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Effectiveness Of Tpack-Based Science Teaching On The Conceptual Knowledge Of Secondary School Students

[1] **Barkatali Halakeri**, [2] **Prof. Manjula P. Rao**
[1] Research Scholar, [2] Research Guide
[1] Department of Education
[1] Regional Institute of Education, Mysore-570006, Karnataka, India.

Abstract: The integration of technology in science education has the potential to transform classroom teaching and enhance student learning. This study explores the effectiveness of the Technological Pedagogical Content Knowledge (TPACK) framework in improving the conceptual knowledge of secondary school students. Using a quasi-experimental design with non-equivalent control and experimental groups, the study involved Class IX students who were taught scientific concepts through TPACK-based instruction, while the control group received traditional teaching. Pre-tests and post-tests were administered to assess conceptual knowledge. Statistical techniques such as paired and independent t-tests were used to analyze the data. The findings reveal that students taught through TPACK-based strategies showed significantly higher improvement in conceptual knowledge compared to those taught through traditional methods. The results highlight the importance of integrating technology, pedagogy and content knowledge in science teaching to foster deeper learning and better academic outcomes in the Indian secondary education.

Index Terms **-** Effectiveness, TPACK, Science teaching, Conceptual Knowledge, Secondary School, Students.

1. INTRODUCTION

In recent years, the integration of technology into the education system has brought about significant changes in teaching and learning methods. Traditional approaches that relied heavily on textbook teaching and lecture methods are being replaced by more dynamic and interactive models. One such talented approach is the Technological Pedagogical Content Knowledge (TPACK) framework, which combines technology, pedagogy and subject content to make teaching more effective and student-centered (Mishra & Koehler, 2006).

In the context of science education, TPACK offers a structured way to use digital tools to improve student engagement, understanding and application of scientific concepts. When teachers use technology effectively along with appropriate teaching strategies and content knowledge, students are more likely to participate actively in the classroom and retain the knowledge better (Ramanathan, 2017). This is especially important in secondary school science, where understanding concepts deeply is essential for higher-level thinking and practical application.

In India, where classroom teaching often remains teacher-centered and limited by traditional methods, adopting TPACK can play a crucial role in enhancing students' learning outcomes (Yadav & Mehta, 2018). The use of animations, simulations, digital laboratories and visual content can help bridge the gap between theory and practice, making science education more relatable and engaging. This study aims to examine the effectiveness of TPACK-based science teaching on developing conceptual knowledge among secondary school students. It compares the performance of students taught using the TPACK model with those taught through traditional methods.

Significance of the Study

This study is significant as it highlights the importance of using the TPACK (Technological Pedagogical Content Knowledge) framework to improve science teaching at the secondary school level. In today's digital era, students are more connected to technology and integrating it meaningfully into classroom instruction can make learning more engaging and effective. By showing that TPACK-based teaching improves students' conceptual understanding better than traditional methods, the study provides valuable insights for teachers, curriculum makers and policymakers. It emphasizes the need for teacher training programs to include TPACK, so educators can confidently use technology alongside strong teaching methods and conceptual knowledge. Ultimately, this research supports the development of innovative teaching strategies that can improve student outcomes and better to prepare them for future academic success and career challenges.

Statement of the Problem

"Effectiveness of TPACK-Based Science Teaching on the Conceptual Knowledge of Secondary School students."

Objective

To study the effectiveness of Technological Pedagogical Conceptual knowledge (TPACK) on Conceptual Knowledge of class IX students

Hypothesis

The conceptual knowledge of experimental group taught by TPACK is significantly higher than the conceptual knowledge of the students belonging to control group.

2. REVIEW OF RELATED LITERATURE

The review of related literature serves as a foundation for understanding how Technological Pedagogical Content Knowledge (TPACK) has been integrated into science education and its effects on students' conceptual knowledge and teacher competence. As 21st-century classrooms increasingly adopt digital tools, numerous studies have explored the effectiveness of technology-integrated pedagogies. These studies emphasize the role of teacher preparedness, innovative instructional models and student-centered approaches in enhancing learning outcomes. In this context, reviewing literature related to TPACK and its components provides insight into the challenges, strategies and potential of using integrated teaching frameworks in Indian and international educational settings.

Fiteriani et al. (2023) highlighted the effectiveness of the Predict-Observe-Explain (POE) model in improving science conceptual understanding and process skills at the elementary level. Their findings confirmed that technology-based instructional methods foster deeper student engagement and learning. Similarly, Putri, Hidayat and Purwianingsih (2019) examined the TPACK levels among biology teachers and found that most teachers were at a pre-TPACK stage, emphasizing the need for targeted professional development to effectively integrate pedagogy, content and technology.

Kumar (2022) explored the influence of experiential pedagogy among tribal students in Kerala and found it effective in improving science learning outcomes. Although learning styles did not show significant differences, the study highlighted the value of context-based teaching approaches. Manoj and Devanathan (2011) validated the benefits of problem-based learning in developing science process skills and fostering a positive scientific attitude, indicating the strength of inquiry-driven instruction.

Sharma (2017) showed that ICT-integrated instruction improved pre-service teachers' TPACK, teaching self-efficacy and teaching effectiveness, indicating the need for integrating technology training in teacher education programs. Sen (2016) provided evidence of effective content delivery in algebra textbooks while recommending enhancements to promote analytical thinking. Bindu (2014) focused on PCK development in Malayalam language teaching and found gaps in teachers' ability to apply innovative strategies, though the enhancement package proved useful. Umesh (2012) concluded that training programs focusing on PCK can positively impact teaching quality, particularly when aligned with students' learning outcomes.

While the reviewed studies emphasize the positive impact of technology integration and pedagogical knowledge on student achievement and teacher development, a noticeable research gap exists in the application of the TPACK framework specifically to conceptual knowledge development in secondary school science classrooms**.** Many of the studies either focus on teacher training, language instruction or elementary-level science education, with limited focus on how TPACK-based strategies directly affect secondary students' conceptual knowledge in science subjects. Furthermore, few studies have compared experimental and control groups using rigorous pre-test/post-test designs in the Indian context. This study seeks to address these gaps by examining the effectiveness of TPACK-based teaching on conceptual knowledge development among secondary school students, thus contributing new information to the field of science education.

3. METHODOLOGY

The present study adopted a quasi-experimental research design to examine the effectiveness of TPACK-based science teaching on the conceptual knowledge of secondary school students. Specifically, the research followed a non-equivalent pre-test–post-test control group design. Two naturally formed (intact) classes from different schools in Dharwad district, Karnataka, were purposively selected. One class was designated as the experimental group and the other as the control group. The experimental group received science instruction using TPACK-based strategies that integrated content knowledge, pedagogy and technology, while the control group was taught using traditional methods.

The sample comprised 66 students in total, including 32 students (17 boys and 15 girls) in the experimental group from JSS Public School and 34 students (18 boys and 16 girls) in the control group from Mallasajjan English Medium School. The students were studying in Class IX and the medium of instruction was English in both schools. All schools followed the NCERT-prescribed science syllabus and the teachers involved in teaching held professional degrees in education. The study was implemented over a period of three months and consisted of five major phases: selection of units, development of TPACK-based task maps and tools, administration of pre-tests, experimental treatment and administration of post-tests.

In the first phase, eight units from the Class IX Science textbook (four in physics and four in chemistry) were selected for instruction. These units included topics such as *Matter in Our Surroundings*, Is matter around us pure, atoms and molecules, structure of the atom, motion, force & laws of Motion, work & energy and sound. In the second phase, the researcher developed tool to assess conceptual knowledge. Each unit was supported by TPACK-based task maps, detailing instructional objectives, activities, technological tools and cognitive processes based on the Revised Bloom's Taxonomy. A total of 35 such task maps were created and implemented.

The third phase involved the administration of pre-tests to both groups to assess baseline performance. The fourth phase encompassed the experimental treatment, during which the experimental group received instruction integrating digital resources such as simulations, videos and interactive presentations, combined with inquiry-based teaching strategies. In contrast, the control group continued with traditional lecture-based instruction. Classroom observations were conducted throughout this phase to document student engagement and interaction.

In the fifth phase, post-tests were administered to both groups using the same assessment tools used in the pre-test. The collected data were analyzed using statistical methods such as paired t-test and independent t-test. Reliability of the tools was established using Cronbach's Alpha and content validity was verified through expert evaluation. The findings provided a comprehensive understanding of the impact of TPACK-based teaching on students' conceptual knowledge, contributing valuable knowledge into the integration of technology in science education.

4. ANALYSIS OF DATA

This section presents the analysis of data collected to assess the effectiveness of Technological Pedagogical Content Knowledge (TPACK)-based science teaching in improving Conceptual Knowledge of Class IX students. The data were analyzed using Paired t-tests and Independent t-test to compare the performance between the Experimental Group (TPACK-based instruction) and the Control Group (Traditional Teaching). The analysis was carried out using SPSS software and MS Excel under expert supervision. Results were interpreted at 0.05 and 0.01 significance levels.

Objective-1

To study the effectiveness of Technological Pedagogical Conceptual knowledge (TPACK) on Conceptual Knowledge of class IX students

Hypothesis-1

The conceptual knowledge of experimental group taught by TPACK is significantly higher than the conceptual knowledge of the students belonging to control group.

Table-1: Paired t-test for Conceptual Knowledge in the Control Group (Traditional Teaching)

Test	No.	Mean	Std. Dev.	df	t-value and (p-value	Sig. Level
Pre	34	21.794	6.069	33	2.00 (0.054)	Not Significant
Post	34	22.647	5.866			

Note: The critical value of 't' at df=33 is 2.04 at the 0.05 sig. level.

The mean score increased slightly from 21.794 to 22.647 after traditional instruction. However, the difference is not statistically significant ($p = 0.054 > 0.05$), indicating minimal improvement in conceptual knowledge using traditional methods.

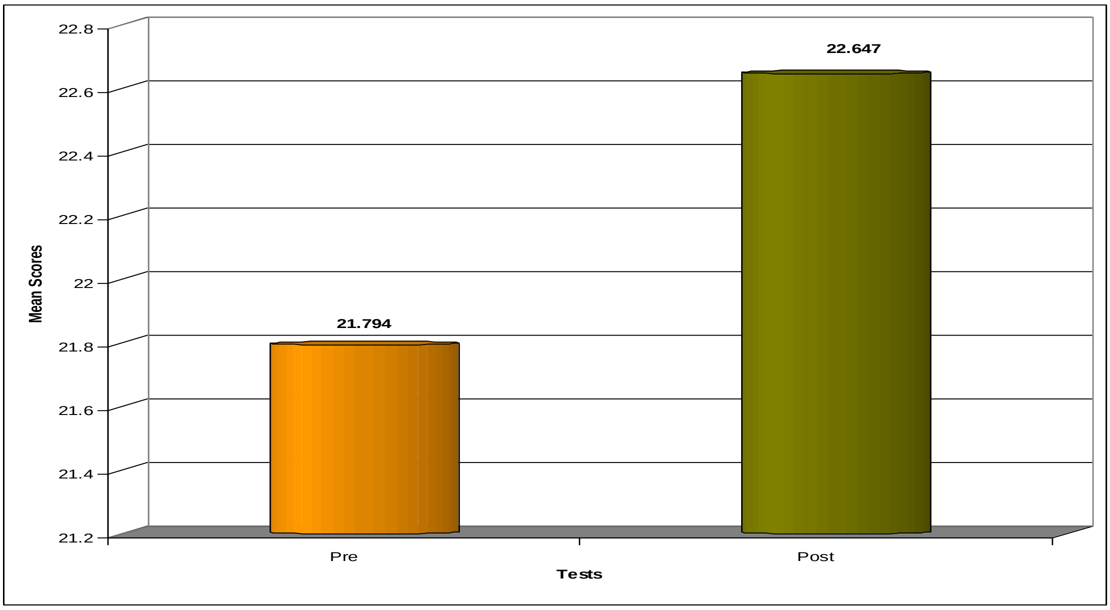

Fig.1: Pre-test and Post-test Comparison in Control Group

This bar graph compares mean scores before and after traditional teaching. A marginal increase is visible but not significant.

Table-2: Paired t-test for Conceptual Knowledge in the Experimental Group (TPACK-Based Teaching)

Test	No.	Mean	Std. Dev.	df	t-value and (p-value	Sig. Level
Pre	32	19.843	6.768	31	16.43 (0.000)	**
Post	32	27.875	6.809			

Note: The critical value of 't' at df=31 is 2.75 at the 0.01 sig. level.

The mean score improved from 19.843 to 27.875, showing a statistically significant improvement in conceptual knowledge ($p = 0.000 < 0.01$). This indicates the strong positive effect of TPACK-based teaching.

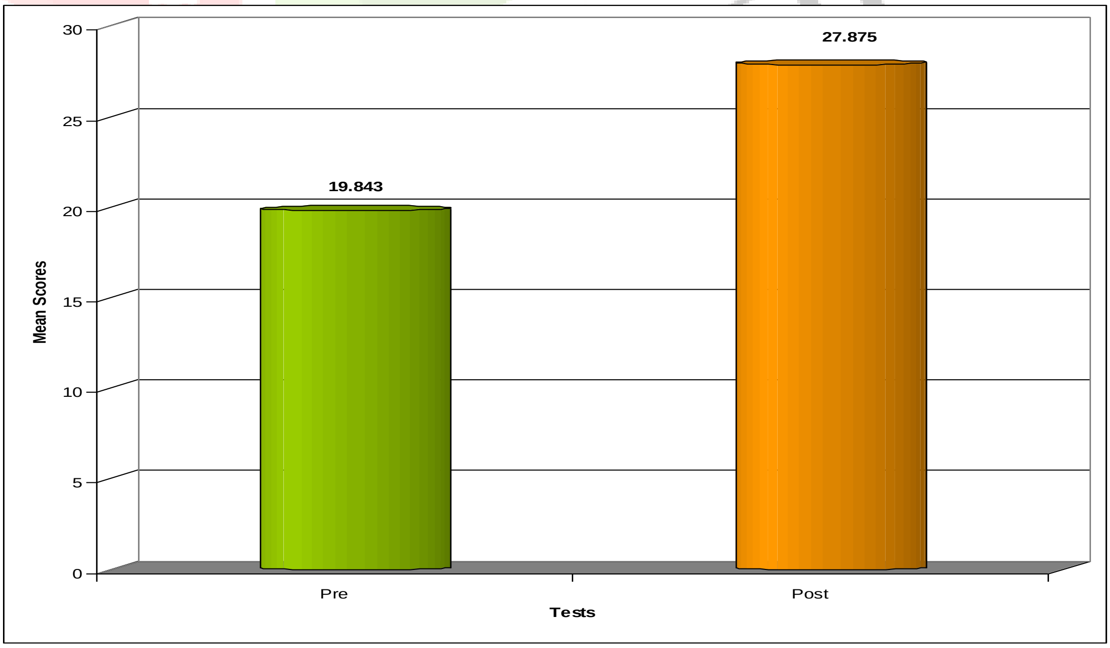

Fig-2: Pre-test and Post-test Comparison in Experimental Group

The graph illustrates a substantial increase in post-test scores, highlighting the effectiveness of TPACK-based instruction.

Table-3: Independent t-test Comparing the Control and Experimental Groups (Pre-test and Post-test)

Test	Group	No.	Mean	Std. Dev.	df	t-value and (p-value	Sig. Level
Pre	Experimental	32	19.843	6.768	64	1.23 (0.223)	NS
	Control	34	21.794	6.069			
Post	Experimental	32	27.875	6.809	64	3.33 (0.001)	**
	Control	34	22.647	5.866			

Note: The critical value of 't' at df=64 is 2.00 at the 0.05 level and 2.66 at the 0.01 sig. level.

The pre-test scores were statistically similar (p = 0.223), indicating equivalent initial stages. Post-test results, however, show a significant difference (p=0.001), with the Experimental Group outperforming the Control Group. This confirms that TPACK-based teaching is more effective than traditional methods.

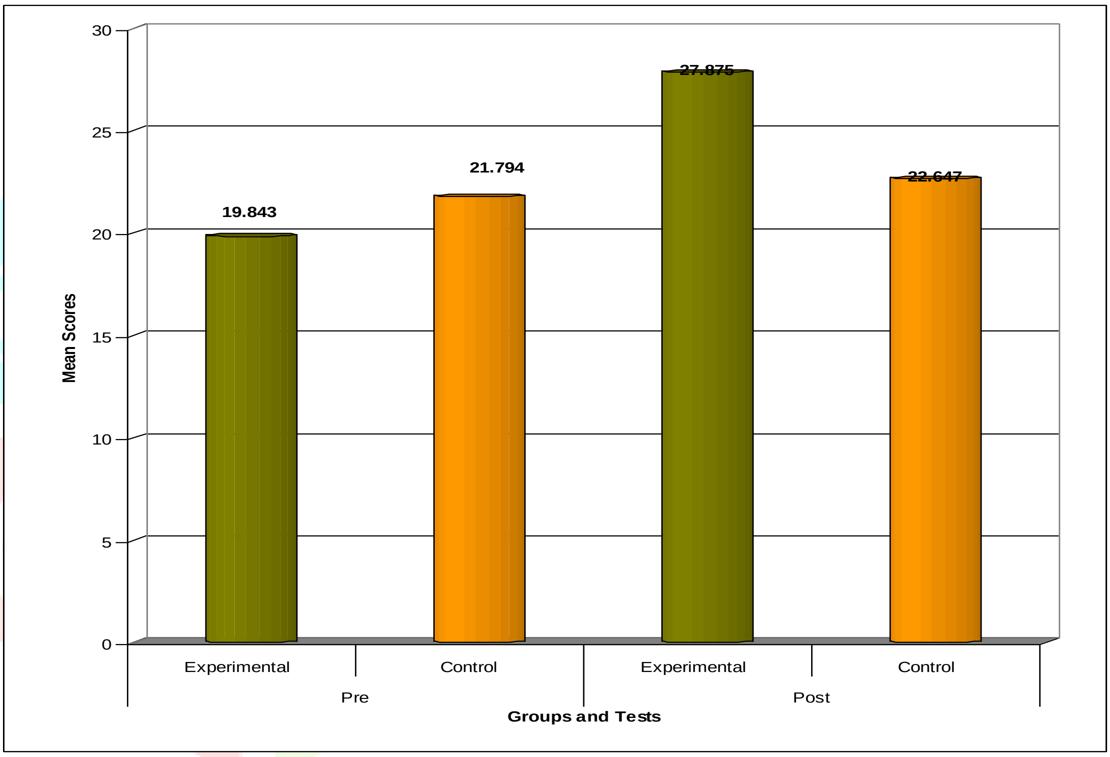

Fig-3: Comparison of Pre-test and Post-test Scores Between Experimental and Control Groups

The graph clearly demonstrates the significantly higher gains in the Experimental Group post-intervention, validating the effectiveness of TPACK-based teaching.

5. RESULTS AND DISCUSSION

The results of the study clearly show that students who were taught using the TPACK-based method (where technology, teaching methods and subject content are combined) performed much better in understanding science concepts compared to those taught through traditional methods. The TPACK method helped students stay more engaged, understand the topic deeply and remember the content better. This supports the study by Fiteriani et al. (2023), who found that students who learned using the POE model (a technology-supported method) showed better understanding and science skills than those taught in a regular way. Like their study, this research proves that using new teaching methods with technology helps improve science learning. Similarly, Sharma (2017) found that teachers who used ICT tools in teaching improved their own teaching skills and helped students learn better. In our study too, students did well when teachers used TPACK-based teaching, showing that trained teachers who know how to use technology in lessons make a big difference. Manoj and Devanathan (2011) also found that using problem-solving methods helped students improve their science skills. This matches the current study, where students in the TPACK group were more active, curious and showed better understanding. Also, Kumar (2022) found that hands-on learning improved science knowledge among tribal students. The TPACK method in our study offered similar hands-on, meaningful learning experiences that helped students learn better than in a traditional system. On the other hand, Putri et al. (2019) showed that many teachers had difficulty combining technology with teaching methods. This shows that training teachers to use TPACK effectively is important so that students can benefit. This study clearly show that when technology is used properly along with good teaching methods and conceptual knowledge, students perform better especially in science.

6. CONCLUSION AND IMPLICATIONS

The study found that TPACK-based instruction improves conceptual understanding. The experimental group regularly outperformed the control group, demonstrating the effectiveness of the training strategy. These findings emphasize the importance of integrating technology, pedagogy and content understanding to create an engaging and inclusive learning environment in science education. The findings of this study have important implications for science teaching at the secondary level. The significant improvement in conceptual knowledge among students taught through the TPACK-based approach suggests that integrating technology with appropriate pedagogical strategies and conceptual knowledge can make science learning more effective and engaging. Teachers should be encouraged and trained to adopt TPACK-based methods to enhance students' understanding and interest in science. Educational policymakers and curriculum developers can also consider incorporating TPACK principles into teacher education programs and classroom practices to improve overall teaching quality and learning outcomes. This approach supports the development of 21st-century skills among students and prepares them better for future academic success and career challenges.

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