The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #41502

Enhancing Chemistry Education through the LHETM Model: A Structured Approach to Knowledge Acquisition and Application

Dr. Xinfeng (Kevin) Quan, Westlake University

Dr. Xinfeng Quan earned his BS in Chemistry from Fudan University, China, followed by a PhD in Chemistry from the University of Pittsburgh. Before joining Westlake University as a Chemistry Lecturer in 2022, he dedicated seven years to teaching at the Sichuan University - Pittsburgh Institute as Assistant Professor and later Associate Professor. With over eight years of experience instructing Chinese freshmen in General Chemistry and related courses, all in English, Dr. Quan has a keen interest in employing active learning strategies and inductive teaching methodologies. Beyond content acquisition, he believes in nurturing students' higher-order thinking and communication skills. At the core of his pedagogical philosophy is a commitment to amplifying students' learning efficacy and holistic development.

Chaoyi Wang, Zhejiang Normal University

Assistant Professor

Chenhui Zhang, Self-employed

Chenhui Zhang, transitioning from law to education, holds a Master of Laws from Duquesne University in the US and a Bachelor of Law from Southwest University of Political Science And Law in China. Chenhui has been enriching her educational expertise through Coursera courses in psychology and learning techniques, including but not limited to "Introduction to Psychology", "Social Psychology" and "How to Learn". Demonstrating practical application, Chenhui teaches English to K-6 learners, leveraging skills gained in legal career such as knowing your clients, analysis and cross-cultural communication. Presently pursuing a Master of Teaching degree to become a K-6 teacher, Chenhui is committed to blending law, education, and psychology in her educational approach. Fluent in English and Mandarin, Chenhui aims to make a significant impact in educational research and practice.

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Introduction

Over recent decades, higher education has shifted from a teacher-centered to a student-centered approach. This transition has seen the rise of numerous pedagogical strategies aimed at enhancing student engagement in the classroom, collectively referred to as “active learning”. There is an increased expectations for students to take greater responsibility for their learning with role of instructors shifted from the primary source of knowledge to facilitator of learning. In some courses, the traditional lecture may serve merely as a supplementary component or be entirely absent, favoring a curriculum that highlights self-directed and collaborative learning throughout the semester. Alongside the redesign of learning activities, instructors have also made efforts to rethink the organization and delivery of course content. For instance, unlike deductive teaching, inductive teaching employs a bottom-up approach where students are first introduced to specific observations, data, cases, or complex problems before being taught general principles or rules. While active learning strategies aims to enhance student engagement in learning and do not necessarily require instructor to organize and deliver course content in a more inductive manner, an inductive teaching method intrinsically relies on active learning strategies for effective facilitation. For example, in inquiry-based learning, lecture must be paused to provide time for students to inquire, explore, and discover.

As students become more engaged in the learning process and take on greater responsibility for the effectiveness of their learning, it is also crucial to monitor and enhance their learning skills. To improve these skills, instructional interventions can generally be categorized into three types: cognitive, metacognitive, and affective. Cognitive interventions aim to help students develop specific cognitive skills, such as those outlined in Bloom’s Taxonomy. Metacognitive interventions are designed to increase students’ awareness of their own cognitive processes and to enhance their ability to regulate their learning strategies. Affective interventions, which are non-cognitive, seek to improve students’ agentic engagement, self-efficacy, growth mindset, and other related aspects.

In recent years, there has been increasing attention paid to students’ epistemic beliefs[1] and their impact on learning efficacy. Epistemic belief, which reflects students’ views on the nature of knowledge and knowing, plays a crucial role in the cognitive, metacognitive, and affective dimensions of students’ learning. Research has demonstrated that interventions targeting epistemic beliefs can significantly enhance learning outcomes (Greene et al., 2018). Epistemic cognition - mostly measured in terms of belief (Greene et al., 2018) – is identified as the apex of cognition, regulating the following cognition and metacognition processes. For instance, students who perceive knowledge as a collection of isolated facts may tend to memorize content without seeking to understand it, whereas those who view knowledge as interconnected concepts are more inclined to employ strategies that promote deep understanding, transfer, and application of knowledge.
While the majority of the literature focuses on how pedagogical approaches influence students’ cognitive and metacognitive knowledge and skills, few studies have integrated epistemic beliefs

[1] The subtle difference between epistemic belief and epistemological belief is ignored in this paper. The two terms are used interchangeably as many studies do.

into course design and implementation (Lazenby et al., 2019). Although epistemic knowledge and skills tend to develop and increase as students age, such changes are not guaranteed with aging (Schommer, 2013). Therefore, it becomes even more urgent for chemistry educators to incorporate epistemic beliefs into their teaching, considering that epistemic beliefs are likely to be domain-specific (Urhahne & Kremer, 2023) and that studies focusing on this aspect within the context of chemistry are even rarer (Blackie et al., 2023).

In this paper, we introduce a novel model for teaching general chemistry, designed with an emphasis on the epistemic perspective. We have named this model "LHETM" (pronounced 'let'em'), where each letter stands for an essential component of scientific inquiry: Law, Hypothesis, Experiment, Theory, and Mathematics. We contend that the LHETM model acts as a comprehensive framework that integrates active learning and inductive teaching methods, thereby enhancing students' cognitive and metacognitive skills. Preliminary results indicate the effectiveness of the LHETM model, prompting us to advocate for further research into its theoretical foundations and practical applications.

The LHETM Model

We first explore the epistemological underpinnings of each component - law, hypothesis, experiment, theory, and mathematics - and their influence on students' cognitive and metacognitive processes. Following this theoretical foundation, we provide a practical example of how the LHETM model can be applied to teaching chemical kinetics.

Law

Laws are qualitative and/or quantitative descriptions of natural phenomena, representing factual information that is objective in nature. Despite any counterintuitive aspects or contradictions with personal experience or perceptions, it is crucial for students to acknowledge and accept laws and other factual information, such as compound names and properties of chemicals in their study of chemistry. Since laws are derived from observable, recurring phenomena and are applicable only within their specific contexts, students are encouraged to memorize not only the law itself but also its assumptions, scope, and the precise physical processes it describes.

Hypothesis

A hypothesis is defined as a tentative and testable explanation for certain laws or phenomena. Unlike laws, which represent factual information requiring memorization, a hypothesis involves logical inferences about how things may be and interact, leading to the observed laws or phenomena. This inferential nature of a hypothesis necessitates understanding rather than mere memorization by students. Understanding involves "constructing meaning from instructional messages," which is distinct from memorization, or "retrieving relevant knowledge from long-term memory" (Anderson & Krathwohl, 2001). Consequently, a hypothesis is distinguished from a law by requiring students to engage in different cognitive processes. Given the limited inclusion of scientific hypotheses in general chemistry textbooks, encouraging students to formulate their own hypotheses after learning about laws and before exploring corresponding theories could enhance their ability to construct logical connections and deepen their understanding of the subject matter.[2]

Experiment

A scientific experiment is a systematically conducted procedure under controlled conditions aimed at testing, validating, or refuting a hypothesis or theory. It's crucial for students to approach the study of scientific experiments beyond mere memorization of facts, procedures, and conclusions. While knowing the setup and key outcomes is important, greater emphasis should be placed on understanding how an experiment's results either challenge or corroborate a hypothesis or theory.

Theory

Theories are not immutable truths but rather hypotheses substantiated through experimental evidence. When new observations contradict existing theories, these theories may need to be modified or discarded. The nature of theories allows for the possibility of multiple theories coexisting to explain the same phenomena. Additionally, just as laws are context-specific, so too are theories. When studying a theory, student should remember the relevant laws, phenomena, the experiments that validate them. More importantly, they should understand how theories are supported by experimental evidence and how new data may challenge or refine them. When applying a theory to solve problems, it's important to assess whether the theory is applicable by ensuring that the problem pertains to the same laws and context.

Mathematics

Mathematics involves abstract logical reasoning and the use of symbols to explore structures, patterns, and conjectures, often without direct empirical evidence. In contrast, an equation in chemistry delineates the relationship between specific physical quantities within particular physical contexts. Thus, the value of a mathematical equation in chemistry lies not in the equation itself but in the physical laws it represents. A deficiency in epistemological comprehension of mathematics and science might contribute to students' challenges in learning chemistry and integrating mathematics into chemical contexts.

Example Course Design Adopting the LHETM Model

In this section, we present a guideline of how the LHETM model can be implemented, using the topic of chemical kinetics as an example shown in Table 1. While the LHETM model can be adapted to traditional lecture-based formats, its strength lies in its ability to weave together active learning and inductive teaching, thereby promoting students' cognitive and metacognitive abilities. The model follows a structured sequence starting with L (Law), followed by H (Hypothesis), E (Experiment), and T (Theory), integrating M (Mathematics) at any stage where appropriate. Depending on the specific focus or requirements of a topic, instructors have the flexibility to adjust the order of these elements to best suit the educational objectives.

Table 1. Guideline of using LHETM model in teaching chemical kinetics.

	Way of instruction	Instructional purpose
Step 1:	Rather than directly presenting rate laws to	Review basic mathematical

[2] The de Broglie hypothesis is termed so historically and has been validated experimentally in the subatomic world. Its designation remains partly because testing across all masses and velocities is impractical.

Formulating Laws	students, lead them to construct these laws from experimental data, such as the concentration of Br_2 in the reaction $Br_2 + HCOOH \rightarrow HBr + CO_2$.	skills and correct possible misconceptions such as laws are (only) the product of theoretical deduction.
Step 2: Proposing Hypotheses	Encourage students to provide explanations using concepts they have learned thus far. Group discussions can be employed to stimulate thinking.	Guide students to adopt a microscopic perspective and bridge their existing knowledge with new insights.
Step 3: Designing Experiments to Test Hypotheses	Enable students to design experiments to test the validity of hypotheses that the class has just proposed. Emphasize how the experimental outcomes would either support or contradict a hypothesis. The instructor introduces actual experiments previously conducted by scientists.	Students develop higher-order thinking skills and bolster their confidence, particularly if their proposed experiments have already been conducted by scientists.
Step 4: Introducing Theory and Applications	Instructors present concepts and topics not explored by students, including the application of chemical kinetics in real-world contexts, such as in biology and materials science and engineering. Briefly mention more advanced theories as appropriate.	Beyond gaining a comprehensive understanding of theories, students also develop and reinforce their awareness that theories may be context-dependent and are continually evolving.
Step X: Applying Mathematics	Introduce Excel, Python, or online tools to students for solving derivative or integration problems if they lack the mathematical skills to find solutions manually. Emphasize the critical role of mathematics in learning and research within science and engineering.	Students should understand that while mathematics is essential for learning and practicing science and engineering, its nature differs from scientific and engineering knowledge.

Implementing the LHETM Model in General Chemistry Teaching and Preliminary Results

Background of the LHETM Model's Development

A comparative study by Bao et al. (2009) reveal that Although Chinese high school graduates outperformed their American peers in content knowledge, the top-performing Chinese students were significantly less likely to achieve the highest scores in the Lawson Classroom Test of Scientific Reasoning (CTSR). This discrepancy might be attributed to findings from later research by Ding (2018), which indicated that Chinese students demonstrated less improvement in controlling variables and hypothetical deductive reasoning throughout their middle and high school education.

These observations resonate with my nine years of teaching experience in China, where students excelled in exam settings but often lacked sensitivity to and awareness of scientific methodologies and learning skills. Many students viewed scientific knowledge as merely the accumulation of past scholars' experiences and considered it to be almost infallible. Predominantly, students preferred traditional lectures over active learning strategies, showing little interest in learning from peer discussions. Furthermore, there was a tendency to conflate memorization with understanding, indicating a reliance on rote learning and practice tests as the primary study strategies.

To foster more active and effective learning, I aimed to shift students' epistemic beliefs by emphasizing the scientific method and the appropriate cognitive processes for assimilating various types of knowledge. Beyond traditional classroom instruction, I conducted workshops for freshmen on active learning strategies and Bloom's taxonomy during orientation weeks. Concurrently, I revised the course structure and delivery to adopt a more inductive methodology. These changes have markedly improved students' attitudes and abilities in learning chemistry. Remarkably, during the Covid pandemic, I managed to maintain effective learning outcomes without live online lectures, as students engaged with the material from their homes(Quan, 2020). Upon my arrival at my current institution in the fall of 2022, I formalized these pedagogical strategies into the LHETM model.

The remainder of the paper presents pilot-like preliminary results, demonstrating how the LHETM model may have bolstered students' cognitive and metacognitive skills in their chemistry studies.

Research Question

Upon joining my current institute, my teaching responsibilities shifted. Whereas I previously taught a two-semester sequence of general chemistry during the first academic year, my current role involves teaching General Chemistry Lab I in the first semester and General Chemistry II in the second. The LHETM model was implemented in a limited capacity during the second semester, specifically targeting cognitive and metacognitive strategies related to chemistry content without explicitly incorporating the scientific method and related concepts into the learning outcomes, homework reviews, or exams. However, all students enrolled in my General Chemistry II course had participated in a 90-minute workshop on the scientific method, Bloom's taxonomy, and their interconnections during the freshman orientation weeks and had attended my General Chemistry Lab I in the first semester.

Given this background, this study seeks to evaluate the impact of the LHETM model through a one-semester intervention, focusing on two key areas:

1. In the absence of direct instruction on the scientific method as part of the course or examination content, does the LHETM model still enhance students' understanding of the scientific method?
2. Does the LHETM model improve students' cognitive and metacognitive skills?

Instrument

To investigate the effectiveness of the LHETM model in enhancing students' understanding of the scientific method and their cognitive and metacognitive skills, a pilot pretest-posttest survey was administered at the beginning and end of the semester. As detailed in Table 2, the survey comprises 12 questions categorized into five areas: knowledge of the scientific method (Items #1, #3, #5, and #11), self-efficacy regarding scientific method knowledge (Items #2 and #4), confidence in learning and problem-solving (Items #6 and #7), metacognitive awareness (Items #9, #10, and #12), and approaches to learning (Item #8). The survey employs various question types: narrative responses (Items #1 and #3) where students provide written answers, multiple-choice questions assessing confidence levels in their narrative answers (Items #2 and #4), and Likert-scale questions (Items #5 to #12) offering a range from strongly disagree to strongly agree.

Table 2. Survey Questions

1. Scientific knowledge is created by humans. Most scientists doing so today are following a concrete method, called scientific method. Please explain what scientific method is?
2. How close do you think your answer is to the definition (of scientific method) from the science community?
3. Explain the difference between a theory and a hypothesis.
4. How close do you think your answer is to the actual difference between theory and hypothesis?
5. If two theories disagree with each other, then at least one of them should be false.
6. I know how to learn new concepts and theories in chemistry.
7. I know how to solve complicated problems, especially those without examples in the textbook.
8. When studying, I like to think and try alone more than to ask and discuss with others.
9. In general, I like to let the course instructor know what I know or don't.
10. I can explain the difference between memorizing something and understanding something.
11. Scientific knowledge is certain and does not change.
12. Knowing how knowledge is created can elevate one's ability to learn.

* Questions #1 and #3 were rated from 1 to 5, where 1 indicates completely incorrect answers and 5 represents a full score. For questions #2 and #4, a rating of 1 signifies the least certainty about the answer, and 5 indicates the most certainty. Questions #6, #7, #9, #10, and #12 used a 1 to 7 scale, reflecting the degree of agreement or disagreement with the statements, ranging from Strongly Disagree (1) to Strongly Agree (7). Questions #5, #8, and #11 were also rated from 1 to 7, but in these cases, the scale was inverted (7 for Strongly Disagree to 1 for Strongly Agree) to ensure consistency across the survey, where a higher value aligns with the anticipated choice.

Additionally, six months following the posttest, structured interviews were conducted in Chinese to delve deeper into the students' survey responses and their reflections on the General Chemistry II course. During these interviews, students were prompted to identify and discuss any major changes in their survey answers, evaluate the significance of these changes, and recount memorable aspects of the course. With verbal consent from the participants, these interviews were recorded and subsequently transcribed into text files using Kafan[3] software for analysis. Researchers made final corrections to the transcripts to ensure their accuracy.

Sample

In the spring semester of 2023, 20 freshmen were enrolled in General Chemistry II, of whom 18 completed both the pretest and posttest surveys. One student withdrew from the course in the second week, and another joined the class after the pretest, thus missing it. This group represents the first cohort of 60 students at a newly established university admitted through a highly selective process. Given the small and distinctive nature of this sample, broader demographic and educational variables such as gender, age, the intensity of high school chemistry training, and first-semester GPA, which might influence their grasp of the scientific method and learning skills, were not

[3] https://voice.kafanpc.com/

systematically analyzed in this study.

Results and Discussion

Survey

The results from the pre- and post-surveys are summarized in Table 3. To assess any significant changes between these two sets of data, the Wilcoxon Signed Rank test was employed, chosen for two main reasons: 1) the relatively small sample size of 18 participants, and 2) the ordinal nature of the responses for the majority of the questions. A one-tailed null hypothesis H_0 was posited that there would be no significant increase in the posttest scores compared to the pretest scores. All calculations were performed twice using the Wilcoxon Signed Rank test available on Statskingdom.com[4]. The Wilcoxon Signed Rank test revealed four levels of difference between the pretest and posttest responses: large differences ($p < 0.05$), large, yet not statistically significant differences ($0.05 < p < 0.10$), medium differences ($0.05 < p < 0.10$), and small to very small differences ($p > 0.10$).

Table 3. Statistics of Students' Pre- and Post-Answers

Item	Pretest	Posttest	Wilcoxon Signed Rank Stats	Differences and significance
1	Mean = 2.94 Mdn = 3 (1 to 5)	Mean = 2.83 Mdn = 3	Z = -0.61; p = 0.728; r = -0.23 (W-, W+) = (17, 11)	Non-significant (N.S.) Small difference (Sm.)
2	Mean = 3.06 Mdn = 3	Mean = 3.56 Mdn = 4	Z = 1.75; p = 0.040; r = 0.58 (W-, W+) = (8, 37)	Significant (Sig.) Large difference (Lr.)
3	Mean = 3.61 Mdn = 4	Mean = 4.06 Mdn = 4.5	Z = 1.29; p = 0.098; r = 0.36 (W-, W+) = (27, 64)	N.S. Medium difference (Md.)
4	Mean = 3.33 Mdn = 3.5	Mean = 3.72 Mdn = 4	Z = 1.89; p = 0.030; r = 0.60 (W-, W+) = (10, 45)	Sig. Lr.
5	Mean = 5.06 Mdn = 6 (1 to 7)	Mean = 5.22 Mdn = 6	Z = 0.275; p = 0.392; r = 0.08 (W-, W+) = (29.5, 36.5)	N.S. Very Sm.
6	Mean = 5.06 Mdn = 5	Mean = 5.56 Mdn = 6	Z = 1.58; p = 0.057; r = 0.46 (W-, W+) = (19, 59)	N.S. Md.
7	Mean = 4.61 Mdn = 5	Mean = 5.11 Mdn = 5	Z = 1.34; p = 0.090; r = 0.42 (W-, W+) = (14, 41)	N.S. Md.
8	Mean = 3.44 Mdn = 3	Mean = 3.56 Mdn = 3	Z = 0.04; p = 0.485; r = 0.01 (W-, W+) = (44.5, 46.5)	N.S. Very Sm.
9	Mean = 5.67 Mdn = 6	Mean = 5.94 Mdn = 6	Z = 1.38; p = 0.084; r = 0.62 (W-, W+) = (2, 13)	N.S. Lr.
10	Mean = 5.56 Mdn = 6	Mean = 5.89 Mdn = 6	Z = 1.81; p = 0.035; r = 0.68 (W-, W+) = (3.5, 24.5)	Sig. Lr.
11	Mean = 6.22 Mdn = 6	Mean = 6.39 Mdn = 6	Z = 0.23; p = 0.412; r = 0.08 (W-, W+) = (16, 20)	N.S. Very Sm.
12	Mean = 6.11	Mean = 6.39	Z = 1.56; p = 0.060; r = 0.64	N.S.

[4] https://www.statskingdom.com/175wilcoxon_signed_ranks.html

	Mdn = 6	Mdn = 6	$(W\text{-}, W\text{+}) = (3, 18)$	Lr.

A visual inspection of the histogram of student responses (Figure 1) corroborates these findings. Excluding items #1, #5, #8, and #11, there is a noticeable shift in student responses towards higher scores for the remaining items, indicating a trend of improved understanding or perception in those areas.

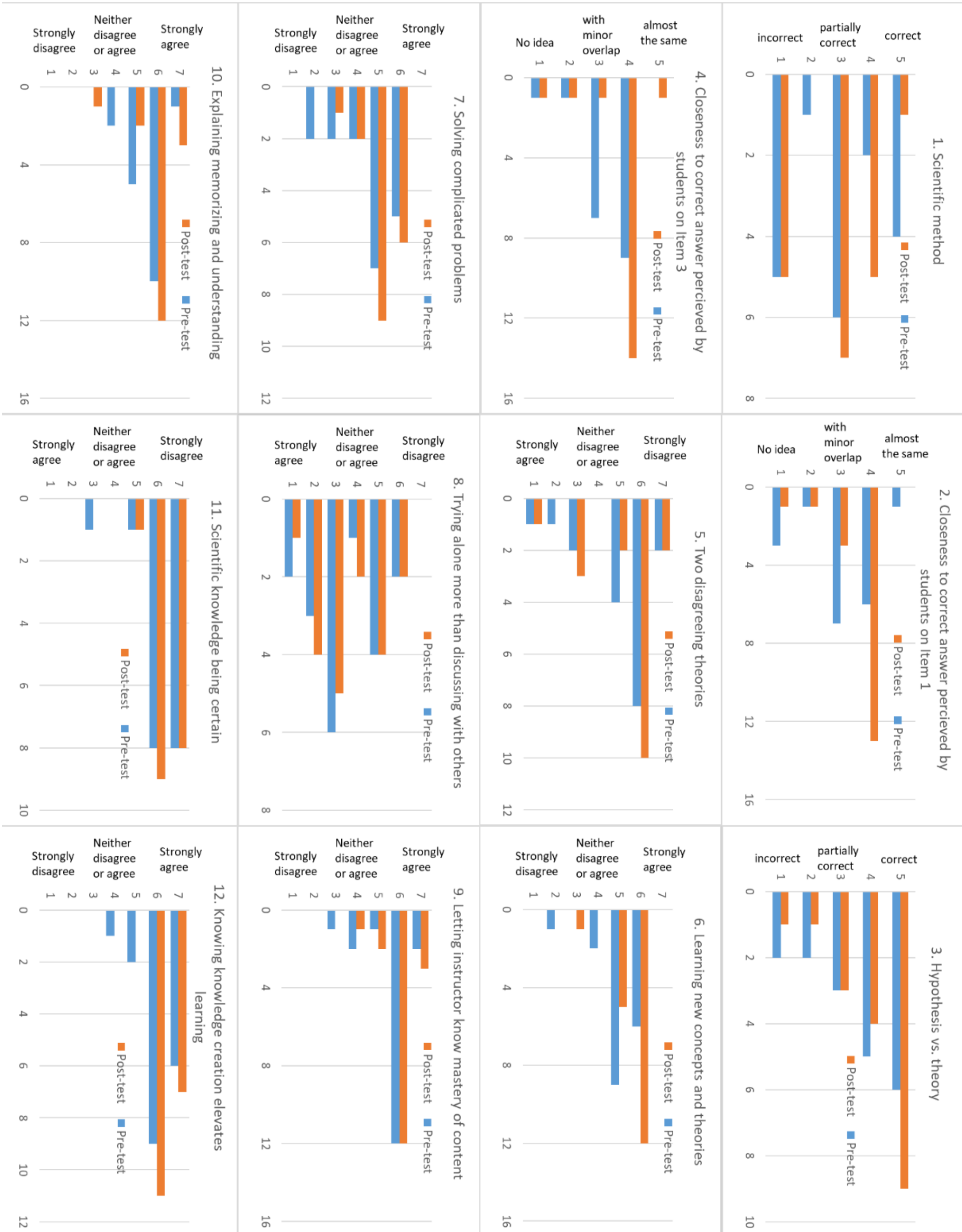

Figure 1. Histogram of students' answers/choices to each survey questions.

Spearman correlation coefficients (ρ) were calculated to explore the relationships between different survey items and assess their impact on learning outcomes. This analysis included not only the pretest and posttest data but also the semester gains (calculated as the posttest value minus the pretest value) as a distinct dataset. Additionally, students' final numerical grades were incorporated as item #13 for a comprehensive view of the correlations between survey responses and academic performance. For clarity and focus, Table 4 lists Spearman correlation coefficients only for those pairs of items that demonstrated statistically significant correlations ($p \leq 0.05$) in at least two of the datasets analyzed.

Table 4. Selected Spearman Correlation Coefficient with Statistical Significance ($p < 0.05$)*

	#2 / #6	#4 / #9	#4 / #13	#6 / #7	#6 / #10	#9 / #12	#10 / #13
Pretest	$\rho = 0.606$ $p = 0.008$	0.544 0.020	0.468 0.050	0.591 0.010	0.560 0.016	*	*
Posttest	0.565 0.014	0.519 0.027	*	0.801 0.000	0.509 0.031	0.548 0.019	0.703 0.001
Semester gain (Post - Pre)	0.469 0.050	*	-0.473 0.047	0.619 0.006	*	0.656 0.003	0.532 0.023

The * sign designites a coefficents with a p value bigger than 0.05 which is not shown in the table.

Interview

During data collection, we prepared a short memo for each participant to capture key observations and reflections. These memos were subsequently coded in Dedoose to help generate codes and themes and provide extra documents to construct meanings. Beginning with a content analysis, which focuses on analyzing text and documents, a thematic analysis was performed with a special emphasis on developing themes. Table 5 summarizes the codes derived from the data.

Table 5. Data Codes Extracted from the Interview Memo.

Emerging Codes	Selected Codes	Descriptions
Students' understanding of the LHETM model	Elements of the LHETM Model	Describe how students understand each component in the LHETM model.
	Scientific Method	Describe how students understand the scientific method.
	Memorization vs. Understanding	Describe how students identify the differences between memorizing and understanding.
Students' Learning experiences	Learning Outcomes	Describe what students learned from the chemistry course.
	Cooperative Approaches	Describe the attitudes towards cooperative approaches in the chemistry course.
	Most Impressive Aspects	Describe what impressed students most and the reasons.

Major findings

1. While students claim their knowledge on scientific method increases, survey and interview results only show student's confidence on their answers but not the quality.

Despite an increase in confidence regarding their understanding of the scientific method, as shown by significant changes in responses to survey items #2 and #4, there was no corresponding improvement in students' performance on items directly assessing knowledge of the scientific method (#1, #3, #5, and #11). No significant correlations were seen between students' perceptions of their mastery of the scientific method and their actual performance, suggesting a disconnect between confidence and competence. Previous studies (Deslauriers et al., 2019) show that while students may feel more confident about their learning in lecture mode than in active learning environment, their actual understanding and skills gain may be less. Given that the scientific method was not included in homework and exam, students' confidence may result from a lack of rigorous cognitive effort in processing such knowledge.

Interview results reveal more complex interaction between students' perceived and actual understanding, influenced by several factors:

a. Reduced Effort in Responses: Some students admitted to less diligent responses in the posttest, which may have skewed results. For instance, Luca[5] explicitly said "我觉得其实(差别)不大，只是我后面一次比前一次感觉懒一点，然后又写的少" "I actually don't think it's a big difference; I just felt lazier the second time and ended up writing less" .
b. Pre-existing Views: The initial relativistic perspective of students towards the scientific method and knowledge limited the scope for substantial shifts in understanding. This was evident from the high baseline scores on items #5 and #11, suggesting that students already possessed a nuanced view of scientific knowledge.
c. Reinforcement of Prior Knowledge: The observed increase in confidence was interpreted by students as reinforcement of their pre-existing understanding, attributed to their exposure to more examples illustrating the relationship between theory and hypothesis in General Chemistry II, as answered by Remi "第一次（回答）基本上就是全靠以前的印象；经过一个学期的学习就会感觉对这个东西更加确定了"" The first time (I answered), it was basically all based on previous impressions; after a semester of study, I feel more certain about this."

2. Gains on cognitive and metacognitive skills are reported by the students after the semester.

Contrastingly, improvements were noted in students' cognitive and metacognitive skills, with increased agreement on their abilities in learning new concepts (#6), problem-solving (#7), communicating knowledge mastery (#9), distinguishing between memorizing and understanding (#10), and recognizing the value of understanding knowledge creation (#12). However, statistically significant change was only observed for item #10.

The consistent correlations observed between items #6 (learning new concepts and theories) and #7 (solving complicated problems) across pretest, posttest, and semester gains underscore a fundamental aspect of the LHETM model: the interdependence of concept learning and problem-solving skills. Although some students account for the gains on item #6 and #7, as Alex noted: "我感觉上这个课，自己去 learn new concepts 也没有那么困难；（解决复杂问题）也不是一件特别难的事，也是可以做的事""I feel that in this class, to learn new concepts by myself isn't so difficult; (solving complex problems) isn't particularly hard either, and it's doable," none of them mentioned any potential correlations between the gains of the two items. Furthermore, the positive correlations within item pairs #6 / #10 (differentiating memorization from understanding), #9 / #12

[5] Pseudonyms are used for privacy and ethical concerns.

(metacognitive awareness), and #10 / #13 (course performance) reinforce the model's role in promoting an integrated learning experience. Specifically, the correlation between items #6 and #10 in both pretest and posttest phases suggests that students' self-perceived learning skills align with their ability to distinguish between rote memorization and genuine understanding—a central goal of the LHETM approach.

The positive correlations between item pairs #6 / #13 ($\rho = 0.579$, $p = 0.012$) and #7 / #13 ($\rho = 0.542$, $p = 0.020$) in the pretest phase alone reveal an intriguing predictive relationship: students' initial confidence in their learning and problem-solving abilities can forecast their final course performance. By the semester's end, course performance (item #13) correlated only with specific aspects of learning: knowledge of the scientific method (item #1) ($\rho = 0.491$, $p = 0.038$), confidence in understanding the scientific method (item #2) ($\rho = 0.510$, $p = 0.030$), and the ability to differentiate between memorizing and understanding (item #10) ($p = 0.703$, p = 0.001). This shift suggests that while initial confidence in cognitive skills is predictive of performance, enduring impacts on course outcomes are more directly tied to students' comprehension of the scientific method and metacognitive awareness.

Limitations

This study faces several limitations, including a small and unique sample size, the lack of control groups, and the use of measurement tools with unverified validity and reliability. Moreover, the experimental group's exposure to the LHETM model should commence post-pretest and continue throughout the study. However, due to ethical and practical reasons, participants were introduced to LHETM elements during freshman orientation and the first semester General Chemistry Lab I, potentially influencing the observed minimal changes in their understanding of the scientific method and in cognitive and metacognitive skill development. The self-developed survey and interview tools might not have fully captured the LHETM model's impact on students, suggesting the need for further, more rigorous research to evaluate its effectiveness.

Conclusion

This paper introduces a new model, the LHETM model, and assesses its efficacy in enhancing students' grasp of the scientific method and improving their cognitive and metacognitive abilities within a General Chemistry II context. While the model demonstrated potential in bolstering students' confidence and skills in learning, problem-solving, and understanding versus memorization, it fell short of significantly advancing their knowledge of the scientific method without direct curriculum integration of this concept. This discrepancy underscores the necessity of embedding explicit scientific method instruction and assessment within the LHETM framework to fully realize its educational benefits.

The study's limitations, including a small, specialized sample and the lack of a control group, temper the conclusiveness of these findings and underscore the imperative for further research. Such future inquiries should aim for larger, more diverse participant pools and the inclusion of control groups to delineate the specific impacts of the LHETM model from other instructional factors.

Nonetheless, the LHETM model, rooted in an epistemological framework that integrates law, hypothesis, experiment, theory, and mathematics, offers a strategic approach for enhancing chemistry education. Designed from the ground up to engage students at the epistemic level, it sets a robust foundation for implementing active learning and inductive teaching approaches in a more integrated fashion. This model encourages students to engage deeply with the content, fostering the selection of more effective cognitive and metacognitive strategies for learning. At this stage, we would like to encourage more instructors and researchers to join our effort in developing the LHETM model and examining its efficacy.

Acknowledgement

We express our gratitude to Dr. Jing Liu for the meaningful discussion on data analysis.

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