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Exploring the impact of virtual laboratory with KWL reflective thinking approach on students' science learning in higher education

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Abstract

The study of pedagogical design and development for virtual laboratory in science education in higher education is limited. Few tailored pedagogical approaches have been adopted for developing students higher order thinking (i.e. reflective thinking skills) in virtual laboratory enabled learning in the university level. For addressing these, this study borrowed the merits of virtual laboratory and Know-Want-Learn (KWL) reflective thinking approach, with considering the development of students reflective thinking, to support university students to learn physical chemistry concepts. To examine the impacts of this virtual lab with KWL reflective thinking approach on students' conceptual understanding and reflections, a quasi-experimental research was conducted among 30 students in experimental group and 28 students in control group in a university located in the north of China. Positive learning outcomes including were received based on quantitative and qualitative data analysis of pre-and post-test scores, questionnaire, reflection journals and selected interview. The study could inform the pedagogical design and the implementation of virtual lab for developing students' higher order thinking skills in the university level.

Keywords Virtual laboratory · KWL approach · Reflective thinking skills · Higher education · Science education

Introduction

In a broader context of technology-supported learning, reflective thinking has been extensively explored as an effective mechanism that mediates and augments learning and thinking (Ghanizadeh, 2017; Oracki, 2021; Rodgers, 2002). In fact, reflective thinking itself is an essential set of critical skills that practitioners and researchers in education have long pursued (Brown et al., 2021; Whalen & Paez, 2022), and deserves inclusion and strengthening in different learning contexts, as the original

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ideas of reflective thinking discussed by Dewey (1933) and Schön (1987) emphasized the importance of reflection with teaching and learning pedagogies. Reflective thinking involves active monitoring, evaluation, and modification of one's thinking compared to expert and peer thinking and is closely tied to flexible thinking and problem-solving (Lin, et al., 1999). It is a form of mental processing for gaining a better understanding of complicated or unstructured ideas and is largely based on the reprocessing of knowledge, evaluation, and decision-making, and as a source for planning and action (Moon, 2008). Reflection is the premise for improved understanding, conceptual change, and knowledge advancement (Strampel & Oliver, 2007). Developing reflective thinking skills is one of the learning outcomes of many universities (Akpur, 2020; Authors, 2020a; Ghanizadeh & Jahedizadeh, 2017). It is a critical research area that needs more exploration, particularly in the technology-supported learning contexts.

Regarding the technology-supported learning contexts in higher education, the virtual laboratory is one of the effective learning tools for universities (Luse, & Rursch, 2021; Paxinou, et al., 2020; Zhang et al., 2020). A virtual laboratory, in essence, is a digital media that utilizes simulations, computerized models, and various other instructional technologies to provide experiment visualizations, an interactive virtual environment, and practical experimentation processes (Ramadhan & Irwanto, 2017). The virtual laboratory enables investigations mainly by leveraging simulated material and apparatus (de Jong et al., 2013). It includes simulations of specific instructions, procedures, data analysis methods, and presentation algorithms for conducting experiments (Flowers, 2011). The laboratory is key process for learning and doing science as they make an indispensable component of scientific modeling and inquiry (Wang et al., 2015).

For science educators, providing students with quality laboratory experiences is of paramount importance, nevertheless, in school-based practices it poses a great challenge to not only the science teachers but also the school management. To design and deploy effective laboratory sessions, the teacher is expected to possess good content and pedagogical knowledge of science, and abundant practical experience in doing and facilitating scientific experiments (Smetana & Bell, 2012). Such endeavors are also subject to practical constraints including but not limited to budget constraints, limited instruction time, and safety and ethical issues (Argyri, 2015; de Jong et al., 2013; Lewis, 2014). Recent empirical research on virtual laboratories, on one hand, continues to investigate and validate the effectiveness of the innovations in facilitating learning in various science programs (Gnesdilow et al., 2022; Wong et al., 2020). On the other hand, a recent discussion on the educational use of virtual laboratory calls for the appreciation of the unique affordances of virtual laboratory and physical hands-on practices respectively (Chatterjee, 2021; Puntambekar, et al., 2021). Recognizing the educational potentials and constraints of virtual laboratory technologies, many researchers focus on identifying the principles, mechanisms, and issues that may improve or impede the design and development of virtual laboratory for supporting science learning. However, the research on virtual laboratory with reflective thinking is still in its infancy, the investigations of more detailed and rigorous instruction are needed (Nouri, 2016; Kageyama, et al., 2022).

With the aims of looking into the learning process of a virtual laboratory-supported learning environment at the university level, a mixed research method was presented in this study for promoting students' conceptual understanding and learning performance. The research findings will inform the relevant studies in the field of virtual laboratory-supported science learning environments in higher education.

Literature review

Reflective thinking and teaching strategies

Reflection is an active, purposeful, and intentional process that aims at understanding and improving one's understanding and is facilitated by social interactions (Lin, et al., 1999). Students frequently reflecting on their current status of understanding and seeking to go beyond is critical to metacognition, an important component for successful learning of new knowledge, solving of problems, and application of knowledge (Lin, et al., 1999). Rapid developments in educational technology, when properly used, may well provide for the pursuit of reflective thinking in a wide spectrum of educational contexts (Strampel & Oliver, 2007). Of the few studies focusing on this topic, Chen et al. (2019) investigated the impact of a reflective thinking guided approach: WSQ (Watch—Summary—Question) on student engagement, participation behaviors, and learning outcomes in a design course for post-graduate students. Employing a quasi-experimental method, the study confirmed the positive effect of the proposed approach. More recently, Hsia & Hwang (2020) also translated and transformed the WSQ strategy to help structure the pre-class activities of a flipped visual art course. The modified WSQ model generated significantly positive results on students' learning outcomes. In Yang's study (2020, 2019), students were actively engaging in reflective assessment processes by investigating and identifying personal and community knowledge gaps and exploring the moves forward, both personally and collectively. The activities contribute to the emergence of students' productive discourses that display and provide for metacognitive, collaborative, and epistemic inquiry. Meanwhile, previous research has also pointed out that the provision of challenging tasks, rich learning resources, and diversified supports may also help students move from lower levels of "simulated reflection" and "descriptive reflection" that major involve lower levels of cognitive activities of simulation and retrieval, to higher levels of "dialogical reflection" and "critical reflection" that enable the development of new understanding and application of knowledge (Strampel & Oliver, 2007). Based on these understandings, as one of effective learning resources, the integration of virtual laboratory into the promotion of reflective thinking could have potential for triggering students higher level reflection.

Virtual laboratory in science teaching and learning in higher education

Laboratory sessions are critical processes for learning and doing science as they make an indispensable component of scientific modeling and inquiry (Wang et al., 2015). In recent years, theoretical discussion and empirical investigation on virtual laboratory in school-based science education accumulate, exploring and elaborating the benefits and possibilities of technological innovation in improving student laboratory experiences (Argyri, 2015; de Jong et al., 2013; Lewis, 2014). The efficiency of virtual laboratories presents in the marginal time it requires to set up the experiment, and in the instantaneous results, it can generate investigations that would otherwise take substantial time in traditional physical settings (de Jong et al., 2013). The opportunities for doing experiments are also increased based on reduced costs, enhanced safety, and exemption from ethical and legal considerations (Argyri, 2015; Lewis, 2014). More importantly, besides practical benefits, the virtual laboratory provides unique affordances for scientific experimentation. In virtual laboratory settings, unobservable variables and phenomena in traditional physical laboratories can be detected and investigated; realities can be adapted and manipulated; and key information and relationship can be made salient. Students can link the unobservable variables and processes to symbols and equations and observable phenomena, making abstractions over different representations (de Jong et al., 2013), and improving the understanding of scientific concepts (Smetana & Bell, 2012).

Reviewing the studies of virtual laboratory in science education in the context of higher education, various pedagogical approach and teaching strategies (i.e. inquiry-based learning, hands-on activity, problem-based learning, cooperative learning, and project-based learning) has been integrated for better results. In the experimental study of Wang et al. (2015) which involved 145 11th graders, the model-based inquiry pedagogy coupled with a virtual laboratory was found more effective in developing scientific inquiry skills than traditional instructional approaches, bringing about significant improvements in process skills, comprehensive skills, and reflection skills of scientific inquiry. Moreover, when combined with an inquiry-based approach, the virtual laboratory can help expand the “traditional” classroom and enable and encourage students to actively participate in science (Argyri, 2015). Makransky et al. (2016), 300 undergraduate students participated in a medical genetics counseling program enabled by a simulation-based virtual environment. Using a mixed method and direct simulation experience, the study uncovered the favorable impact of the proposed design on student learning, intrinsic motivation, and self-efficacy, and in helping students translate laboratory diagnosis to clinical practices and health decision-making. Adopting the method of design research, August, et al. (2016) developed a simulated virtual environment featuring real-life problem-solving and cooperative learning could help undergraduate students learn engineering science. Piloting the system confirmed its potential to complement learning and enrich student learning interests. In some studies, the virtual laboratory was integrated with the lab experiments as the pre-laboratory activities in the teaching of science for undergraduates. The approaches made students more confident in and comfortable with the operation of laboratory equipment (Blackburn et al., 2019; Dyrberg et al., 2017Reeves et al., 2021).

Based on the above literature review, on the one side, it was found that among all the models and strategies that possess good potentials to improve the processes and outcomes of the virtual laboratory, the promotion of reflection was very limited. On the other side, the virtual laboratories in the form of simulations was usually taken as pre-laboratory activities before lab activities without any pedagogical approaches and follow-up structural strategies (Chan & Lee, 2021). To address this research gap, an experimental study consisted of a self-developed simulation based virtual laboratory guided by a reflective thinking teaching approach: Know-Want-Learn (KWL) were conducted.

Research purpose and research questions

This study focused on exploring the impact of a virtual Laboratory guided by KWL reflective thinking approach on students learning outcomes and attitudes. The research findings would answer the following questions:

1) To what extent did the students improve conceptual understanding after experiencing this virtual laboratory guided by KWL reflective thinking approach?
2) To what extent did the students enhance their reflective thinking after experiencing this virtual laboratory guided by KWL reflective thinking approach?
3) How about students' attitudes toward the virtual laboratory guided by KWL reflective thinking approach?

Research methods

Participants

In this study, the convenience sampling approach was used in selecting the participants in a university in Shaanxi, China, because of the ease of research team to access to them (Kivunja, 2015). The participants were notified with the research purposes and methods, as well as related procedures in the consent form. They were voluntarily to participated in this project. Finally, 58 year-two undergraduate students (the rate of male and female was 2:3; age ranged 18–19 years old) majoring in Chemistry signed agreement on the consent form. These 58 participants were randomly divided into two groups based on the quasi-experimental design methods with an experimental group of 30 students and a control group of 28 students. The teaching team, including three researchers, were responsible for this project, and two participated teachers who co-designed the lessons and implemented the lessons had similar teaching experiences in this course. The intervention was conducted in Semester I of 2020/2021 school year.

The key features of virtual lab

In this study, a set of university self-developed virtual lab system was implemented in physical chemistry courses. There were 12 simulations in this virtual lab system. The virtual lab system was developed by Labview software (Bai et al., 2021; Mohamed et al., 2020). In the study, the simulation of Determination of Molar Mass by Freezing Point Depression was used. The experiment was one of the classic physical chemistry experiments involving key concepts of dilute

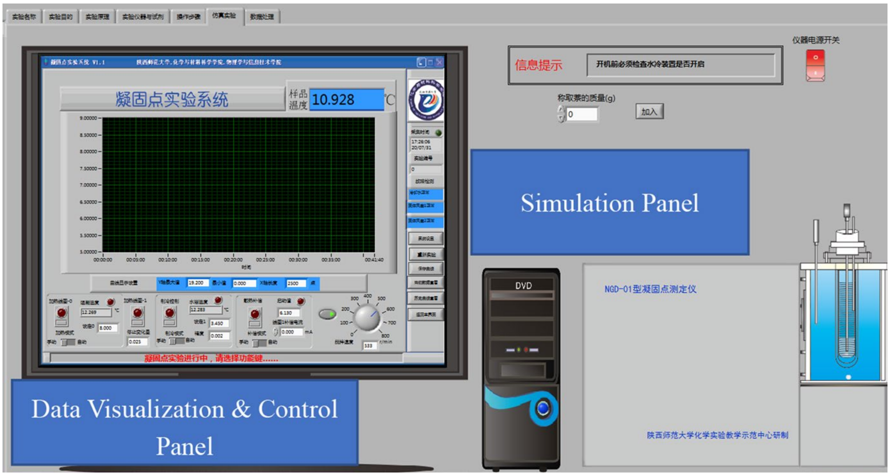


Fig. 1 The basic structure of the virtual lab system

solution, new phase formation, phase balance reversibility, temperature control and measurement. It was a very comprehensive experiment and played an important role in cultivating students high order thinking and practical skills. Figure 1 shows the simulation interface of the mentioned virtual experiment. It consists of two main panels: data visualization & control panel, and simulation panel. With the simulation, the experimental error was reduced from about 10% to 0.2%.

Pedagogical design of virtual laboratory guided by KWL reflective thinking approach

KWL reflective thinking approach

The virtual laboratory guided by KWL reflective thinking approach was implemented in the experiment group. KWL strategy (K-What do you know; W-What do you want to know; L-What have you learnt about the topic) is a commonly adopted teaching method and has been widely accepted by educators and researchers in different subject areas (Tok, 2013), which is vital for improving students conceptual understanding and promoting students' critical thinking and reflective thinking skills in different subjects (Ogle, 1986; Wagner, 2014). Specifically, the KWL reflective thinking approach is using KWL charts to guide the students to complete the tasks and conduct reflections before, during and after learning activities (Bogdanović, et al., 2022). The reflections are conducted to answer the questions before activities: What do you know? And what do you want to know, and What have you learnt after activities. The structure of KWL reflection process has also been verified to active students' prior knowledge, improve students' metacognition, and self-directed learning skills (Greenwood, 2019; Kumari & Jinto, 2014).

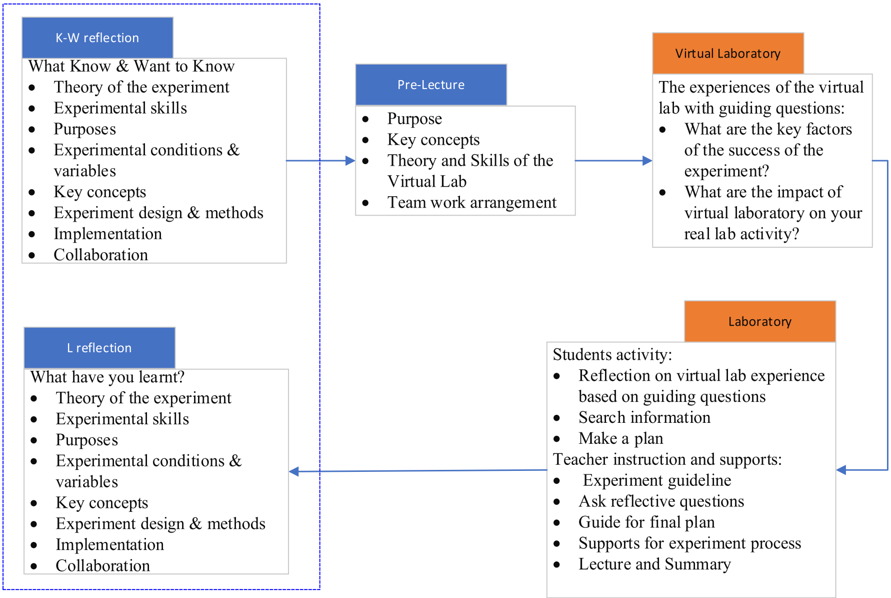
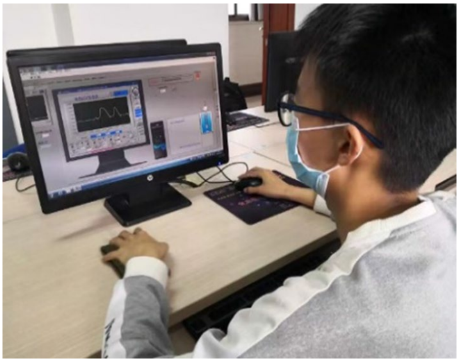


Fig. 2 Instructional design of KWL guided virtual laboratory

Instructional design of KWL guided virtual laboratory

There were five sessions of the instructional design (Fig. 2): ① K-W reflection (15 min): before the real lab activities, the students reflected upon on what they knew and they want to know about the experiment of Determination of Molar Mass by Freezing Point Depression in K-W reflection forms including the theories, skills, key concepts, conditions & variable the purposes, experiment design and methods, implementation and the arrangement of the collaboration. ②Pre-lecture (10 min): the pre-lecture was conducted by the teacher for introducing the purpose and the key concepts, theory and skills, and team work arrangement of the virtual laboratory. ③ Virtual laboratory (45 min): the students conducted the virtual laboratory and manipulated the simulation (Fig. 3), with answering two guiding questions: what are the key factors of the success of the experiment? What is the impact of virtual laboratory on your real lab activity? ④ Laboratory (4 h): during the laboratory activity, two students worked together for hands-on experiments. Students made the final plan and carried out the experiment with the facilitations of the teacher. The teacher provided the experiment guideline and asked reflective questions to guide the students' experiment activities (Arnold et al., 2014). ⑤ L-reflection (15 min): students conducted post reflection on what they have learnt on the theories, skills, key concepts, conditions & variable, the purposes, experiment design and methods, implementation and the collaboration.

Fig. 3 Student in experimental group is manipulating the virtual lab simulation



Procedures

Using a random selection method to divide the participants into a control group and an experimental group. The traditional teaching methods which integrated virtual lab exercises into lab experiment were used for the control group. The KWL guided virtual laboratory was implemented in experimental group. Before the experiment began, the teacher in the experimental group was trained in reflective teaching mode, which lasted for two weeks. The procedures of this teaching intervention are shown in Fig. 4.

The entire quasi-experiment process mainly consisted of following activities: 1) Pre-test: pre-test (15 min) was assigned to both groups before the class with the aims of examining students' prior knowledge of the designed topic and experiment: Determination of Molar Mass by Freezing Point Depression from the year-2 Physical Chemistry curriculum. 2) KWL guided Virtual Laboratory and Laboratory activities as Fig. 2 shows. 3) Post-test: the post-test tested students conceptual understanding of the key concepts of the experiment. The pre and post tests were identical ones. 4) Evaluation of students reflective thinking levels: students reflective thinking was evaluated by a 5-Likert survey. 5) Interview: five students were asked about their attitudes toward the KWL guided virtual laboratory.

For the control group, students experienced traditional teaching methods which included teacher lectures and lab experiment without any reflection activities. Table 1 shows the key activities of the lessons for both groups. In order to avoid mutual influence, the two groups were taught separately by two teachers.

Data collection and data analysis

Pre-and post-tests for examining students' conceptual understanding

In this study, the identical paper pencil based pre and post-tests were designed for examining and comparing students changes in conceptual understanding after the intervention. The test consisted of 17 short answer questions (5 points for each), with a total score of 85 points (See Appendix 1). The three researchers and two experienced teachers involved in designing the test items based on the existing test

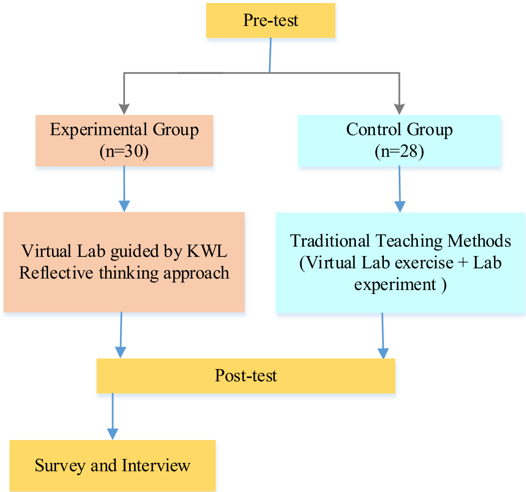


Fig. 4 Procedures of quasi-experimental research

Table 1 Key activities for experimental and control groups

Groups	1) Pre-reflection (K-W)	2) Pre-class (virtual lab)	3) Lecture (PPT, discussion & questions)	4) Lab Experiment	5) Post reflection (L)
Experimental group	✓	✓	✓	✓	✓
Control group	X	X	✓	✓	X

sources and textbooks in physical chemistry. Then expert review was further conducted for ensuring the clarity, readability and content validity of items validation of the test.

Besides descriptive data analysis of test results, paired samples *t*-tests were conducted for comparing the performance of conceptual changes before and after the intervention. In order to more accurately verify whether the experimental group achieved performance, one-way ANCOVA was used for analyzing test data.

KWL journal for evaluating students' reflective thinking of the experiment

Before and after class, students were required to fill in a KWL journal based on three dimensions. The first dimension of K is What did you know. The purpose of this section was to allow students to review the knowledge and skills they have acquired prior to the class. The second is the W (What do you want to know). This part let students plan what they want to master from the course. The last part L is What have you learnt, students summarized what they got after KWL learning mode. In this study, students' responses to KWL were intentionally retrieved and analyzed qualitatively using the keywords visualization mapping tool, as it could better represent students' reflections before and after the intervention (Xie & Sharma, 2011). The approach highlighted the keywords based on their frequency in the reflection journals, the size of the keywords presented how the concepts/principles were emphasized.

Survey for identifying students reflection levels

The survey was designed for contrasting the effect of KWL based reflective teaching approach on students' reflective thinking. The survey design was handled in the way of the Likert 5-level scale modified from the reflection questionnaire designed by Kember et al., (2000). Specifically, the questions were designed based on the four-category scheme for determining levels of reflection, they are habitual action (4 items), understanding (4 items), reflection (4 items) and critical reflection (4 items) (Kember et al., 2008), which represent the levels of reflection from low levels to high levels. The sample questions are as below:

- I like to think over what I have been doing and consider alternative ways of doing it.
- This course has challenged some of my firmly held ideas.
- I often reflect on my actions to see whether I could have improved on what I did.

Based on students agreement level, 1–5 points were given to strongly disagree to strongly agree responses. The reliability of the questionnaire α coefficient was 0.809. According to Nunnally (1978), Cronbach α must be at least 0.7 to be acceptable. Therefore, the reliability of the above survey acceptable, and then the validity test was carried out in groups. The overall performance on reflection was calculated using descriptive data analysis.

Interview

Five students from the experimental group were randomly selected for interview. The interview mainly asked students attitudes toward the whole learning process through five questions (Vossen et al., 2018), 1) students' summary of the characteristics of this experiment class, 2) students gains, 3) the challenges encountered in the class, 4) whether the students doing experiments in an active way or passive way? 5) students' interests in this class. Students responses to interview questions were analyzed qualitatively as the supplementary evidence of students' attitudes toward the intervention.

Results

Students performance on conceptual changes

In order to confirm whether the participants in the two groups had any differences of their prior knowledge, an independent t-test was carried out on the pre-test data. The p value was obtained from the result ($p = 0.859 > 0.05$). It suggested that there was no significant difference between the experimental group and the control

Table 2 Descriptive data analysis of the pre-test and post-test results

		N	Mean	S.D	Std. error
Pre-test	Experimental group	30	55.83	11.867	2.167
	Control group	28	54.94	6.901	1.304
Post-test	Experimental group	30	64.29	9.33	1.703
	Control group	28	58.93	3.691	0.698

Table 3 Paired samples t-test results

	Pre-test	Post-test	t	*p*
Experimental group	55.83 ± 11.867	64.29 ± 9.33	−2.845	0.008
Control group	54.94 ± 6.901	58.93 ± 3.691	0.328	0.745

Table 4 One-way *ANCOVA results of experimental group*

Group	df	Mean Square	F	*p*
group*pre-test	1	199.336	2.542	0.117
group*post-test	1	530.163	12.551	0.001

group, which proved that the participants in this experiment had no special effects. A descriptive data analysis was made of the pre-test and post-test results. Table 2 shows the mean of the experimental group in the pre-test and posttest were 55.83 and 64.29, respectively, while the results of the control group were 54.94 and 58.93. It could be seen that the experimental group gained more conceptual understanding after reflective teaching mode comparing with control group.

Further, Table 3 illustrates the paired samples t-test results with the comparison of pre-test and post-test between two groups. The results showed that the experimental group had significant differences in the pre-test and post-test mean scores ($p = 0.008 < 0.05$), while the control group had no significant difference ($p = 0.745 > 0.05$).

To more accurately verify whether the experimental group achieved performance improvement through the KWL reflective teaching method, ANCOVA was conducted. The study used Levene's test to test the homogeneity of variance, and used the Shapiro–Wilk test to investigate whether the distribution satisfies the normality criterion. The test results showed that the data meets no significant results ($p > 0.05$), indicating that the sample confirms homogeneous variance and data normal distribution, so the one-way ANCOVA method is supported. As shown in Table 4 below, it indicates there is a significant difference in the post-test scores of the students in the experimental group and control group ($P < 0.05$).

a b

Fig. 5 **a** K reflection. **b** W reflection

Fig. 6 Keywords of L reflections

Students performance on KWL reflections

Studies mentioned that the KWL reflections provided an opportunity for students to self-evaluate their knowledge and to make self-judgments through reflections (De Silva, 2020). Keywords were nouns or phrases that reflected the core content of writing activities in KWL Journal. In this study, there were 30 KWL journals collected from the experimental group. As shown in the Fig. 5a and b, before intervention, students' responses to the section 'What I already know (Part K)' focused on the freezing point, colligative property, phases, solutions, experiments (Fig. 5a). This indicated that students have already learned some of the concepts and experimental principles in advance, this prior knowledge would further affect their performance in the experiment activities (Van Riesen, et al., 2018). For what students wanted to know, it was more about the operation of the freezing point depression method and information about experimental operations (i.e. the keywords are experimental, freezing point, method, operation).

For the reflection activity about "What have you learnt", Fig. 6 shows that students conducted more critical reflection on the solution, methods, principles, instruments, factors (i.e. temperature, solvent, data) and learning process and procedures-related knowledge and skills, which were the key elements of an experiment. And meanwhile, students also paid considerable attention to the scientific phenomenon, for example, condition, liquid, concertation, crystallization etc. Overall, students developed a more comprehensive understanding of the key concepts and elements related to this experiment.

Students reflective thinking levels

Table 5 shows the results of descriptive data analysis of students' responses to the survey. Comparing with control group students, experimental group students performed more critically in reflecting their learning process. For example, when asked "As a result of this experiment course I have changed the way I look at myself", the experiment group and control group got 3.57 and 3.13, respectively, which means more students in the experiment group selected agreement or strongly agreement than control group. In general, students achieved higher agreement in Q2 (M = 4.41) (habitual action level), Q6 (M = 4.51) (understanding level), and Q10 (M = 4.33) (reflection), which suggested most of students performed actively in understanding the relevant content and paid more attentions in understanding before doing. For Q14, 15, 16 which represents critical reflection levels, students in experimental group responded with higher agreement then control group.

Students responses to interview questions

Based on students interview responses, it suggested that students generally believed that they benefited from this kind of learning activities as it saves more experiment time and the use of virtual lab facilitates their pre-study in the classroom and promotes their further thinking before lab experiment. This benefit could also be indicated by their responses to the questionnaire. Students expressed strong interest in participating in this kind of learning activity in other topics in the physical chemistry curriculum. Through the practice of virtual experiment, they could be better familiar with the operation process and avoid errors in real experiments and improve operation efficiency. The KWL reflection guided them into the critical reflection process in a more comprehensive way. But the challenge was that students need more assistance to operate the virtual experiment at the beginning stage and more explanations and guide during lecture time. Regarding students' engagement in the activities, four of them expressed that they could learn actively, one of them explained that more guides were needed. One of the students mentioned the reflective teaching could improve autonomous learning during the experiment.

Table 5 Descriptive data analysis of the survey results

Question items	Mean	
	Experimental group	Control group
Q1 When I am working on the experiment, I can do them without thinking about what I am doing	2.14	2.50
Q2 This experiment course requires us to understand concepts taught by the lecturer	4.41	4.00
Q3 I sometimes question the way others do something and try to think of a better way	3.31	3.12
Q4 As a result of this experiment course I have changed the way I look at myself	3.57	3.13
Q5 In this course we do things so many times that I started doing them without thinking about it	2.04	2.50
Q6 To pass this course you need to understand the content	4.51	4.19
Q7 I like to think over what I have been doing and consider alternative ways of doing it	3.49	3.41
Q8 This course has challenged some of my firmly held ideas	3.35	3.21
Q9 As long as I can remember handout material for examinations, I do not have to think too much	2.29	2.44
Q10 I need to understand the material taught by the teacher in order to perform practical tasks	4.33	4.37
Q11 I often reflect on my actions to see whether I could have improved on what I did	3.75	3.53
Q12 As a result of this course I have changed my normal way of doing things	3.75	3.22
Q13 If I follow what the lecturer says, I do not have to think too much on this course	2.35	2.74
Q14 I often re-appraise my experience so I can learn from it and improve for my next performance	3.98	3.61
Q15 In this course I have to continually think about the materials you are being taught	3.57	3.57
Q16 During this course I discovered faults in what I had previously believed to be right	3.20	3.11

Discussion and conclusions

This study explored the impact of an innovative teaching approach which integrates KWL reflective thinking approach into the virtual laboratory. A quasi-experimental research was conducted for examining the impacts of this innovative teaching intervention on students learning performance in conceptual understanding and reflective thinking. It is the first time to integrate KWL reflective thinking approach with the virtual laboratory in science education at the university level, which is few explored in the teaching of physical chemistry in higher education, and has been recommended in relevant studies (Bogdanović, et al., 2022; Chan & Lee, 2021; Ryan, 2013; Zouhor, et al., 2017). Specifically, in Nicol et al. (1994), they suggested a structured learning cycle that encouraged regular reflection, which could promote students deep learning in laboratory practices. This claim further verified by Gupat et al. (2015) that structural reflection could facilitate students critical thinking skills in laboratory instruction. These early studies suggested that the necessity of integrating reflective thinking approach with laboratory teaching and learning. Therefore, our study is a new response to the call for integrating a structural reflective thinking approach-KWL reflection in science laboratory teaching and learning supported by virtual lab technologies (Loughlin et al., 2021; Sarmouk, et al., 2020).

After collecting data and analyzing data, positive research findings were obtained for answering the research questions. In the study, pre and post tests were conducted and the scores were compared between the experimental group and control group. The results showed that the students in experimental group improved more in conceptual understanding than students in control group. The changes in conceptual understanding were significantly for experimental group. The findings further indicated the positive impacts of the reflective teaching mode implemented in the classrooms, particularly in science class or practical activities, which echoes other studies' findings (Tseng et al., 2022; Vollmer & Drake, 2020). In this study, the KWL approach serves as formative assessment tool for promoting students reflective thinking during the laboratory as well (Wagner, 2014). Particularly, through visualizing the content of students KWL reflective journals, students' reflections on the key concepts were highlighted and emphasized. It was found that the KWL reflection helped the students to focus more on their understanding of key concepts, principles and methods of an experiment before and after the virtual experiment, which promotes students to develop elaborated understanding of the knowledge and skills involved in the laboratory activities, particularly, students improved more in methods and process related knowledge in the laboratory. The findings are consistent with reports of earlier studies (Alsalhi, 2019; Seung & Pestel, 2016), and the relationship of reflection and students' metacognition was also related to the findings here (van Opstal et al., 2015). Further, the survey results indicated students could also improve in their reflection levels through this innovative approach, and the ways of conducting pre-reflection and post reflections in the form of KWL before virtual and real laboratory activities would trigger students critical thinking skills, the findings have been discussed by Gupta et al., (2015).

To design and deploy effective laboratory sessions, the teacher is expected to possess good content and pedagogical knowledge of science, and abundant practical experience of doing and facilitating scientific experiments (Smetana & Bell, 2012). Such endeavors are also subject to practical constraints, including but not limited to budget constraints, limited instruction time, venues, and safety and ethical issues (Argyri, 2015; Lewis, 2014). The students in experimental expressed their positive attitudes toward the learning activities, and especially, they appreciated the benefits of this kind of learning with pointing out the usefulness of virtual lab for consolidating their initial understanding of the experiment and related knowledge and skills without teacher assistance, as similar to other technology-assisted learning environments, virtual laboratory usually supports automatic recording and diagnosis of student activities and achievement that facilitates students' engagement and self-regulation (Van Den Beemt, et al., 2022; Rutten et al., 2012). However, students felt challenging when manipulating virtual laboratory without more explanations and guides, which has been found and proposed that the provision of challenging tasks, rich learning resources, and diversified supports may also help students move from lower levels of reflection to critical reflection (Strampel & Oliver, 2007). As mentioned in other studies, the involvement of virtual laboratory also enhances the non-cognitive aspects of student learning (i.e., motivation, interest, and perception) (Ramadhan & Irwanto, 2017). Comparing with control group, students in experimental group agreed on items in higher refection levels. We expect there should be some internal connection between the use of virtual lab in pre-class activities and students understanding and performance in the lab experiment, which is worth further study.

In conclusion, our study is just the first step, and a trial instruction for integrating the KWL reflective mode into the virtual laboratory practices. The key elements in this teaching intervention are KWL and virtual laboratory, which are rarely combined and integrated into the teaching of science topic in higher education levels. The initial findings of this instruction could shed light on the following aspects: 1) Lesson design for laboratory practices in universities: the tailored design of learning activities with aims of enhancing students high order thinking is limited in the area of teaching and learning of laboratory. Therefore, the attempts of integrating related student-centred teaching approaches or strategies into the laboratory instruction, especially for the structural teaching mode, students will benefit more from the conceptual understanding and learning process involved in the laboratory. 2) pre-class activity design for the laboratory: The educators and researchers are suggested adopting virtual lab, simulations, and videos in pre-class activities for providing students more opportunities to self-investigate the experiment activities or practical activities before getting into the lab. 3) teaching of reflective thinking guided laboratory: the teachers are suggested to design or provide more scaffoldings for the students' pre-class activities for better guide students virtual lab activities in and out of classroom.

Appendix 1: Students' conceptual understanding pre and post tests

Q1 How the sample should be cooled when measuring the step cooling curve?
Q2 Requirements of the inner sleeve used for the experiment
Q3 If the pure solvent used is benzene, the normal freezing point is 5.5 °C. The molar mass is measured by the freezing point depression method at 20 °C room temperature and atmospheric pressure. In order to make the cooling process in a relatively close to equilibrium, what is the more suitable thermostatic medium bath as a chilling agent.
Q4 Differential thermal analysis is similar to the step-cooling curve method in that it also measures the phase change temperature of the material system, but ——.
Q5 When measuring the molar mass of naphthalene by the freezing point depression method, what is the temperature of the chilling agent (ice and water mixture) to be controlled?
Q7 When adding naphthalene to cyclohexane, a small amount of the drug falls out and what happens to the molar mass of naphthalene as a result.
Q8 What is the most appropriate way to handle an experiment in which the solution is found to be too cold?
Q9 In the determination of the exact freezing point of the pure solvent cyclohexane, when the temperature of the cyclohexane solution drops to how many degrees above the approximate freezing point is the frozen tube quickly removed?
Q10 The key to the molar mass determination experiment by the freezing point depression method is——.
Q11 When using the freezing point depression method to determine the molar mass of a solute, what is the key factor in the success or failure of the experiment?
Q12 Which solution is suitable for determining the molar mass of a solute using the freezing point depression method
Q13 Whether the freezing point depression experiment can be used for electrolyte solutions?
Q14 During the temperature drop, do we need to make sure that the temperature drops slowly to achieve accurate observation of the freezing point.
Q15 Is it correct to say that the molecular weight of a measured solute will be high when the solute associates or forms complexes in solution?
Q16 When selecting the solvent type, the smaller the kf the higher the accuracy of the measured value. Is this statement correct?
Q17 When determining the freezing point, the less solid that precipitates the more accurate the molecular weight of the solute is determined. Is this statement correct?

Appendix 2: Survey on Students Attitudes toward the teaching intervention

Q1 When I am working on the experiment, I can do them without thinking about what I am doing

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q2 This experiment course requires us to understand concepts taught by the lecturer

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q3 I sometimes question the way others do something and try to think of a better way

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q4 As a result of this experiment course I have changed the way I look at myself

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q5 In this course we do things so many times that I started doing them without thinking about it

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q6 To pass this course you need to understand the content

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q7 I like to think over what I have been doing and consider alternative ways of doing it

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q8 This course has challenged some of my firmly held ideas

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q9 As long as I can remember handout material for examinations, I do not have to think too much

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q10 I need to understand the material taught by the teacher in order to perform practical tasks

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q11 I often reflect on my actions to see whether I could have improved on what I did

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q12 As a result of this course I have changed my normal way of doing things

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q13 If I follow what the lecturer says, I do not have to think too much on this course

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q14 I often re-appraise my experience so I can learn from it and improve for my next performance

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q15 In this course I have to continually think about the materials you are being taught

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Q16 During this course I discovered faults in what I had previously believed to be right

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

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Declarations

Conflict of interest The authors declare no competing interests.

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