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ENHANCING SCIENCE TEACHERS' SCIENCE PROCESS SKILLS USING TECHNOLOGY-DRIVEN INTERDISCIPLINARY PROJECT-BASED LEARNING

Abstract: Recognizing the necessity for robust Continuing Professional Development (CPD) programs, the Programme for International Student Assessment (PISA) recommended such initiatives in light of the 2022 results to improve the quality of science education. This study responds to that need by assessing the effectiveness of a CPD program aimed at technology-driven, interdisciplinary project-based learning (PBL) to enhance the science process skills of in-service science teachers in the Kashkadardya Region of Uzbekistan. The research employed a sequential explanatory mixed-methods design. The study unfolded in two phases using this design. The quantitative phase involved pre-tests and post-tests, while the qualitative design incorporated phenomenology. Results from the quantitative phase indicated a significant improvement in teachers' science process skills, evidenced by paired t-test results and a notable effect size, confirming the enhancement of these skills. The qualitative findings revealed three primary themes: the seamless integration of scientific practices into PBL, fostering supportive collaboration and teamwork, and the augmented ability of teachers to deliver effective science education. Employing tools like Canva, menti.com, and YouTube within the CPD program proved beneficial for promoting experiential learning, creative engagement, and collaborative problem-solving. These findings emphasize the importance of integrating science process skills within interdisciplinary and inquiry-based frameworks that encourage critical thinking and real-world applications. This research underscores the vital importance of CPD in advancing science education and urges policymakers and educational institutions to prioritize such programs. The CPD program can be implemented in other regions of Uzbekistan and around the world to strengthen science teachers' process skills. Various educational institutions can adopt the CPD framework and incorporate it into their future in-service training programs.

Keywords: Canva; menti.com; project-based learning; continuing professional development; science process skills; mixed-method design.

1. INTRODUCTION

The education of the 22nd century is shifting towards practical, experiential, and transformative education. The emergence of artificial technologies has made the roles and responsibilities of the teacher more and ever demanding. In this case, the in-service teachers should be updated with the latest trends. They should become more facilitators of learning and with the students as co-learning, students can be supported to enhance their critical thinking and collaborative skills. The implication of the Program for International Student Assessment (PISA) of 2022 is that teachers should have enriched skills that will improve their teaching craft.

The preparation of 22nd-century education begins now. Teachers should be trained to become facilitators of learning to ensure the success of the teaching and learning process[1]. As facilitators, teachers need to comprehend each student's facilitating techniques and unique characteristics, enabling them to provide more personalized facilitation. The teaching approach of the 21st century is shifting from being centered around teachers to focusing on students. Malik [2] argued that modern education aims to equip students with content knowledge and knowledge of subjects and technology, promote their development as global citizens, and prepare them for future success.

The problem statement. Most research in this field focused on traditional Project-based learning (PBL) rather than interdisciplinary PBL with technology support. Holubova [3] and Han et al. [4] examined the effectiveness of the traditional PBL method among in-service physics teachers through qualitative studies. Siew et al. [5] conducted a mixed-method study on teachers' perceptions of PBL, finding that it enhanced students' curiosity, motivation, and interest in science. Similarly, Alexander et al. [6] reported positive changes in pre-service teachers' attitudes and skills after participating in traditional PBL method training. This research focused on interdisciplinary PBL with integrating technologies like Canva, which still needs to be explored despite its potential to foster motivation and positive beliefs among teachers [7]. Purnama et al. [8] further emphasized this gap, noting that their systematic review of PBL’s impact on students' science process skills included only five studies, signaling the need for further research in this area. This study is unique in its style of learning methodology of interdisciplinary PBL because this Continuing Professional Development (CPD) program will integrate technologies like YouTube, menti.com, and Canva in the development of learning materials and projects (e.g., PowerPoint and respiratory system model).

Analysis of recent studies and publications. There are areas of concern, though, which are stated by Viadero and Sparks [9] in the Education Week special report. They highlighted six challenges science teachers face, including low scientific achievement, gaps in curricula, educational inequality, insufficient teacher training, lack of diversity among teachers, and limited integration of technology, all of which hinder progress in science and technology. Amigo et al. [10] pointed out that inadequate teacher preparation exacerbates learning gaps caused by the COVID-19 pandemic, while Ntuli et al. [11] observed that many teachers resort to traditional teaching methods due to difficulties in adopting modern strategies, resulting in shallow learning and passive student participation. More Continuing Professional Development (CPD) programs focusing on active learning methodologies like PBL are vital to address this issue. This method encourages students to tackle real-life problems collaboratively while developing problem-solving and research skills [12]. The PBL methodology provides new teachers with whole-rounded learning experiences that enhance their personal development and future professional well-being [3]. Hart [15] argued that deeper interdisciplinary projects enhance employability skills. This study builds on this foundation by incorporating an interdisciplinary approach to PBL, as emphasized by Cabanillas [14], who noted its role in enhancing multidisciplinary interaction and communication competencies. Ramorola (2013) stressed that identifying and addressing barriers to integrating technology in teaching is crucial for effectively supporting instructional practices. Technology-driven interdisciplinary PBL needs to be more effective in improving in-service teachers' science process skills, which should be explored more. Although there are outstanding publications on the perception and attitude of in-service teachers, these are purely qualitative, and only a mixed-method study using a sequential explanatory approach can fully describe how these compounding variables emerge during the training.

The research goal. The research aims to determine the effect of interdisciplinary project-based learning on science process skills following a CPD program among in-service science teachers and explore their perceptions, attitudes, and beliefs about the intervention. This commitment to rigorous investigation and a more integrated understanding of research issues indicates this.

The specific questions this research sought to address were:

(1) What are the changes in the in-service teacher’s science process skills before and after the implementation of the intervention?

(2) Is there a significant change before and after the intervention, as indicated by the paired t-test and effect size?

(3) What are the perspectives and lived experiences of the participants during the CPD program?

By employing a mixed-method approach, the study collected and analyzed data with a combination of quantitative, which enhances the credibility and confidence of the study [16].

2. THE THEORETICAL BACKGROUNDS

The foundational theories of this CPD program are active learning and constructivism. Active learning theory emphasizes student engagement in the learning process, where learners are active participants rather than passive recipients of information. Active learning and constructivism involve students in personal and group discussions, problem-solving, and hands-on tasks, encouraging critical thinking, collaboration, and applying knowledge to real-world scenarios. Zhou et al. [12] argued that active learning theory is rooted in constructivist principles and highlights the value of experiential learning, where students build knowledge through direct experience and reflection.

Anchored on active learning and constructivism theories, PBL is an instructional method that aligns closely with active learning theory. This methodology involves students working on complex, real-world projects over an extended period, requiring them to research, problem-solve, and present their findings. PBL integrates interdisciplinary knowledge, and in this CPD program's case, it captures the ideas of various natural science disciplines like Physics, Chemistry, and Biology. PBL fosters student-teacher, peer-to-peer, and interdisciplinary relationships as teachers engage learners in complex, real-world projects that require research, collaboration, and presentation of findings. In this study, the relationship between the teacher and another teacher is emphasized as the study integrated interdisciplinary teaching into the PBL strategy. Authentic professional challenges that foster the development of collaboration, communication, and critical thinking skills will result in a well-rounded outcome. By engaging students in meaningful and context-based learning, PBL nurtures a deeper understanding of content and prepares learners for practical application.

In line with active learning theory and PBL principles, the CPD program integrated technological tools like YouTube, Canva, and Menti.com in the training design. These tools provide interactive platforms for teachers to explore, predict, and present findings, enhancing engagement and comprehension. Hence, the model of learning, active learning and constructivism theories are aligned with technology-enhanced PBL. This strategy demonstrated how integrating technology into active, project-based tasks could prepare teachers to create innovative, technology-supported learning experiences for their students.

3. RESEARCH METHODS

3.1. Research Design

This research undertaking used a sequential explanatory mixed-method design. The researcher collected and analyzed qualitative data in the first phase. Consequently, these findings provided the basis for further developing or expanding a quality component in the second phase. This research design enabled the researcher to get a more complete and comprehensive view of the effectiveness of interdisciplinary project-based learning through quantitative and qualitative methods. This method allowed the researcher to see both the numerical results and the qualitative aspects of teacher experience. Researchers can verify their findings against a sequential set of quantitative and qualitative methods [17]. As data from different sources and perspectives are considered, triangulation improved the reliability and credibility of study results [18].

In the quantitative phase, the study employed quasi-experimental methods using pre-test and post-test results. The purpose is to determine if there is a significant difference between the pre-test and post-test results regarding the science process skills of the in-service teachers and if this increase in science process skills is significant. In the qualitative phase, the study used a phenomenological approach to explore the in-service science teachers' perspectives, beliefs, and attitudes. This qualitative data explained whether there was a significant difference between the pre-test and post-test results in the teachers' science process skills.

The dependent variable in this CPD program is the science process skills, and the independent variable is the technology-driven interdisciplinary method, which is aligned with the active-learning approach and constructivism theory. During the program, it was emphasized that the atmosphere would be collaborative participation from each science teacher with a unique discipline (e.g., physics, chemistry, biology). Therefore, the outcomes that can be derived from the relationship between science teachers would enhance confidence and competencies in using the learning method used.

3.2. Research and Training Model

The assessment framework utilized was for diagnostic, corrective training, and testing functions. The diagnostic test was the pre-test. The CPD program used technology-aided interdisciplinary PBL as the intervention and corrective measure for science process skills. Also, the entire CPD is training and testing.

Following this training design, the training was held for two days. This discussion exemplified how interdisciplinary project-based learning was conducted during the CPD. At first, the trainers showed the participants the project's objective, which aligned with the Uzbekistan Curriculum and Cambridge Assessment International Education. The aim of Day 1 was to develop and present a diagram using a system and function (e.g., respiratory system or conservation of energy) using Canva. The second day's objective was to build a respiratory system model. At the start of each day and following the training sessions, the trainer used menti.com to gather participants' moods and expectations. Next, the trainers asked the participants about the significance of a model that led to the world challenge or the essential question of project-based learning. The participants wanted to connect it to health, so the challenge was to "Design and build a model of the respiratory system to demonstrate the impact of environmental factors."

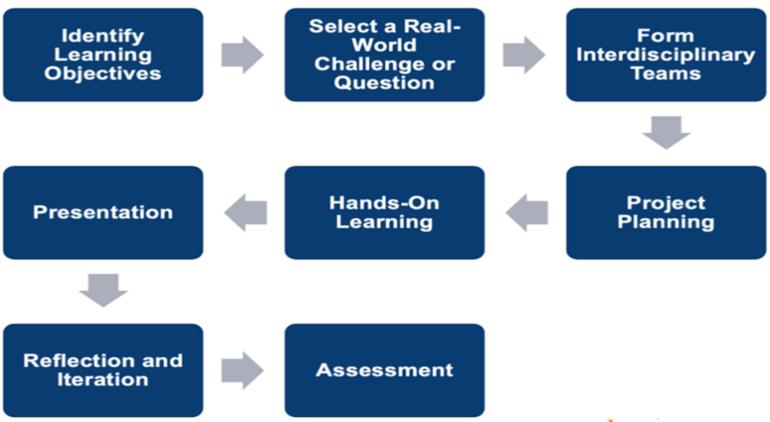

Figure 1. The research and training model follows the principles of interdisciplinary project-based learning

Following this, the participants were grouped into several expertise. Each group has a member who is a chemistry, physics, biology, and one with high communication skills. We can group the students in the classroom based on their dominant learning style or intelligence. When these groups were formed, the teacher-participants planned what to do. The trainers gave the assessment criteria, the number of minutes for the hands-on activity, and the number of minutes for the presentation. They planned to build their project with numerous tools like YouTube video tutorials and websites that present these topics.

After the project planning, the project-making commenced. On day 1 of the CPD program, the trainers facilitated the participants' use of Canva to build a diagram. Numerous technical questions followed, which meant an in-depth discussion of Canva was needed. This day 1 project-making lasted for 1 hour and 30 minutes. This day 1 activity corresponded to the observing and classifying skills of the science process skills. During the second day of the project-making activity, only 30 minutes were given to the students to do the project. During these 30 minutes, the role of the trainer is to facilitate the participants, making sure they are at pace and all materials they need are available. They were taught how to present the Canva-produced diagram effectively, which is part of enhancing their communication skills. After 30 minutes, they were given five more minutes to practice for the presentation. In reality, the PBL can take a week to complete. In the classroom, students should be consulted on the progress of their project. Each team was given five minutes to present their project. Day 1's presentation was aided by the classroom's smart board, as shown in Figure 3.

The selection of the topic was not based on the participants’ personal and professional needs since the ministry had formulated the topic and provided it to the trainers. Therefore, a needs assessment was not conducted. The research solely relied on the given theme. However, in the future, a personal and professional needs assessment should be performed.

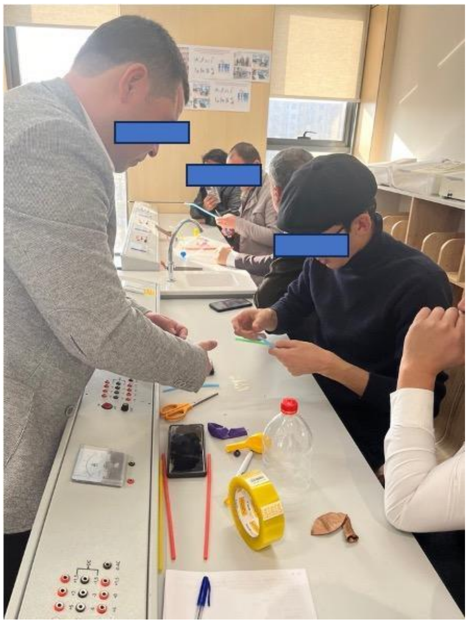

Figure 2. The hands-on activity in designing and making a model of a respiratory system

Following the Canva presentation, another project was conducted to build a respiratory system model. Each member was able to demonstrate the project based on their expertise. For instance, one physics participant said the ribcage should have high tensile strength or the internal organs will not be protected. This project was in the stage of predicting and inferring skills. Thought-provoking questions were written on the white by the facilitators, like "How do you think the movement of the diaphragm in your model will affect the airflow into and out of the lungs?" and "If one lung in your model stops inflating, what might this suggest about possible causes in a real respiratory system?" During the presentation of this second project, they were asked thought-provoking questions and more related to predicting and inferring. The presentation was part of the assessment. However, in classroom reality, you could assess the students' conceptual understanding of the model. Finally, teachers were asked to reflect on the interdisciplinary project-based learning on day two. The project presentation task is aligned with enhancing communication skills.

3.3 Research Participants

There was a total of 31 participants during the CPD. They came from different towns and cities in the Kashkadarya Region of Uzbekistan. These participants were sent by the district office of the Ministry of Education, so there is no chance of randomizing them. This process reduced the selection bias because the researcher could not select the participants. For the quantitative phase, a total of 31 participants were involved. During the qualitative phase, a Focus-Group Discussion (FGD) was conducted. Only selected participants were involved using random sampling by random.org, and there were 15 of them.

The researcher is the trainer, while one local teacher helped translate and facilitate the activities. Three expert teachers reviewed the research instrument, which was then fielded and tested on 35 teachers.

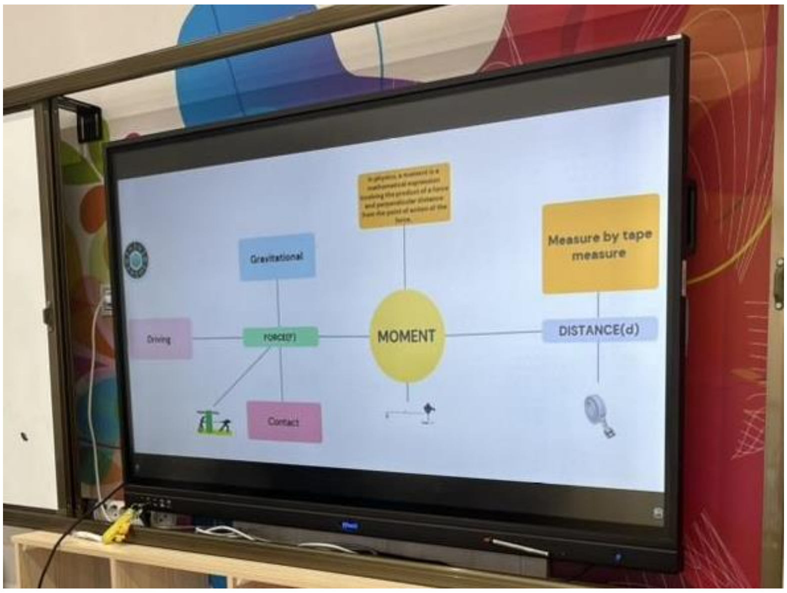

Figure 3. A sample presentation output of the participants was presented using a smartboard.

3.4. Research Instruments

The first instrument collects data for the quantitative phase. It is a researcher-made multiple-choice test that measures science process skills. This test comprised five sections: observing, classifying, predicting, inferring, and communicating. The instrument was aligned with the Cambridge Assessment International Education (CAIE) curriculum and the Uzbek National Curriculum. As shown in Table 1, the science process skills assessed in the study represent foundational competencies.

The test was designed according to these criteria: (1) alignment with internationally recognized and national science curricula to guarantee its relevance, (2) inclusion of essential science process skills identified in current literature, (3) appropriate cognitive demand that requires higher-order thinking skills rather than just recall, and (4) relevance for in-service teachers, taking into account their existing knowledge and professional context.

This instrument underwent content validity and reliability testing. Initially, 20 questions were developed and subjected to content validation using Waltz and Bausell's [19] content validity rating scale. Three experienced teachers reviewed the instrument, and only 18 questions were retained. These 18 items then underwent item analysis to assess their discriminatory power and difficulty index, ensuring that each question effectively measured the intended construct. The difficulty index was 0.65, reflecting a suitable mix of both easy and challenging items. Meanwhile, the discrimination index values ranged from 0.30 to 0.55, indicating that most items effectively differentiated between high and low-performing individuals.

These 18 questions underwent an internal consistency analysis and were tested on a group of teachers participating in similar training. The scores were analyzed using Cronbach's Alpha, yielding an overall Alpha value of 0.70. According to Pacala [20], this indicates good internal consistency. The assessment consisted of 15 multiple-choice questions at the end of the validation and reliability testing.

Table 1

Item distribution of the Test of Science Process Skills

Section	Item distribution	Total
Observing	1, 2, 3	3
Classifying	4, 5, 6	3
Predicting	7, 8, 9, 10	4
Inferring	11, 12, 13	3
Communicating	14, 15	2

For the qualitative phase, semi-structured questions were prepared. These questions were about the perspectives, beliefs, attitudes, and experiences of the participants during the training on interdisciplinary project-based learning. The format used an FGD.

3.5 Data Collection Procedure and Analysis

Before the start of the training, the in-service teachers answered a pre-test on science process skills. A post-test was answered after the training to check if the intervention successfully registered an effect on the science process skills of the in-service teachers. These marks were categorized according to the CAIE [21] grading scale, which can be viewed in Table 3. The CAIE grading scale is used because the trainers are using this curriculum, and the data can serve as a basis for the in-service teachers involved in their standing for the objective used. To analyze these data, a paired t-test was conducted while Cohen's d was used to determine if the increase in science process skills was significant. The data were analyzed using JASP. The JASP program, supported by the University of Amsterdam, has been made available as open-source software for analyzing statistics [22].

During the training, the researcher gathered data like feedback from the participants, observations from the participants, reflections of the participants, and focus group discussions. The training language was mixed English and Uzbek; however, the participants were allowed to talk in plain Uzbek language. The co-teacher of the researcher translated the data transcripts. These data were analyzed following the thematic analysis by Braun & Clarke [23]. According to the authors, thematic analysis has six phases: becoming familiar with the data, generating initial codes, searching for themes, reviewing the themes, defining the themes, and writing the results and discussion. When the themes were generated, reviewed, and refined, they were compared and contrasted with existing literature. This process allows us to check the similarity or uniqueness of the participant's perspectives, beliefs, attitudes, and experiences [23].

Moreover, the qualitative data findings were also used to explain the findings of the quantitative phase. This is the essence of a sequential explanatory research design.

Table 2

Examples of questions from the Test on Science Process Skills

Inferring	Classifying	Communicating
What is the purpose of incorporating balloons into the respiratory system model? a) To represent the lungs and simulate the breathing process. b) To provide structural support to the model. c) To illustrate the circulatory system. d) To represent the digestive system.	Which component of the model primarily serves to simulate the airflow in the respiratory system? a) coca-cola plastic bottle b) drinking straws c) scotch tapes d) balloons	Explain the role of the Coca-Cola plastic bottle in the respiratory system model. How does this component contribute to the overall representation of the respiratory system? a) It acts as a decorative element in the model. b) It symbolizes the heart's function in the circulatory system. c) It represents the trachea and facilitates the flow of air. d) It serves as a container for the balloons.

4. THE RESULTS AND DISCUSSION

4.1. Quantitative Results

As shown in Table 3, the C group (60 to 69%) had a considerable decline from 12 in-service teachers (12%) in the pre-test to 3 teachers (10%) in the post-test. The significant mean Difference of -9 shows a drop in in-service teachers with only 60-69% of science process skills. This means they were elevated to the upper grade scale. No teachers in the D category (50 to 59%) scored in this range on the post-test, resulting in a negative mean difference of -2. This means that performance within this grade range improved. Finally, the E category (40 to 49%) held steady, with no teachers falling into this range in both the pre-test and post-test.

Table 3

The science process skills of the participants

Grade Category	Pre-test No. of Teachers	%	Post-Test No. of Teachers	%	Mean Difference (95% CI)
A* (90 to 100%)	1	3	8	26	7
A (80 to 89%)	6	20	9	29	3
B (70% to 79%)	10	10	11	35	1
C (60% to 69%)	12	12	3	10	-9
D (50% to 59%)	2	2	0	0	-2
E (40% to 49%)	0	0	0	0	0

Table 4 shows the results of the intervention using interdisciplinary project-based learning in various test areas, such as observation, classifying, forecasting, inference, and communication. The intervention involved participants responding to a set number of items in each section, with mean scores recorded for both pre-test and post-test assessments, the associated mean differences, and their 95% confidence intervals (CIs).

Participants demonstrated improvements in their observation skills in the observation section, with the mean score increasing from 2.2 to 2.5 in the pre-test and from 2.5 to 2.5 in the post-test. The statistical significance of this improvement is highlighted by the mean Difference of 0.3, with a 95% CI ranging from 0.2 to 0.4. The analyzed data suggests that interdisciplinary project-based learning interventions enhanced participants' observation and data interpretation skills. In the classification skills, comparable similar trends were seen. The average score increased from 2.5 to 2.7, resulting in a mean difference 0.2. A small 95% confidence interval (CI) between 0.1 and 0.3 also supported statistically significant improvement in the participants' classification skills.

Table 4

The mean scores of each section of the test on science process skills

Test Section	No. of Items	Mean Score		Mean Difference
		Pre-test	Post-test	(95% CI)
Observing	3	2.2	2.5	0.3
Classifying	3	2.5	2.7	0.2
Predicting	4	2.6	3.2	0.6
Inferring	3	2.1	2.4	0.3
Communicating	2	1.4	1.5	0.1

The prediction section showed significant progress between participants, with mean scores climbing from 2.6 in the pre-test to 3.2 at the end of the test. This resulted in a significant mean difference of 0.6, with a 95% CI between 0.5 and 0.7. In the inferring section, participants exhibited positive advancements, as indicated by the mean score ascending from 2.1 in the pre-test to 2.4 in the post-test. The concept that intervention has positively impacted participants' ability to make judgments and derive conclusions from the information presented was supported by mean differences of 0.3, coupled with 95% confidence intervals between 0.2 and 0.4. A modest but statistically significant improvement was seen in the communication section. The participants' mean score increased from 1.4 to 1.5 in the pre-test to 1.5 in the post-test, resulting in a mean difference of 0.1.

The results indicate a collective effect of the interdisciplinary, project-based learning interventions that promote positive change across different science process skills such as observation, classification, prediction, inference, and communication.

Table 5

Test of normality (Shapiro-Wilk)

Variable	W	p-value
Science Process Skills (Pre-test and Post-test)	0.934	0.193

The Shapiro-Wilk test resulted in 0.934 with a p-value of 0.193. This p-value is higher than the 0.05 significance level, indicating that the pre-test and post-test data are normally distributed. This suggests that the paired t-test is possible.

As revealed in Table 6, The mean Difference between the pre-test and post-test scores is 5.20, and the degrees of freedom (df) for the test are 30. The p-value associated with the test is below 0.001 and has a level of significance lower than 0.05, which indicates a highly significant result. The substantial p-value indicates convincing evidence to reject the no hypothesis and demonstrate a significant difference in science process skills scores between the pre-test and post-test. A positive average difference of 5.20 indicates improved science process skills from the pre-test to the post-test.

Table 6

Results of the paired t-test conducted to the pre-test and post-test on science process skills

Variable	t	df	p-value	Cohen's d	SE Cohen's d
Science Process Skills (Pre-test and Post-test)	5.20	30	<0.001	0.934	0.249

The effect size (Cohen's d) of 0.934 further emphasizes the practical significance of the observed Difference. The Cohenian d value of 0.934 indicates that this is a significant change. The more Cohens d, the greater the practical significance of the observed effect. In addition, a standard error of 0.249 for Cohen's d is presented to estimate the accuracy of the effect size.

4.2. Qualitative Results

Three main themes emerge from the reflections and focus group discussion with the in-service science teachers. These are integrating science process skills into project-based learning, collaboration, and teamwork, which are valued and enhance teachers' capability and skill to teach science as a subject. These themes support a vivid reflection on why there is an enhancement of science process skills among teachers during the CPD.

The first theme explores how science process skills are integrated and used in interdisciplinary project-based learning. This theme focuses on comprehending how science process skills encompass observing, classifying, predicting, inferring, and communicating are interwoven into science curricular experiences through project-based learning (PBL). During the training, teachers realize that a simple project can teach important lessons to the students, such as conceptual understanding, science process skills, creativity, teamwork, and communication. They argued that test questions from PISA contain science process skills that are vital for students to learn, and the training gave them a clear view that a simple project can improve science process skills among students. Ten teachers claimed this theme, and the following are some noteworthy statements supporting this theme.

"I have realized how seamlessly the science process skills can be integrated into Project Based Learning." It is not just about teaching content; it is about fostering curiosity-driven journeys where students naturally apply critical thinking, problem-solving, and collaboration." – Teacher 1

"It was eye-opening to integrate the science process skills into project learning. I am no longer a passive transmitter of knowledge. Now, I can become an active participant in the class and lead the students through a dynamic process where they formulate hypotheses, analyze data, and communicate their findings."- Teacher 5

The second theme talks about the valued collaboration and teamwork during project-based learning. The complexities of collaboration processes and their impacts on student engagement, motivation, and the achievement of learning objectives are illustrated in this theme. The in-service teachers felt that the students would be more engaged in learning than being passive receptors of learning. They narrated that collaboration and teamwork would promote a positive attitude among students and enhance the camaraderie among the youths. The following are outstanding statements selected from nine teachers who narrated the say.

"By solving common problems, students in our school can build comradeship. They must communicate, share ideas, and work together as part of interdisciplinary projects." – teacher 5.

"We are talking about how these projects encourage students to value different perspectives in our CPD. That is not about tolerating differences. It is about recognizing the unique strengths that every student brings to the table." – Teacher 3

The third theme is about enhancing teachers' competencies to teach science as a subject. This theme emerged from a view of the teachers to transform the way they teach science from traditional teaching methods towards student-centered and inquiry-driven practice. Teachers showed greater adaptability in integrating interdisciplinary approaches and using readily available materials to foster a dynamic and engaged environment for science education that would respond effectively to diverse learning needs. Teachers narrated that through this CPD, they become aware of how to use the invention on other curricular topics. They recounted to do more active learning approaches in science. Eleven out of 31 participants asserted a similar experience with the following remarkable statements. *"CPD has given me a fresh view of how I can use innovative teaching techniques outside the field of science to discover new ways for innovation across different curricula." – Teacher 11*

"I have become an advocate of active learning in educating kids in science as I recon my experience in the training. The CPD program lit a fire and made me more committed to hands-on, inquiry-driven approaches, recasting my narrative of science education into one centered on dynamic and participatory learning experiences." – Teacher 10

4.3. Discussion

The quantitative phase of this study aims to determine the effectiveness of interdisciplinary project-based learning (PBL) among in-service science teachers in terms of science process skills, with evidence supporting a positive gain. The A* star teachers increased from 3% to 28%, and A-level teachers improved from 20% to 29%. These findings align with Hernamawati et al. [24], who found that integrating project activities into the learning process enhances science process skills and self-efficacy in biology teachers. Similarly, Purnama et al. [8] reviewed studies on integrating science process skills into PBL for students. They concluded that inquiry-based projects develop these skills, preparing students for the real world.

Furthermore, this study revealed a large effect size (Cohen's $d = 0.934$), consistent with Balemen and Keskin [25], who noted that project-based learning shows larger effect sizes across subjects and education levels, with higher levels yielding larger effects. Additionally, a significant difference between pre-test and post-test scores in science process skills was found, like Hernamawati et al. [24] and Bhakti et al. [26]. However, the latter did not compute the p-value to determine statistical significance. Both studies focused on PBL, further supporting the findings of this research.

The qualitative findings support the positive results from the quantitative phase, showing a significant increase in science process skills among in-service teachers. Collaboration, teamwork, hands-on learning, and integrating science process skills in interdisciplinary project-based learning were key factors in this success. Observational skills were enhanced as teachers observed their teammates and other participants during activities, deepening their understanding of the scientific method and improving qualitative and quantitative observations. Using Menti.com encouraged participants to actively engage by sharing their observations, reactions, and questions. This contributed to improved collaboration within teams. Creating diagrams and flow charts using Canva enabled participants to visually represent how different variables affect outcomes, such as classifying objects by properties like conductivity and material, further enhancing their classifying skills. In predicting, teachers practiced making informed predictions about experimental outcomes, using prior knowledge and video simulations (e.g., YouTube) to predict changes, such as the effect of diaphragm movement on lung expansion. Communication skills improved as teachers learned to explain complex scientific concepts clearly through reports, presentations, and collaborative discussions. Canva helps them create visually appealing charts to communicate their findings. These results are consistent with studies that highlight the benefits of collaboration and teamwork in PBL ([27];

[28]), which emphasize how PBL enhances educational experiences by fostering hands-on investigations, peer collaboration, and adaptable learning environments tailored to individual needs.

Science education in the Kashkadarya Region is transitioning from a traditional approach to 21st-century education and a more active learning approach. That is why the in-service science teachers were excited to learn more hands-on activities to enhance their science teaching. This means that the training increased the capabilities of the teachers to teach the subject and their standing in future PISA examinations. This is also why the teachers realize that science process skills can be integrated with interdisciplinary project-based learning. Several teachers described how, despite limited resources, they had been motivated by project-based learning to teach innovatively [5]. There is also a shred of compelling evidence that teaching physics using a project-based approach can develop scientific process skills and impact attitudes toward science. The excitement, the fun, and the experience of learning with a co-learner are proving to be a guide to a more effective way of educating the students. This CPD was overwhelming to let that same touch and experience to the in-service teachers, and they were invigorated to try that out in their classroom with the students.

Moreover, the study recognizes some limitations. Firstly, the personal and professional needs of the teachers were not considered. Although the CPD program proved to be effective in enhancing the science process skills of the teachers, there may be other needs of the science teachers of the area. Future CPD programs can recognize the needs of the teachers first. For the second limitation, the post-CPD program interventions were not in place, such as forming a chat group to discuss activities that can be aligned with interdisciplinary PBL or forming a mentorship group (e.g., mentorship by a seasoned teacher to a novice teacher).

4. CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

In summary, the quantitative findings indicate a substantial improvement in the science process skills of in-service teachers following the implementation of interdisciplinary project-based learning. The number of teachers in various grade categories is showing a positive change, with substantial increases seen in the higher range grades A* and A*, which shows the effectiveness of the intervention. The positive change of an interdisciplinary learning approach on enhancing scientific process skills is also supported by the mean scores for all test sections involving observation, classification, prediction, intervention, and communication. In each area, statistically significant increases have been observed that highlight the effectiveness of interventions in various skill areas. This study concluded that research questions one and two have been answered appropriately.

Qualitative insights from teachers provide a more detailed understanding of the transformative effect of continuing professional development programs, complementing these quantitative results. The teachers' reflections lead to three guiding themes: the smooth integration of scientific practice skills into project learning, the value placed on collaboration and team building, and the enhancement of teachers' capacity to teach science as a subject. These topics highlight the holistic impact of project interdisciplinary learning, extending beyond skills development and incorporating changes in pedagogical practices and collaboration dynamics at the school level. The combination of quantitative and qualitative findings contributes to a comprehensive understanding of the multifaceted positive outcomes of the intervention on in-service science teachers.

The research aims to determine the effect of technology-enhanced interdisciplinary project-based learning to the in-service teachers' science process skills and pedagogical practices. From the above, this aim is realized, and the CPD program has contributed to enhancing their science process skills. The lessons they learned are hoped to be translated into productive teaching and learning activities in the classroom. The in-service teachers can hold a seminar session in their respective schools to transfer the learning to those teachers who did not attend. This way, the knowledge and skills they received from the seminar will be multiplied across Kashkasdarya and Uzbekistan.

Based on this study's comprehensive findings, the following recommendations can be made to enhance further the effectiveness of interdisciplinary project-based learning initiatives for in-service science teachers. First, the needs of the teachers can be analyzed for a more targeted CPD program. Since the link between the specific technologies (e.g., menti.com and Canva) was not fully discussed, including their affordances, further studies can focus on these technologies, like doing qualitative research on the affordances of the Canva during a CPD program. Also, a post-CPD program can be made to support novice teachers who need more assistance. The findings of this program are now vital for learning institutions and policymakers to prioritize integrating the science process competencies in curricula that emphasize hands-on, inquiry-based approaches fostering critical thinking and problem-solving. To ensure continued growth and adaptability of teaching practices, educators should also have access to continuing professional development opportunities related to the program evaluated in this study. Collaboration and teamwork should be actively promoted within schools to cultivate a positive learning environment, and teachers should be encouraged to share best practices and experiences related to interdisciplinary project-based learning.

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DISCLOSURE

Some sections of the paper have been AI-enhanced using Grammarly to improve clarity, coherence, and clarity of language.

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РОЗВИТОК ДОСЛІДНИЦЬКИХ УМІНЬ УЧИТЕЛІВ ПРИРОДНИЧИХ ДИСЦИПЛІН ЗА ДОПОМОГОЮ МІЖДИСЦИПЛІНАРНОГО ПРОЄКТНОГО НАВЧАННЯ

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Анотація. Визнаючи необхідність надійних програм безперервного професійного розвитку (БПР), Програма міжнародного оцінювання учнів (PISA), за результатами оцінювання 2022 року, рекомендувала ініціативи, спрямовані на покращення якості природничо-наукової освіти. Це дослідження оцінює ефективність програми підвищення кваліфікації, спрямовану на технологічно орієнтоване міждисциплінарне проєктне навчання (ПН) для підвищення кваліфікації вчителів природничих дисциплін без відриву від виробництва у Кашкадар'їнській області Узбекистану. У дослідженні використовувався послідовний пояснювальний дизайн змішаних методів. Дослідження розгорталось у два етапи з використанням цього дизайну. Кількісна фаза передбачала пре- і пост-тести, тоді як якісний дизайн мав феноменологію. Результати кількісного етапу засвідчили значне покращення дослідницьких навичок учителів, про що свідчать результати парних t-тестів, та значний розмір ефекту, що підтверджується покращенням цих навичок. Якісні висновки виявили три основні теми: безперешкодна інтеграція наукових практик у навчально-професійну освіту, сприяння співпраці та командній роботі, а також підвищення здатності вчителів до ефективного викладання природничо-наукових дисциплін. Використання таких інструментів, як Canva, menti.com і YouTube, у програмі підвищення кваліфікації виявилося корисним для сприяння експериментальному навчанню, творчому залученню та спільному розв'язанню проблем. У дослідженні підкреслено життєву важливість безперервного професійного розвитку і наголошено на пріоритетності таких програм. Програма безперервного професійного розвитку може бути впроваджена в інших регіонах Узбекистану і в усьому світідля поліпшення технологічних навичок учителів природничих дисциплін. Навчальні заклади іншого спрямування можуть інтегрувати систему безперервного професійного розвитку у свої майбутні програми підвищення кваліфікації.

Ключові слова: Canva; menti.com; проєктне навчання; безперервний професійний розвиток; навички викладання природничих дисциплін; змішаний дизайн.