UNIJERPS
Unizik Journal of Educational Research and Policy Studies VOL.20 (1);
July-December, 2025 https://unijerps.org
2023 Impact Factor: **6.834;** 2022 ***Impact Factor***: 5.156; ***2021 Impact Factor: 5.641;***
2020 Impact Factor: 5.355. *Indexing and Impact Factor URL: http://sjifactor.com/passport.php?id=21363*

COMPARATIVE EFFECT OF DIGITAL LEARNING ENVIRONMENT AND PROBLEM-BASED LEARNING ON STUDENTS' METACOGNITIVE SKILLS

Prof. Gladys Uzezi Jack & Sadiq Baba Muhammad
jackgladys1970@gmail.com
Department of Science Education, Taraba State University, PMB 1167, Jalingo.

ABSTRACT

This study explored the comparative effectiveness of digital learning environment and problem-based learning on secondary school students' metacognitive skills in chemistry in Jalingo Education Zone, Taraba State. A quasi-experimental research design of pre-test, post-test non-equivalent group was used as design. The population comprised all the 5361 secondary school one (SS 1) students taking chemistry in the Jalingo Education Zone. The sample size was 150 students from the two sampled intact classes with 70 students in the experimental group 1 and taught chemistry in a digital learning environment (DLE) aided by Physics Education Technology (PhET) Package while 80 students were in the experimental group 2 and learned through problem-based learning (PBL). Metacognitive Awareness Inventory (MAI) was used for data collection. MAI was validated by three experts, and reliability index of MAI was found to be 0.79 through Cronbach alpha method. Mean and standard deviation and Analysis of Covariance (ANCOVA) were used for data analyses with the hypothesis testing at 0.05 level of significance. The findings revealed that the metacognitive skills' rating of students in DLE was significantly higher than PBL ($p<0.05$). There was no significant effect of gender on metacognitive skills ($p>0.05$) in both groups. It was concluded that when students learn in a digital environment, their metacognitive skills are greatly enhanced. It was recommended among others that teachers should integrate digital learning into chemistry instructions for enhancement of metacognitive skills.

Keywords: Digital learning, problem-based learning, metacognitive skills, gender, chemistry

Introduction

Science is so crucial to national development that it is being taught in schools. School is one of the agents of social changes; consequently, science is being taught in schools as that is a great avenue to have science popularized. Nigeria is also one of the countries that have adopted teaching and learning of science in schools. The students at the secondary school level of education are taught science subjects which will foster scientific literacy. The secondary school level of Nigeria is the level in which students learn the science subjects of biology, chemistry, and physics among others which were previously lumped as basic science and technology at the primary level. Chemistry was the science subject of interest in this study. Chemistry is a branch of science studies matter, its composition, its reaction, interaction and uses (Ababio as cited in Udodi et al., 2023). Promoting effective teaching and learning of chemistry is promoting scientific literacy which in turn brings the needed development since chemistry is also a science subject. Scientific

phenomena such as acid rain, global warming, change in states of matter and bleaching among others could be explained by secondary school students with adequate knowledge of chemistry. Students' exposed to appropriate teaching and learning activities in chemistry could make these scientific explanations typically show good metacognitive skills.

Bouiri et al. (2023) defined metacognitive skills as the ability to understand, control and regulate one's own thinking and learning process. It is an offshoot of the term 'metacognition'. Metacognition is the students' knowledge of their own cognitive processes (Kaur & Saini, 2020). It comprises students' knowledge and regulation of their cognition. According to Bouiri et al. (2023), metacognition plays an important role in attainment of the ultimate goal of teaching and learning (which in chemistry is to enable students learn effectively). Apparently, when students are fully aware of their personal learning needs, how they learn, how their brain processes a newly learned concept, they will adopt strategies that could help them learn better. As aforementioned, in addition to knowledge of cognition, metacognition involves the regulation of cognition. Regulation of cognition consists of skills such as planning; monitoring, control and evaluation of cognitive processes are referred to as metacognitive skills (Ader in Guner & Erbay, 2021). Hence, metacognition involves knowledge about cognition (understanding your strengths and weaknesses as a learner) and regulation of cognition (planning, monitoring, and evaluating your learning process). Apparently, if students plan how and what to learn, monitor their learning progress and process, and reflectively evaluate the whole process, they could have a boost in achievement. Students' metacognitive skills could be influenced by external factors outside the students' control such as teachers' teaching strategy. Metacognitive skills are higher order skills which involve critical thinking and could align better with constructivists' strategies which demand the students to be actively involved in knowledge acquisition rather than being passive listeners. The quest to proffer alternative learning strategies which could enhance metacognitive skills and improve achievement formed the backbone of the study. The digital learning environment (DLE) and problem based learning (PBL) were considered in this study.

One of the trademarks of learning in the 21st century is the digitalization of learning. Walker (2024) defined digital learning as one that is supported by technology; it is an umbrella name for all forms of learning involving computers, internet, and mobile phones among others. Science is dynamic and so also should its teaching and learning be. The dynamics here entails that since the world is currently in the information age where computers have been inseparable with human activities and endeavours, the teaching and learning of science should tilt to that effect. It was observed in Walters (2022) that schools have recognized that digitalization is crucial in providing positive learning experiences. Gunawan and Liliasari suggested that computers can be used to practice problems, games, to teach problem-solving (cited in Gunawan et al., 2017). For the purpose of this study, the Physics Education Technology (PhET)

interactive simulation was considered for the digital learning environment. PhET interactive simulation belongs to the class of education delivered via computer, mobile phone or internet accessible device. Interactive computer simulations offer interactive and appealing interfaces with functions of repeated manipulations and observations (Banda & Nzabahimana, 2023). PhET simulations are research-based, highly interactive, animated, and easy to use interactive digital environment and they create a game-like environment which models real-life scenarios, and do not need many computer specifications (Banda & Nzabahimana, 2023). PhET Interactive Simulations are dynamic, interactive tools created by the University of Colorado Boulder to facilitate the learning of science and mathematics through exploration and discovery. These simulations are available for practical exploration across various scientific disciplines, including biology, chemistry, physics, and mathematics.

Generally, one pedagogical advantage of digital learning environments is that they could also be combined with other instructional strategies to make learning more effective. This explains why numerous studies have demonstrated the effectiveness of various digital learning environments in different contexts. For instance, Al-Duhani et al. (2024) found that web-based virtual laboratory significantly enhanced students' metacognitive self-regulation ability. Similarly, Alzahrani and Alharthi (2023) explored virtual laboratory and metacognitive skills and found that digital virtual laboratory enhances students' metacognitive skills more than conventional strategy. Anyawu (2020) also conducted a similar study, exploring students' metacognitive skills using computer assisted instructions and observed that students who learned through computer assisted instructions significantly acquire improved metacognitive skills more than students in the lecture method group. PhET simulation has no space and time restriction as students can utilize this environment within and outside the classroom. Some teachers are not technologically literate and may opt for a not digital strategy of learning. In this case, problem based learning was considered.

Problem based learning (PBL) is a classroom learning model that in the classroom learning activities, there are real problems used as a reference for students to be able to think creatively and critically in order to find solutions to problems given by the teacher (Susilawati & Doyan, 2023). Imaniah et al. (2023) saw it as a learning concept that helps educators build a learning environment that begins with important and relevant issues for students to enable them obtain a more real-life learning experience. Essentially, in this strategy, problem drives learning. Problems are posed or presented such that the solving process instills content knowledge and higher order thinking skills in the learners. These higher order thinking skills are important in science and chemistry particularly as chemistry has a wide range of real life applications. The choice of problem based learning as an instructional strategy is guided by Anyawu (2020) who believed that educators must create learning environments that foster the acquisition of scientific and technical

skills, catering to all learners' diverse needs and interests. Sitorus et al. (2016) posited five steps involved in resolution of problems in this strategy: definition of problem, problem diagnosis, formulation of alternative strategies, implementation of strategies of choice and evaluation of the process and result. When teachers painstakingly implement this strategy, students' higher order skills such as metacognitive skills will receive a boost.

This is evident in the empirical studies that have demonstrated the effectiveness of problem-based learning to this regards. Winarti et al. (2021), for instance, reported that problem based learning significantly enhanced students' metacognitive skills. Sutarto et al. (2022) found a significant effect for problem based learning on students' metacognitive abilities. In addition, Kuvac and Koc (2019), and Majeed (2024) all found that problem based learning is effective in improving students' metacognitive awareness and metacognition respectively. The literatures showed that both digital learning environment and problem based learning enhance students' metacognitive skills; however, limited studies have been conducted to compare the two approaches and arrive at which is better at enhancing students' metacognitive skills. This problem (gap) was filled by the current study.

Gender was also considered in the study as a moderator variable of interest. Owoyemi and Adesina (2021) pointed out that gender is a set of socially influenced roles and associations, human traits, attitude among others that differentiate both sexes. Gender is shaped by culture, social relations and natural environments. Gender influences science learning in general and chemistry specifically. Gender bias, gap or difference occurs when either male or female students are prioritized. In chemistry learning, a teacher may unconsciously give more opportunity for male students to answer questions and participate in class activities. It is undeniable that gender differences exist; in fact, Ajai and Azuaga (2022) asserted that this gender gap in Sub-Saharan African nations when it comes to education in science, technology, engineering, and mathematics at all levels remains relatively large. Apparently, being a sub-Saharan country, in Nigeria, gender gaps occur in treatment of males and females students and this has resulted into a deterred progress and achievement in schools. However, empirical studies have demonstrated mixed results. For instance, Supahar and Widodo (2020) found no significant gender difference in problem solving skills of students. Misu and Misu (2019) also reported that no significant difference is found in metacognitive skills of male and female students. Ahmed et al. (2019) further found no significant gender difference in metacognitive skills of students. Contradictorily, Barokah et al. (2020) found that metacognition of female students is significantly better than their male counterparts. The variation in findings of literature in this regards coupled with Ajai and Azuaga's (2022) position that gender gap in Sub-Saharan African nations when it comes to education in science, technology, engineering, and mathematics at all levels remains relatively large, informed the exploration of gender as moderator variable.

The background for this study lies in the growing interest in innovative teaching methods, particularly digital and problem-based learning, and their potential to enhance student metacognitive skills in subjects like chemistry. The problem addressed is the need for a comparative analysis of these approaches to determine which method is more effective in promoting these outcomes. It is in light of this and the foregoing that this study investigated the comparative effectiveness of digital and problem-based learning on metacognitive skills among secondary school students in chemistry in Taraba State. Consequently, the study sought to answer the question: 'Which will improve students' metacognitive skills: Learning in digital environment or using problem-based learning; and any gender difference in both strategies?'

The purpose of the study was to compare the effectiveness of digital learning environment and problem-based learning on metacognitive skills among secondary school students in chemistry in Taraba State. Specifically, the study determined the;

1. Metacognitive skills of students taught chemistry concepts through digital learning environment and students taught using problem-based learning.
2. Metacognitive skills of male and female students taught chemistry concepts through digital learning environment.
3. Metacognitive skills of male and female students taught chemistry concepts through problem-based learning.
4. Interaction effect of gender and strategies on students' metacognitive skills.

Research Questions/Hypotheses

The following research questions guided the study:

1. What is the mean metacognitive skills rating of students taught chemistry concepts through digital learning environment and students taught using problem-based learning?
2. What is the mean metacognitive skills rating of male and female students taught chemistry concepts through digital learning environment?
3. What is the mean metacognitive skills rating of male and female students taught chemistry concepts through problem-based learning?
4. What is the interaction effect of gender and strategies on students' metacognitive skills?

The following null hypotheses were formulated and tested at 0.05 level of significance.

$H_0$1: There is no significant difference in the mean metacognitive skills rating of students taught chemistry concepts through digital learning environment and students taught using problem-based learning.

$H_0$2: There is no significant difference in the mean metacognitive skills ratings of male and female students taught chemistry concepts through digital learning environment.

$H_0$3: There is no significant difference in the mean metacognitive ratings of male and female students taught

chemistry concepts through problem-based learning.

$H_0$4: There is no significant interaction effect of gender and strategies on students' metacognitive skills.

Methodology

The study adopted a quasi-experimental research design of pre-test, post-test non-equivalent groups. The research design was considered appropriate because the study inferred cause-and-effect relationship between digital learning environment and problem based learning being the independent variables and students' metacognitive skills being the dependent variable with gender as moderator variable. This was done using non-random criteria of intact classes. The population comprised all the 5361 secondary school one (SS 1) students taking chemistry in the Education Zone in the 2024/2025 academic session. The sample size was 150 students from two sampled intact classes. Purposive sampling was used to select two intact classes while random sampling was used to assign the classes into experimental group 1 and 2 with the criteria being the availability of functional computers with which the digital learning was conducted. A total of 70 students were in the experimental group 1 and taught chemistry in a digital learning environment aided by Physics Education Technology (PhET) Package while 80 students were in the experimental group 2 and learned through problem based strategy.

Lesson plans were provided and handed over to the research assistants who helped in the implementation of the treatment exercise. Students were taught Boyle's law, Charles' law and balancing chemical equation for a period of four weeks using digital (PhET simulations) and PBL instructional strategies. The PhET simulations used for this study provided a visual and interactive platform for students to explore complex chemical concepts, potentially making them more engaging and easier to understand. It offered a virtual laboratory experience, allowing students to conduct experiments and manipulate variables without the limitations of physical lab equipment or safety concerns. It also helped the students visualize abstract concepts through active exploration of the stipulated PhET sim on topics taught using the inclusive features and provide access to wider range of resources. While, the PBL encouraged active learning and critical thinking by presenting students with real-world problems that they need to solve through research and collaboration on the topics Boyle's and Charles' law and balancing chemical equations. It emphasized the application of learned concepts to solve practical problems, promoting deeper understanding and retention of knowledge. It also fostered the development of essential skills like problem-solving, critical thinking, communication, and teamwork.

A 35-item Metacognitive Awareness Inventory (MAI) was used for data collection. It has two sections, A and B. The section A of MAI accounted for the socio-demographic information of the students while section B consists of the adapted items to test students' metacognitive skills. For positively worded items, SA, A, D and SD translate into ratings of 4, 3, 2 and 1 respectively.

However, for negatively worded items, the scales SA, A, D and SD translated into 1, 2, 3 and 4 respectively. MAI was validated by three experts: two from science education and one from measurement and evaluation unit all from Taraba State University, Jalingo. Reliability indices of MAI was found to be 0.79 using Cronbach Alpha reliability method following a pilot test with 35 students in Zing Education Zone. Mean and standard deviation were used to answer all the research questions raised while Analysis of Covariance (ANCOVA) was used for hypothesis testing at 0.05 level of significance.

Results

Research Question 1: What is the mean metacognitive skills' rating of students taught chemistry concepts through digital learning environment and students taught using problem-based learning?

Table 1: Mean and standard deviation of metacognitive skills rating of students taught through digital learning environment and problem-based learning

Group		PreMAI	PostMAI	Mean gain
	Mean	2.39	3.70	1.31
DLE	N	70	70	
	Std. Deviation	0.30	0.17	
	Mean	2.35	3.45	1.10
PBL	N	80	80	
	Std. Deviation	0.41	0.25	
Mean difference		0.04	0.25	0.21

Table 1 indicates that before treatment, students in the digital learning group, being the experimental group 1, had mean metacognitive skills rating of 2.39 with standard deviation of 0.30; while students in the experimental group 2 exposed to problem-based learning had a mean of 2.35 with standard deviation of 0.41. This means that initially, students in the digital learning group performed slightly better than students in the problem-based learning group with mean difference of 0.04. The standard deviation values at this stage depict that the rating of students in the problem-based learning group were more dispersed compared to students in the digital learning group since it had a higher standard deviation (0.41 to 0.30). After the exercise, students in the digital learning environment group had mean metacognitive skills rating of 3.70 with standard deviation of 0.17 while students in the problem-based learning group had mean metacognitive skills rating of 3.45 with standard deviation of 0.25. The standard deviation values at this stage depict that the ratings of students in the problem-based learning group were more dispersed compared to students in the digital learning group since it had a higher standard deviation (2.03 to 1.88). Students in the digital learning group showed gained higher metacognitive skills than their counterparts in problem-based group as they gained 1.31 to 1.10 obtained by students in the problem-based learning group. The difference in mean gain is 0.21 in favour of digital learning environment group. But, $H_0$1 was used to test if the difference was significant as presented in Table 2.

H_{01}: There is no significant difference in the mean metacognitive skills ratings of students taught chemistry concepts through digital learning environment and students taught using problem-based learning.

Table 2: ANCOVA statistics of the difference in metacognitive skills rating between students exposed to digital learning environment and problem-based learning

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2.363a	2	1.182	24.716	.000	.252
Intercept	41.092	1	41.092	859.536	.000	.854
PreMAI	.021	1	.021	.445	.506	.003
Groups	**2.307**	**1**	**2.307**	**48.252**	**.000**	.247
Error	7.028	147	.048			
Total	1915.113	150				
Corrected Total	9.391	149				

Table 2 shows that F (1,147) = 48.252 and p = 0.000 which is less than the benchmark 0.05. This means that there is a significant difference in the mean metacognitive skills of students exposed to digital learning environment and problem-based learning. Consequently, null hypothesis 1 is rejected. Table 2 indicated that students in the digital learning group gained more in metacognitive skills. Subsequently, this test of hypothesis proves that the earlier established difference is statistically significant in favour of digital learning environment. This means that digital learning improved students' metacognitive skills in chemistry significantly more than problem-based learning. In addition, the partial eta squared value of 0.247 shows that about 25% of the variation of the students' metacognitive skills in chemistry is accounted for by the effect of the treatment exercise.

Research Question 2: What is the mean metacognitive skills rating of male and female students taught chemistry concepts through digital learning environment?

Table 3: Mean and standard deviation of metacognitive skills rating of male and female students exposed to digital learning environment

Gender DLE		preMAI	postMAI	mean gain
	Mean	2.43	3.71	1.28
Male	N	31	31	
	Std. Deviation	0.32	0.17	
	Mean	2.36	3.69	1.33
Female	N	39	39	
	Std. Deviation	0.28	0.17	
Mean difference		0.07	0.02	0.05

Table 3 indicates that at pre-test, male students in the digital learning group had mean metacognitive skills rating of 2.43 with standard deviation of 0.32 while their female counterparts had a mean rating of 2.36 with standard deviation of 0.28. This means that initially, the male students' metacognitive skills' rating was slightly higher than female students in the digital learning group with mean difference of

0.07. The standard deviation values at this stage depict that the scores of male students were more dispersed compared to the female students' scores since it had a higher standard deviation (0.32 to 0.28). After the exercise, male students in the digital learning environment group had metacognitive skills rating of 3.72 with standard deviation of 0.17 while female students in the same group had mean metacognitive skills rating of 3.69 with standard deviation of 0.17. The standard deviation values at this stage depict that the ratings of both male and female students were evenly distributed (0.17). Apparently, female students appeared to benefit slightly more in terms of metacognitive skills than their male counterparts as they gained 1.33 to 1.28 obtained by male students. The difference in mean gain is 1.02 in favour of the female students in the digital learning group. But, $H_0$2 was used to test if the difference was significant as presented in Table 4.

$H_0$2: There is no significant difference in the mean metacognitive skills ratings of male and female students taught chemistry concepts through digital learning environment.

Table 4: ANCOVA result of metacognitive skills rating of male and female students taught using digital learning environment

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.009a	2	.004	.152	.860	.005
Intercept	14.826	1	14.826	518.575	.000	.886
DLEpreMAI	.005	1	.005	.178	.674	.003
DLEgender	**.005**	**1**	**.005**	**.161**	**.690**	.002
Error	1.916	67	.029			
Total	959.167	70				
Corrected Total	1.924	69				

Table 4 shows that F (1,67) = 0.161 and p = 0.690 > 0.05. This means that the significance level is higher than the benchmark of 0.05. Consequently, the null hypothesis is accepted as this signifies that there is no significant difference in the mean metacognitive skills rating of male and female students exposed to digital learning environment. Table 4 showed the mean difference in metacognitive skills of male and female students in the digital learning environment where female students gained more in metacognitive skills than their male counterparts. However, the result of the test of hypothesis presented in Table 4 shows that the difference is not significant. This means that male and female students taught chemistry through digital learning environment will gain equally in terms of metacognitive skills. The partial eta squared value to this regards is 0.002 meaning only 0.2% of the variation of students' metacognitive skills rating in digital learning environment group was due to gender differences.

Research Question 3: What is the mean metacognitive skills rating of male and female students taught chemistry concepts through digital learning environment?

Table 5: Mean and standard deviation of metacognitive skills rating of male and female students exposed to problem-based learning

Gender PBL		PreMAI	postMAI	mean gain
	Mean	2.25	3.41	1.16
Male	N	38	38	
	Std. Deviation	0.40	0.26	
	Mean	2.44	3.48	1.04
Female	N	42	42	
	Std. Deviation	0.40	0.25	
Mean difference		0.19	0.07	0.12

Table 5 indicates that at pre-test, male students in the digital learning group had mean metacognitive skills rating of 2.25 with standard deviation of 0.40 while their female counterparts had a mean rating of 2.44 with standard deviation of 0.40. This means that initially, the female students' metacognitive skills' rating was higher than male students in the problem-based learning group with mean difference of 0.19. The standard deviation values at this stage depict that the ratings of male students and female students' were evenly dispersed since identical figures (0.40) were found. After the exercise, male students in the problem-based learning group had metacognitive skills rating of 3.41 with standard deviation of 0.26 while female students in the same group had mean metacognitive skills rating of 3.48 with standard deviation of 0.15. The standard deviation values at this stage depict that the ratings of both female students were slightly more evenly distributed (0.25 to 0.26). In addition, male students benefitted more in terms of metacognitive skills than their female counterparts as they gained 1.16 to 1.04 obtained by female students. The difference in mean gain is 0.12 in favour of the female students in the digital learning group. But, $H_0$3 was used to test if the difference was significant as presented in Table 6.

$H_0$3: There is no significant difference in the mean metacognitive skills ratings of male and female students taught chemistry concepts through problem-based learning.

Table 6: ANCOVA result of metacognitive skills rating of male and female students taught using problem-based learning

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.122a	2	.061	.941	.395	.024
Intercept	24.722	1	24.722	380.532	.000	.832
PBLpreMAI	.023	1	.023	.359	.551	.005
PBLgender	**.074**	**1**	**.074**	**1.134**	**.290**	.015
Error	5.003	77	.065			
Total	955.945	80				
Corrected Total	5.125	79				

Table 6 shows that F (1,77) = 1.134 and p = 0.290 > 0.05. This means that the significance level is higher than the benchmark of 0.05. Consequently, the null hypothesis is accepted as this signifies that there is no significant difference in the

mean metacognitive skills rating of male and female students exposed to problem-based learning. Table 6 showed the mean difference in metacognitive skills of male and female students in the problem-based learning where male students gained more metacognitive skills than their female counterparts. However, the result of the test of hypothesis shows that the difference is not significant. This means that male and female students taught chemistry through problem-based learning will gain equally in terms of metacognitive skills. The partial eta squared value to this regards is 0.002 meaning only 0.2% of the variation of students' metacognitive skills rating in the problem-based learning group was due to gender differences.

Research Question 4: What is the interaction effect of gender and strategies on students' metacognitive skills?

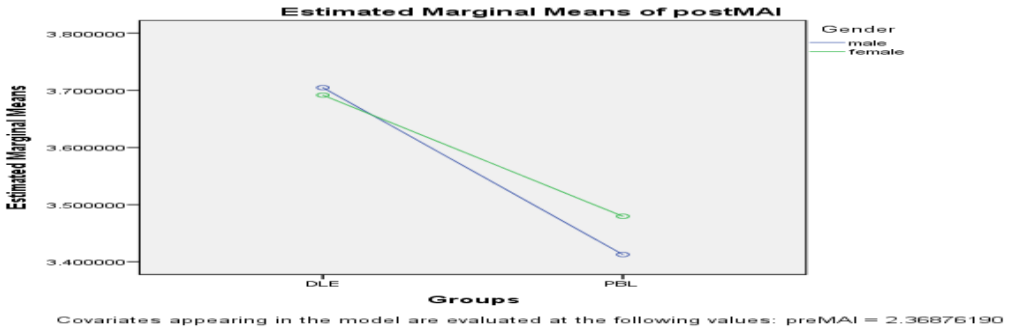


Figure 1: Graph of interaction effect of strategies (digital learning environment & PBL) and gender on students' metacognitive skills

Figure 1 shows the interaction effects of the two strategies and gender on students' mean metacognitive skills' rating. From the graph, it could be deduced that the male and female lines intersect between the two strategies closer to the digital learning environment plot. Since the two lines are not parallel and intersect with each other, it means there is an interaction effect of strategies and gender on students' metacognitive skills. This means that there is slight possibility of male students being favoured more in the digital environment than their counterparts in the problem-based learning group while the female students in the problem-based learning group could be more favoured than female students in the digital learning environment group. But, $H_0$4 was used to test if the interaction effects was significant as presented in Table 7.

$H_0$4: There is no significant interaction effect of gender and strategies on students' metacognitive skills.

Table 7: Two-way ANCOVA result of interaction effect of gender and strategies on students' metacognitive skills

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2.452a	4	.613	12.807	.000	.261
Intercept	40.217	1	40.217	840.353	.000	.853
PreMAI	.007	1	.007	.149	.700	.001
Groups	2.339	1	2.339	48.884	.000	.252
Gender	.027	1	.027	.555	.458	.004
Groups * Gender	**.057**	**1**	**.057**	**1.195**	**.276**	.008
Error	6.939	145	.048			
Total	1915.113	150				
Corrected Total	9.391	149				

Table 7 shows that interaction effect of strategies and gender, F (1,145) = 1.195; p = 0.276 > 0.05. This means the result of test of significance is higher than the benchmark 0.05; consequently, the null hypothesis is accepted. This implies that there is no significant interaction effect of strategies (digital learning environment and problem-based learning) and gender on students' metacognitive skills. Figure 1 showed that there is an intersection of the plots of gender and strategies. However, this test of hypothesis confirms that the intersection, otherwise called interaction is not significant. Essentially, this infer that the metacognitive skills gain accompanying the use of either digital learning environment and problem-based learning does not depend on whether the student involved is a male or female. In other words, both male and female students benefit equally with regards to gain in metacognitive skills when digital learning environment and problem-based learning are involved. The partial eta squared value of 0.008 means that only 0.8% of the students' metacognitive skills gain in both groups was as a result of the interaction of the strategies and gender of students.

Discussion of Findings

Key findings:

1. Students in the digital learning group showed higher metacognitive skills than their counterparts in problem-based group and this difference was statistically significant. This means that students' metacognitive skills will be significantly enhanced upon the utilization of digital learning environments.
2. Female students in the digital learning environment showed slightly more metacognitive skills gain than their male counterparts. This difference was not significant statistically. This means that both male and female students will have nearly equal metacognitive skills when they learn in the digital learning environment.
3. Male students in the problem-based learning group showed slightly more metacognitive skills gains than their female counterparts. This

difference was not significant statistically. This means that both male and female students will have nearly equal metacognitive skills when they learn through problem-based learning.

4. There is an interaction effect of strategies and gender on students' metacognitive skills. However, the interaction effect was not statistically significant. This means that using digital learning group and problem-based learning environment will make students have equal metacognitive skills gains without depending on gender.

The first finding revealed that students who were exposed to digital learning environment significantly had better metacognitive skills than their counterparts in the control group. This shows that learning through digital means helps students acquire metacognitive skills much more than learning in a non-digital environment. When learning through digital means, the software is programmed. Once a wrong command is entered, there will be no response or wrong result will be provided. This is important in making the students learn that they need to constantly review their learning process whether or not they are taking the right steps. By doing this, metacognition is in place. The finding corroborates the observation of Al-Duhani et al. (2024) that web-based virtual laboratory significantly enhanced students metacognitive self-regulation ability. It also agrees with Alzahrani and Alharthi (2023) who found that digital virtual laboratory enhances students' metacognitive skills more than conventional strategy. The finding further affirms Mohamedi et al. (2016) who found that interactive e-learning improves students' problem solving and independent learning skills while also agreeing with Anyawu (2020) that students who learned through computer assisted instructions significantly acquire improved metacognitive skills more than students in the lecture method group. The finding however disagrees with Winarti et al. (2021) who reported that problem-based learning significantly enhanced students' metacognitive skills. It also disagrees with Sutarto et al. (2022) who found a significant effect for problem-based learning on students' metacognitive abilities. It is not in line with Kuvac and Koc (2019), and Majeed (2024) who all found the effectiveness of problem-based learning on improving students' metacognitive awareness and metacognition respectively.

Secondly, the finding on metacognitive skills of students in the digital learning environment based on gender revealed that gender does not significantly influence metacognitive skills even though male students had slightly higher metacognitive skills rating. Digital learning environment by this finding allows both male and female students to have equally improved metacognitive skills. This is consistent with Supahar and Widodo (2020) who found no significant gender difference in problem solving skills of students. Similarly, it agrees with Misu and Misu (2019) who reported that no significant difference is found in metacognitive skills of male and female students. Contradictorily, it disagrees with Barokah et al. (2020) who found that metacognition of female students is significantly better

than their male counterparts. This is unlike the current study's finding with this regards which revealed that both male and female students are essentially the same on metacognitive skills post treatment.

Thirdly, the finding revealed that male and female students in the problem-based learning group showed no significant difference in metacognitive skills. Problem-based learning strategy by this finding allows both male and female students to have equally improved metacognitive skills. This is consistent with Ahmed et al. (2019) who found no significant gender difference in metacognitive skills of students. Furthermore, it agrees with Misu and Misu (2017) who found no significant gender effect in the metacognitive awareness of male and female students. Notwithstanding, disagrees with Barokah et al. (2020) who found a significant difference in metacognition of male and female students in favour of female students.

Lastly, the findings of the study also revealed that there is no significant interaction effect of strategies and gender on students' metacognitive skills. This further confirms the position that both digital and problem-based learning improves the metacognitive skills of male and female students without depending on the gender of the students. It further proves that the simplicity of learning in a digital environment could be attributed to this finding. The finding agrees with Nkok (2022) that there is no significant interaction effect of gender and strategies (with one being digital inclined strategy) on students' learning outcomes. It further agrees with Mohammadi et al. (2016) that there is no significant interaction effect of strategies of learning and gender on students' problem solving and independent learning skills.

The findings had attested that the integration of digital tools and online resources in education has gained significant traction, offering new possibilities for engaging and personalized learning experiences. While PBL, which involves students working collaboratively to solve real-world problems, is known to foster higher-order thinking skills, critical thinking, and problem-solving abilities. Hence, the need for adoption of these effective teaching methods which significantly impacts student learning outcomes and the development of essential skills such as metacognition, which is crucial for effective and lifelong learning; mostly digital tools (PhET Sims) for abstract concepts and topics that involve harmful substances or gases.

The implications to chemistry education is that chemistry teachers who are not computer literate need to train themselves and develop self-efficacy in selecting and setting up a digital environment with which students can learn from. It also implied that curriculum makers and developers need to lay strong emphasis in proffering digital learning platforms such as PhET simulation for students to learn chemistry as abstract concepts are better represented in the digital environment. The findings have provided professional bodies such as STAN with more empirical evidence on the effectiveness of digital learning environment and these calls for creation of awareness and amplification of these findings to reach more chemistry teachers during conferences and workshops.

Conclusion/ Recommendations

The study concluded that learning in a digital environment significantly improved students' metacognitive skills especially in comparison with students who learnt without the backing of digital technology. Similarly, irrespective of whether the learner is a male or female, upon exposure to learning through digital means, the students' metacognitive will be improved greatly with no gender difference. Teachers of chemistry in the light of these findings ought to think towards improving on extent of digitalization of chemistry learning.

The following recommendations were made:

1. Teachers and school administrators are encouraged to provide students with opportunity to learn through digital environment in order to promote their metacognitive skills
2. Teachers can use digital learning environment to enhance male and female students' metacognitive skills since it is not gender sensitive.
3. School administrators should provide the infrastructure needed to utilize digital learning without which it will be difficult for teachers and students to use this strategy.

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