL share commonalities such as "collaborative and hands-on, asking students to work with peers" (Nichols & Cator, 2008, p. 1; Leijon et al., 2021), the former was done in a classroom and did not require students to collaborate with experts outside the school setting.

PPST allows pre-service teachers (PSTs) not only to handle real objects but also to experience practical tasks themselves. The literature appears to categorize PPST in a broad spectrum of teaching learning approaches such as practical work, context-based problem, unstructured laboratory, discovery learning, and inquiry-based learning (Affriyenni et al., 2023; Avena et al., 2021; Abd-El-Khalick et al., 2004; Chi et al., 2023; Chin & Chia, 2005; Gijlers & Jong, 2005; Hodson, 1992; Sobral, 1995; Wu et al., 2019). Though these approaches differ in PPST in some ways, they share the essence of manipulating materials, exploring possibilities, and seeing outcomes, all necessary for forming connections between previously learned and new information (Dods, 1997; Lawson, 1995; Skolnik, 1995).

According to Ausubel (1968, 2012), the more meaningful, relevant, and complex the sensory input, the more the brain integrates and develops patterns. Novak (1990, 1993, 2002) hinted at the subsequent influence of problem-solving on ML and the importance of relevant prior knowledge in problem-solving. In this view, Novak (1990) considers problem-solving a special case of ML. While Novak (2002), during that time, did not explicitly examine the empirical and detailed theoretical support of his assertion, the implication is that this represents very fruitful prospects for ML research.

Although the research on problem-solving is informative, the key issue of the role of practical problem-solving remains inadequate. This lack of research is due to the untested assumption that problem-solving is a vehicle for learning. Furthermore, there is a paucity of research on the relationship between problem-solving, conceptual understanding, and ML. Despite the growing theoretical evidence on the importance of hands-on activities on learning, it is evident that a study on the influence of PPST on ML and MR in college chemistry remains under-researched, hence this research.

RESEARCH PROBLEM

Formal laboratory experiments to complement lectures have been the norm in teaching college chemistry. Current reforms in the curriculum have removed the laboratory component in traditional chemistry classes to infuse more science content courses in pre-service science teacher education. This calls for alternative courses of action to infuse problem-based, hands-on, and inquiry-based instruction in teaching major science courses of PSTs. Thus, this study investigated the influence of PPST, as an alternative to traditional laboratory-based college chemistry, on ML and retention among pre-service science teachers taking a freshman college chemistry course. This overarching question guided our inquiry: Does PPST promote ML and retention of college chemistry concepts?

Specifically, this study sought answers to the following questions:

1. Does PPST promote ML as evidenced by a higher mean in the ML test of PSTs exposed to PPST compared to those who are not exposed to PPST?
2. What are the patterns of change in PSTs’ conceptual understanding before and immediately after exposure to PPST compared to those not exposed to PPST?
3. Does PPST promote MR as evidenced by a higher mean in the meaningful retention test (MLT) of PSTs exposed to PPST compared to those who are not exposed to PPST?
4. What are the patterns of change in PSTs’ conceptual understanding one month after exposure and non-exposure to PPST?

RESEARCH DESIGN AND METHODS

This mixed-methods study utilized a quasi-experimental design (Fraenkel et al., 2012) modified as a pre-/post-test-delayed post-test control group design. The treatment group utilized the PPST in combination with a lecture method, while the control group utilized the purely expository lecture method (ELM). A modified feature of this design was the addition of another post-test in the form of a ML test, given a month after the post-test. Although this study used an experimental design, it included a qualitative analysis of patterns of change and regression in conceptual understanding among case participants.

The study sample consisted of two intact groups of 80 PST education freshmen who took natural science 102 (physical science), a general education subject in a teacher education curriculum. Random assignment was utilized to determine the control and the treatment group. The researcher was guided by the following exclusion criteria in coming up with 40 PSTs per group for the data analysis:

(1) PSTs who failed to take any of the three tests, namely, ML pre-test, ML post-test, and MRT,

(2) PSTs who did not match in other variables such as gender and ML pre-test score, and

(3) PSTs whose ages were outliers (i.e., 24 years old and above).

Due to partially matched scores (mechanical matching) in the ML pre-test via mechanical matching, statistical matching was performed using the t-test for two independent samples. Results showed that no significant difference existed in the ML pre-test scores of the two student groups before the intervention. Furthermore, the university college admission test (CAT) scores of 40 partially matched pairs of PSTs were tested for equality of means, and the difference was found statistically insignificant (p-value=0.148). To select PSTs for the qualitative analysis, 10 matched pairs were randomly selected to develop 20 case PSTs to compare patterns of change in conceptual understanding.

Instruments and Tools

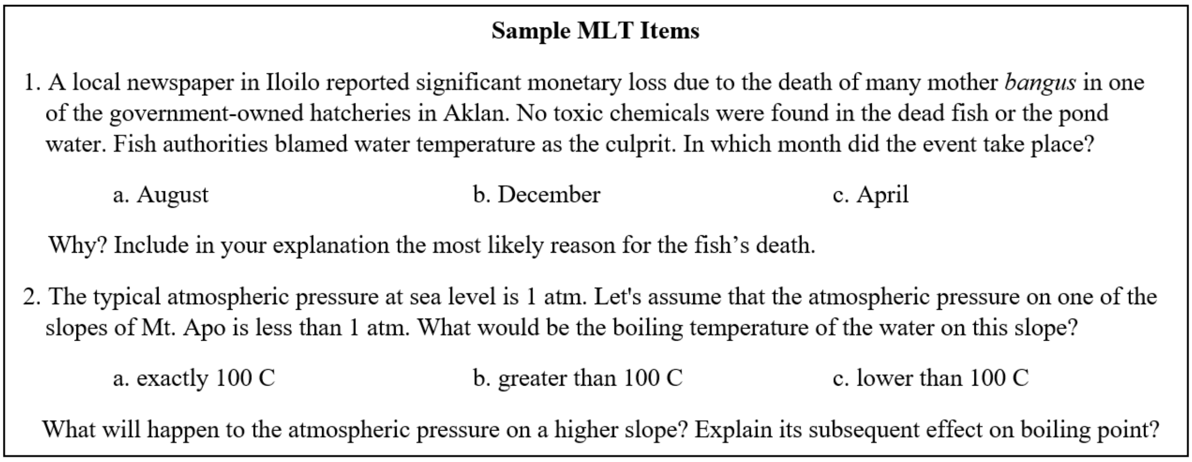
The researcher constructed the following instruments and tools for use in the study:

(1) the ML test,

(2) MRT, and

(3) PPST.

According to Okebukola (1990), ML is assessed by the higher-order understanding of concepts. Cavalcante et al. (1997) consider conceptual understanding as a product of a mental process that establishes



Sample MLT Items

1. A local newspaper in Iloilo reported significant monetary loss due to the death of many mother *bangus* in one of the government-owned hatcheries in Aklan. No toxic chemicals were found in the dead fish or the pond water. Fish authorities blamed water temperature as the culprit. In which month did the event take place?

   a. August b. December c. April

   Why? Include in your explanation the most likely reason for the fish's death.

2. The typical atmospheric pressure at sea level is 1 atm. Let's assume that the atmospheric pressure on one of the slopes of Mt. Apo is less than 1 atm. What would be the boiling temperature of the water on this slope?

   a. exactly 100 C b. greater than 100 C c. lower than 100 C

   What will happen to the atmospheric pressure on a higher slope? Explain its subsequent effect on boiling point?

Figure 1. Representative sample items (Source: Authors)

relationships between what would otherwise be isolated facts. Understanding requires the integration of new information with existing knowledge, which is the underlying premise of ML. This was measured by the learners' ability to apply new knowledge to other situations and generate explanations, justifications, and predictions, where appropriate.

The researcher-constructed MLT was composed of a 25-item (worth three points each) multiple-choice test with three distracters and an open-ended question requiring explanations, justifications, predictions, and/or application of knowledge to other situations. The items in MLT were based on the competencies required by the syllabus. MLT was pilot tested after going through the content and phase validity. The computed internal reliability of the MLT using the coefficient alpha was 0.74. Furthermore, the Pearson r coefficient of the MLT and the MRT was 0.90. This was obtained using the combined test-re-test and equivalent form methods. Representative sample items are found in **Figure 1**.

MRT was equivalent, also called the alternate or parallel form, of MLT. It was administered a month after the giving of the post-test. To establish the equivalence of MLT and MRT, the following measures were observed:

1. 19 of the test items in the MRT were the same as those in the MLT. Subject matter experts validated the new six items and found they were similar in content to those in MLT. The choices in the item and the test items' general order were reshuffled in the MRT.
2. Some of the items in the MRT were equivalent in content to that of the MLT but applied in other situations (e.g., places, objects, and events).

The study also utilized the researcher-constructed PPST. A PPST is made up of two parts. The first part of the PPST includes the PPST number, an overview, the problem, materials, the task, and the condition (if necessary). The overview provides background knowledge about the problem. The second part comprises the PPST record sheet, which summarizes what learners did to solve the problem, their solutions' conceptual and/or procedural bases, and the meaningful, relevant learning they derived from the experience. A meaningful solution to any problem requires procedural knowledge of how to execute a problem solution and a conceptual understanding of concepts, laws, principles, and theories that provide meaning to procedures. The construction of PPST was based on specific competencies and objectives required by the course syllabus. The researcher used a total of 16 PPST in the study. **Figure 2** shows PPST number 1.

Data Analysis

The study utilized both quantitative and qualitative analyses of PSTs' responses to MRT and MLT. The scoring system of the MLT and MRT was based on the PSTs' level of conceptual understanding, namely:

0. No understanding (NU): Incorrect choice with incorrect or no explanation.
1. Incomplete understanding (IU): Correct choice with incorrect or no explanation.

Atmospheric Pressure: Lever in Space

Overview

Air exerts pressure on a surface area. This task will familiarize you with how principle of atmospheric pressure is applied in identifying points of same level above ground, which is utilized in building construction.

Problem

Using materials below, how do you know that two or several points are of the same level from the ground?

Materials

A 20-meter transparent plastic tube
Water
Food color
Marker

Condition

Do not use other measuring tools (e.g., ruler, meter stick, and tape measure).

Figure 2. PPST number 1 (Source: Authors)

Table 1. Descriptive statistics and t-test for equality of means of ML post-test results

Mode of instruction	n	Mean	Standard deviation	df	t-value	p-value
ELM	40	20.03	5.29	78	2.80	0.006
PPST	40	23.78	6.61			

2. Partial understanding (PU): Correct choice with a partially correct explanation (responses have descriptive conceptions with partially correct conceptual understanding).
3. Full understanding (FU): Correct choice with the correct explanation (responses have complete theoretical explanations with a high degree of organization and quality of understanding).

Since homogeneity in conceptual understanding between student groups was established prior to intervention, the researcher used the t-test to compare means between the PPST and the ELM group to test the null hypotheses, set at alpha 0.05. In the quantitative analysis, the researchers also used descriptive statistics such as percentage, mean, and standard deviation.

Consistent with the postpositivist theoretical research perspective (Crotty, 2015; Treagust et al., 2014), the researchers used coding and thematic analysis to generate patterns of change in conceptual understanding in the MRT and MLT. He coded and categorized student responses to an open-ended question following each item of the multiple-choice test to generate patterns of change in conceptual understanding.

RESULTS AND DISCUSSION

Mode of Instruction and Meaningful Learning

Table 1 shows the descriptive statistics of ML post-test results in two modes of instruction. Results show that ELM has a mean score of 20.02, while the PSST group has a mean score of 23.78. Using the t-test for equality of means in two modes of instruction, the obtained p-value of 0.006 is less than the 0.05 level of significance. Hence, there was a significant difference in the MLT mean scores of PSTs in the two modes of instruction in favor of the PPST group. This result affirms the effectiveness of PPST in promoting ML in chemistry among college PSTs. Hands-on, PPST effectively supplement PSTs to learn chemistry concepts in a nonlaboratory setting meaningfully.

Patterns of Conceptual Understanding Based on Pre-Service Teachers' Explanations

The characterization of the general patterns of conceptual understanding considers the PSTs' specific responses in each item of the MLT and MRT and the patterns of explanation across concepts. The study found three major patterns of conceptual understanding based on PSTs' explanations in open-ended questions following the multiple-choice items.

Conceptual Understanding using a single-factor rationalization

This type of conceptual understanding considers the single component condition that accounts for the observed phenomenon in question. This understanding is limited because it only refers to the mere identification of cause, effect, or condition, given in a test item's stem, but does not explain concepts. When quantified, this type of explanation falls within the incomplete or partial understanding level. Typical answers under this category are found below:

Charles's law: When asked why the balloon shrinks when dipped in ice-cold water, case PSTs wrote this typical line of reasoning: "Because of the low temperature around the balloon" (Case PST 10A). Such an explanation is an example of cause identification. However, it does not provide a deeper understanding of the relationship between temperature and the volume of gas.

Vapor pressure and boiling point elevation: When asked what would happen to the boiling point of the solvent when added with a nonvolatile solute, a typical answer by the case PSTs was: "It will have [a] higher boiling point" (Case PST 5A). This kind of answer is classified as an effect-identification type of explanation. It does not provide a deeper explanation of the concept or principle.

Osmosis: When asked to explain why the soaked radish in a concentrated salt solution will shrink, case PSTs typically answered: "because of the higher concentration of salt solution" (Case PST 4A). This was an example of a condition reiteration type of explanation.

Case PSTs reiterated the condition provided in the stem of a multiple-choice test item. There were no attempts to justify the observed phenomena using scientific concepts and principles.

Conceptual understanding using a two-factor rationalization

This conceptual understanding considers the two-component/factor explanation of an event, phenomenon, or concept among case PSTs. It explains the two-factor relationships, conditions, or effects. When quantified, this type of conceptual understanding falls within the partial or full understanding level, depending on the depth of the answers to the questions. Examples of this type of conceptual understanding are, as follows:

Boyle's law: "Since volume and pressure are inversely proportional, the balloon on the 30th floor of the building would increase its volume because of the low pressure above" (Case PST IA). Apparently, this is the type of explanation that implores a cause-and-effect relationship.

Air and gas pressure: "The gas pressure in the container is greater than the atmospheric pressure because the gas occupies a larger space and the mercury level on the right is higher" (Case PST 10A). Apparently, this type of explanation is focused on the two-component system found in a figure of the test item [space occupied by the gas and the mercury level] to justify the conceptual understanding.

Conceptual understanding using a multiple-factor rationalization

This type of conceptual understanding considers three or more factors/conditions/ variables to explain the surrounding concept. The explanation may take the form of explaining the cause and its chain effects or various solutions, conditions, or views. In other words, this is a holistic and complete conceptual understanding. When quantified, this explanation falls within the level of full understanding.

Strength of forces of attraction: "Since Mg^{2+} is located first [relative position in group IIA] in the periodic table, it has the smallest size compared to other ions [Ca^{2+} and Ba^{2+}]. The smaller the size, the lesser the distance between the ion and the water molecule. The lesser the distance, the greater is the force of attraction" (Case PST 1A). Apparently, this explanation provides multiple correct relationships, such as location and ion size, ion size and distance between particles, and distance and force of attraction.

Vapor pressure and boiling point: "There is a higher boiling point in station 1 than in stations 2 and 3 because it is closest to the sea level; thus, the [atmospheric] pressure is high. The vapor pressure takes longer to equalize the atmospheric pressure in low areas because of the high pressure.

Consequently, the boiling point is also high" (Case 3A). This explanation shows multiple rationalizations because it considers multiple variables (e.g., location, atmospheric pressure, vapor pressure, and boiling point) that contribute to the highest boiling point of water in low areas.

Table 2. Percentage of pre-test to post-test change in the level of conceptual understanding

Topic	ELM				PPST			
	ICU[1]	RCU[2]	NC[3]	NU[4]	ICU	RCU	NC	NU
1. Air and gas pressure	20	20	30	30	60	0	20	20
2. Gas laws								
2.1. Boyle's law	70	0	0	30	60	0	20	20
2.2. Charles' law	30	20	30	20	60	0	0	10
2.3. General Gas law	20	10	50	20	50	10	30	0
2.4. Avogadro's law	50	10	10	30	60	20	0	20
2.5. Ideal gas law	0	30	30	40	80	0	10	10
3. Forces between atoms								
3.1. Ion-dipole interaction	40	20	20	20	20	30	20	30
3.2. Strength of interaction	70	0	0	30	50	20	20	10
4. Properties of liquids								
4.1. Surface tension	50	10	0	40	50	20	0	30
4.2. Capillary action	50	20	10	20	70	0	30	0
5. Vapor pressure	20	10	20	50	0	10	30	60
6. Phase & phase changes	50	20	10	20	70	0	30	0
7. Conc. of solutions	20	40	0	40	30	0	20	50
8. Solubility								
8.1. Saturation & solubility	30	10	30	30	20	20	20	40
8.2. Molecule structure & solubility	30	10	40	20	0	0	90	10
8.3. Pressure& solubility	40	50	0	10	60	0	10	30
8.4. Temp. & solubility	40	10	50	0	50	10	30	10
9. Colligative properties								
9.1. VP& BP elevation	30	10	10	50	50	20	20	10
9.2. VP & FP depression	40	20	2G	20	50	20	30	0
9.3. Osmosis	20	10	40	30	50	10	20	20
10. Classification of mixture	0	0	0	100	20	0	0	80
J. 1. Separation of mixtures	10	20	20	50	30	0	20	50

Note. [1]ICU: Incomplete conceptual understanding; [2]RCU: Regression in conceptual understanding; [3]NC: No change in conceptual understanding; & [4]NU: No understanding

Patterns of Change in the Level of Conceptual Understanding

The change in the level of conceptual understanding was tracked in each of the ten case participants. **Table 2** summarizes the change in the level of conceptual understanding across topics among student groups.

Summary and Discussion of Patterns of Change in Level of Conceptual Understanding

Tracking each level of conceptual understanding of case PSTs across topics supports the effectiveness of PPST in promoting conceptual understanding. The following were key points in the patterns of change in the level of conceptual understanding found in **Table 2**:

1. Case PSTs exposed to PPST develop a higher level of conceptual understanding in 16 out of 22 topics in chemistry. This detailed analysis further supports the effectiveness of PSST in promoting conceptual understanding.
2. PPST case PSTs show a higher level of conceptual understanding of the following sub-topics: air and gas pressures, Boyle's law, Charles' law, general gas law, Avogadro's law, ideal gas law, phase and phase changes, the concentration of solutions, molecular structure and solubility, pressure and solubility, temperature and solubility, vapor pressure and boiling point elevation, vapor pressure and freezing point depression, osmosis, and classification and separation of mixtures. Most of these topics have PPST counterparts. This supports the effectiveness of ML.
3. ELM case PSTs have improved conceptual understanding in four out of 22 sub-topics: ion-dipole interaction, the strength of interaction, vapor pressure and temperature of liquids, and saturation and solubility. Three of these four sub-topics have no corresponding PPST due to the abstract nature of the concepts, especially on ion-dipole interaction and strength of attraction between atoms, ions, and molecules. This finding supports the importance of PPST; without it, a lecture method is more advantageous.

Table 3. Descriptive statistics and t-test for equality of means of MRT scores

Mode of instruction	n	Mean	Standard deviation	df	t-value	p-value
ELM	40	18.70	5.06	78	2.91	0.005
PPST	40	23.22	8.44			

4. PPST and ELM case PSTs have similar levels of conceptual understanding of topics such as surface tension and capillary action. This means that the PPST in these two topics is ineffective in promoting conceptual understanding.
5. When taken as a whole, the following persistent misconceptions are identified in at least 50% of ELM or PPST case PSTs after the intervention:
   a. Water has a higher boiling temperature at higher altitudes than at lower altitudes.
   b. A nonvolatile solute (e.g., sugar) increases water vapor pressure.
   c. All solutions must be in a liquid phase; solutions do not exist in a solid phase.
   d. Generally, PSTs only identified one set of materials (either a local winnowing basket and magnet or the magnet and water) in separating the mixture of safety pins, rice husks, and corn kernels.

Mode of Instruction and Meaningful Retention

Table 3 shows the descriptive statistics and t-test for equality of means of the ML post-test results. Results show that the ELM group has a mean score of 18.70, while the PPST group has a mean score of 23.22. Data shows a regression in the conceptual understanding of ELM and PPST PSTs. However, there was a greater regression of conceptual understanding among ELM than among PPST PSTs. The mean difference between the MRT and ELM delayed-post-test scores was 4.52. The obtained p-value of 0.005 is less than the 0.05 level of significance. Hence, PSTs exposed to PPST have a significantly higher mean score in the MRT than those exposed to ELM. This result affirms the effectiveness of PPST in promoting the meaningful retention of learning in a college nonlaboratory chemistry.

Patterns of Regression in Conceptual Understanding

Based on the concept-based patterns of change in the level of conceptual understanding and on the specific responses of PSTs to the multiple choice and essay questions, the following are the qualitative patterns of regression found in the study.

Regression in use of key terms

This regression pattern occurs when key terms essential to understanding concepts are omitted or changed in the retention test. This type of regression may occur in the multiple-choice and/or open-ended component. This regression was observed on topics such as air and gas pressure, capillary action, surface tension, temperature and solubility, phase and phase changes, intermolecular forces of attraction, and molecular structure and solubility. The following are the specific examples of this type of regression in the short-answer component of the test:

Pressure and solubility: Case PST 3B made a correct answer when she selected the correct concept in the multiple-choice test, "There are more dissolved gases in a glass of water in a city close to the sea level than in a city atop a mountain range." Her post-test explanation was: "Two cities are located at different elevations. The lower the elevation, the greater the [atmospheric pressure and the greater the solubility of gases." Meanwhile, her retention test explanation became: "The lower the place, the pressure is low[er]. More gases [are] dissolved in a lower city than in a higher city." Apparently, regression in the use of key terms (greater and lower) affects the content of the explanation.

Vapor pressure and boiling point elevation: Case PST 10B correctly answered the multiple-choice component: "Sugar, a nonvolatile solute, increases water vapor pressure." An open-ended question asked, "Predict what will happen to the boiling point of water." Her post-test explanation was: "The boiling point will increase." Meanwhile, her retention test explanation was: "The boiling point will decrease." This was a case of regression in the use of key terms. The student did not fully understand the relationship between vapor pressure and boiling point elevation.

In the multiple-choice section, regression using key terms may also occur. The following is a specific example of this type:

Strength of interaction: When asked which ion (Ba^{2+}, Ca^{2+}, Mg^{2+} arranged from top to bottom of group II A of the periodic table) has the strongest force of attraction with a water molecule, Case PST 5B's answer in the post-test was Mg^{2+}. However, this correct answer was changed to Ba^{2+} in the retention test.

Regression in understanding the concept

This regression occurs when the retained concept differs entirely from the post-test concept. Most of this type of regression occurs in the multiple-choice section. This type of regression occurs on topics such as saturation and solubility, ion-dipole interaction, classification of mixtures, and vapor pressure and solubility. Examples of this type of regression are the following:

Saturation and solubility: When asked where dynamic equilibrium occurs, Case PST 2B's answer in the post-test was "saturated sugar solution." However, this answer was changed to "unsaturated atmosphere" in the retention test. Apparently, the student forgot the concept of dynamic equilibrium a month after the intervention.

Ion-dipole interaction: When asked what kind of interaction occurs between water and Na^+, K^+, Rb^+, Case PST 5B's answer in the post-test was "ion-dipole interaction." However, this answer was changed to "ion-ion interaction" in the retention test. Apparently, the concept of ion-dipole interaction was forgotten by this student a month after the intervention.

Regression in understanding a principle

This type of regression occurs when a correct explanation of a principle in the post-test is totally omitted in the retention test. This type of regression occurs on topics such as Boyle's law, Charles's law, general gas law, Avogadro's law, ideal gas law, osmosis, vapor pressure and freezing point depression, temperature, pressure, and boiling point.

Boyle's law: When asked to explain why the balloon increases in size on the 30th floor, Case PST 7A's explanation in the post-test was: "As the balloon goes up [30th floor], the atmospheric pressure decreases, and the balloon expands." When asked the same question in the retention test, Case PST 7A gave a blank explanation. Apparently, the whole principle of Boyle's law was forgotten by this student a month after the intervention.

Generally, PSTs who fully understand the concept do not exhibit regression in conceptual understanding regardless of their exposure or non-exposure to PPST. Furthermore, PSTs exposed to PPST have less regression in 20 out of 22 topics than those exposed to ELM. PSTs with misconceptions in the post-test carry over similar misconceptions in the retention test. Case PSTs exhibit a slip back to their pre-test misconceptions if full understanding is not attained in the post-test or the retention test.

CONCLUSIONS

The context (PPST), the process (patterns of change in conceptual understanding), and the outcome (ML post-test and retention mean scores)–all support the major argument of this study. PPST is an effective context and teaching strategy to supplement a nonlaboratory chemistry lesson. Given the findings of the study, the following conclusions are drawn:

1. PPST promotes ML as evidenced by a significantly higher MLT mean score of PSTs exposed to PPST than those not exposed to PPST.
2. The general patterns of change in the level of conceptual understanding are generally grouped as
   (a) change towards the improvement of conceptual understanding,
   (b) change towards the regression of conceptual understanding, and
   (c) no change in conceptual understanding.
3. Case PSTs exhibit the following patterns of explanation across concepts:

   (a) concept understanding using a single-factor rationalization, a conceptual understanding that takes into consideration the single component condition around the concept in question, such as the identification of the cause, effect, or condition,

   (b) conceptual understanding using a two-factor rationalization, a conceptual understanding that takes into consideration the two-component explanation of a concept in question, and

   (c) conceptual understanding using a multiple-factor rationalization, a conceptual understanding that takes into consideration three or more factors surrounding the concept in question.

4. PPST promotes meaningful retention as evidenced by a significantly higher MRT mean score of PSTs exposed to PPST compared to those who are not exposed to PPST a month after the intervention.
5. Generally, PSTs who attain incomplete conceptual understanding tend to show regressions in conceptual understanding regardless of their exposure or non-exposure to PPST. Meanwhile, PSTs who attain full understanding do not exhibit regressions in conceptual understanding regardless of their exposure or non-exposure to PPST.
6. The patterns of regression in conceptual understanding a month after the intervention occurs in the:

   (a) regression in the use of key terms,

   (b) regression in concept understanding, and

   (c) regression in explanation.

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Data availability: Data generated or analyzed during this study are available from the authors on request.

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