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Effect of the Practical activities on Students' Higher-Order Thinking: An effective Use of Science Laboratories at Secondary Level

Maria Farooq
M.Phil. Scholar, Department of Education, University of Gujrat, Punjab, Pakistan,
Email: hooriahooria973@gmail.com
Sher Zaman
Assistant Professor, Department of Education, University of Gujrat, Punjab, Pakistan, Corresponding Author's Email: smzaman@uog.edu.pk

Abstract

The present study is to investigate the effect of practical activities, performed in science laboratory for teaching the subject of physics, on the development of higher-order thinking skills (HOT) among secondary school students. The instruction of the contents of the target subject, according to hands-on approach; and in line with a minds-on approach (Oliveira, H. and Bonito, J., 2023), needs to be integrated with practical work, for effective and effective transfer on learners. Simultaneously, higher-order thinking being dependent variable, on the theoretical basis, is assumed to be developed through laboratory based instructional activities. For the purpose of empirical evidence, keeping in view the systematic review of the literature, as well as the theoretical assumptions should be integrated for the effective teaching of the physics as a branch of science at secondary level. Hence the present experimental study even having certain limitations, i.e., access, permission and feasibility, a sample of 9th-grade science, 10 students from a Government Girls High School, AJK was selected as convenient sample. The study followed ABAB single-subject research design having suitability to small sample size with no comparison group. The experiment was repeated twice on same subjects, where they were taught different contents twice at the A, and B repeated phases. Accordingly, two related tests on HOT skills, comprising 30 items were applied four times at the initial and end of the both phases, to collect data on measuring variables. Results revealed significant improvement in students' HOT skills, while taught through lab-based activities, as compared to a commonplace content-based teaching in prevailing classrooms. The results showed the pragmatic pedagogical value of the learners' laboratorial experiences, for the enhanced students' cognitive engagement, resulted in their scientific thinking at higher level.

Keywords: *Higher-Order Thinking (HOT); Scientific thinking skills; Lab-Based Activities Instruction, and Content-Based Instruction*

Introduction

Teaching profession is the profession where the department of education has an important role. The department of education recruits' teachers and gives training to preservice teachers. This department has an important role in shaping the society (Kamran et al., 2015). In the contemporary era of science and technology, scientific literacy is essential for navigating a world increasingly shaped by rapid technological advancement. Science, by nature, investigates real-world phenomena through systematic observation and experimentation, offering solutions to many modern-day problems (Goodrum, Druhan, & Abbs, 2012). Among the sciences, physics stands out as a foundational discipline that fosters analytical reasoning and problem-solving abilities. To fully grasp the complex concepts related to physical sciences, students need to be beyond passive learning and engage in active, experience-based instruction, which is possible through hands-on practical activities that serve as a critical foundation for effective education, particularly in developing scientific thinking.

Laboratory activities is widely regarded as a pedagogical tool that strengthens conceptual understanding by encouraging personal observation and experimentation. It transforms the classroom into an active learning environment where students can manipulate materials and observe physical phenomena directly. The study of matter, energy, and their interactions, physics is inherently suited to an activity-based instructional approach. Hofstein and Hugerat (2021) describe practical work as any hands-on engagement with materials or data that helps learners observe and interpret the world around them. Such engagement supports not only conceptual understanding but also the development of scientific skills and higher-order thinking (HOT) abilities.

Higher-order thinking extends beyond the memorization of facts and involves critical skills such as analysis, evaluation, and synthesis. When students participate in Laboratory activities, they are mentally, visually, and physically involved in the learning process, which enhances cognitive performance and promotes independent reasoning (Fadzil & Saat, 2013; Schwichow et al., 2016). However, the effectiveness of Laboratory activities is often limited by a lack of laboratory resources, untrained teachers, and an overemphasis on traditional teaching approaches. Without structured practical experiences, students may struggle to develop a deep understanding of scientific concepts (Gudyanga & Jita, 2019; Millar, 2004).

Despite its importance, practical work is often neglected in science classrooms, particularly in Pakistan, where education systems are heavily focused on content delivery and examination performance. Most schools prioritize content-based instruction, which relies heavily on textbook learning and rote memorization, often at the expense of students' ability to apply knowledge creatively or critically. Content-based instruction (CBI), although is useful for reading and comprehending scientific texts, often lacks the experiential component needed to foster HOT skills (Gross & Harmon, 2013). While CBI provides foundational knowledge, it does not necessarily cultivate students' ability to apply that knowledge in novel contexts (Lyster, 2011; Creese, 2005).

To assess the true impact of Laboratory activities on students' cognitive development, it is essential to compare it against traditional content-based instruction. In this study, teaching method is the independent variable, with two levels: practical work and content-based instruction. The dependent variable is higher-order thinking. Without such a comparative approach, the specific contribution of practical work to students' cognitive development remains unclear.

In Pakistan's educational context, there is an urgent need to shift from memorization-based methods to practices that nurture creativity, critical thinking, and application-based learning. This study focuses exclusively on the subject of physics at the secondary level, aiming to measure whether the integration of practical work enhances students' higher-order thinking more effectively than traditional content-based instruction alone. Below is Figure,1 to illustrate the conceptual frame work of the study.

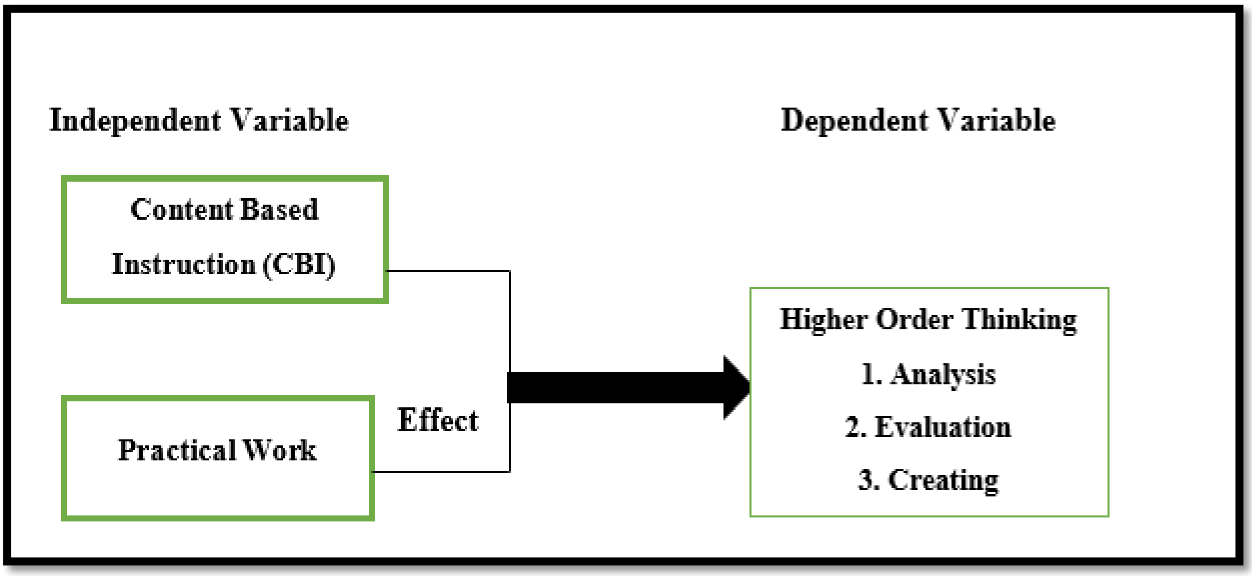


Figure 1 illustrates the conceptual framework of the study, highlighting the relationship between the independent and dependent variables. The independent variable in this research is the teaching method, which includes two approaches: Laboratory activities integrated and traditional content-based instruction. These instructional strategies are the elements manipulated by the researcher to examine their impact. The dependent variable is students' higher-order thinking, which is the outcome being measured. Higher-order thinking encompasses cognitive skills such as analysis, evaluation, and synthesis skills that go beyond basic recall or memorization. The arrow labeled ‘Effect’ represents the presumed influence of the independent variable (teaching method) on the dependent variable (higher-order thinking). This indicates that any changes in the teaching method are expected to result in measurable changes in students' higher-order thinking abilities. This framework serves as the foundation for the research design and guides the data collection and analysis process, aiming to determine whether practical work leads to greater enhancement of higher-order thinking compared to content-based instruction.

Review of the Related Literature

The identified existing literature related to science education, practical work, and higher-order thinking, focusing particularly on the teaching of physics in secondary schools is summarily presented in the following.

Science and technology have become central to modern life, influencing every aspect of our personal and professional environments. Whether residing in urban industrial centers or rural agricultural regions, individuals are continually interacting with scientific advancements (Sutherland et al., 2017). This underscores the growing need for scientific literacy and education, especially in developing nations like Pakistan. Among scientific disciplines, physics is particularly significant due to its role in explaining natural phenomena and fostering analytical and problem-solving skills.

Physics education at the secondary level is pivotal for cultivating students’ understanding of matter and energy. It plays a central role in developing higher-order thinking (HOT) skills such as analysis, evaluation, and creation which are essential for success in STEM fields. Research has consistently supported the integration of Laboratory activities in physics education as a strategy for enhancing students' learning outcomes and cognitive development (Abrahams & Millar, 2008).

In Pakistan, traditional teaching methods dominate the classroom, with a strong emphasis on content delivery. Practical activities are often postponed until the end of the academic year, reducing their effectiveness. Studies reveal that this method fails to engage students in meaningful learning and does not support the development of HOT skills. The literature suggests that integrating practical activities into regular instruction can significantly improve student understanding and foster deep learning.

Despite challenges, science education is seen as a key driver of national progress. As Ravetz (2020) points out, while science may sometimes contribute to complex global issues, it also provides the tools to resolve them. For nations like Pakistan, scientific education is not only a path to economic advancement but also a means of fostering critical citizenship and informed decision-making (Fagerberg, 2018; Volchik & Maslyukova, 2019). A robust science education system empowers individuals at personal, civic, and professional levels.

Science Education in Pakistan

Science education in Pakistan faces numerous hurdles. Many students drop out after primary or secondary school due to weak foundational knowledge and unclear conceptual understanding. While various policy efforts have aimed to improve science instruction, implementation remains inconsistent. As early as 1959, the importance of science and mathematics in the curriculum was recognized, yet quality instruction has often been hampered by a lack of trained teachers and inadequate infrastructure (Bear & Skorton, 2018).

The government has attempted to address these issues through the National Education Policies (2009 & 2017), which stress science and technology's role in economic development. Secondary education, in particular, should serve as a bridge to both higher education and the workforce, equipping students with essential scientific knowledge and vocational skills (Brubacher, 2017; Simonson et al., 2019).

Role of Practical Work in Science Education

Modern pedagogy has shifted from teacher-centered approaches to student-centered learning. Practical work allows learners to engage directly with scientific concepts, enhancing understanding and retention. Defined as hands-on interaction with materials or data, Laboratory activities promotes the development of scientific skills and reinforces theoretical knowledge (Evagorou et al., 2015).

Internationally, the value of Laboratory activities is widely recognized. In countries like the UK, it is considered fundamental to science education (Gore et al., 2017). Studies have shown that students who engage in Laboratory activities exhibit greater motivation, improved attitudes toward science, and better academic achievement (Martin, 2020; Bilgin et al., 2015). Without practical experiences, learners may lack essential scientific skills and fail to fully grasp core concepts (Millar & Lubben, 2005).

Role of Laboratory activities in Teaching of Physics

Physics requires experiential learning. The subject's abstract nature makes it difficult for students to understand concepts through lectures alone. Laboratory activities such as experiments and field work allow students to observe physical principles firsthand, making learning more meaningful (Motlhabane, 2005).

Numerous studies have highlighted the superiority of practical methods in teaching physics. Educators emphasize the importance of 'learning by doing' and agree that hands-on experimentation is essential for developing scientific reasoning (Babalola et al., 2020; Zoker et al., 2022). These activities also prepare students for assessments and real-world applications, reinforcing their skills in observation, measurement, and data interpretation.

Higher-Order Thinking

In the 21st century, education must empower students with a range of cognitive skills to succeed in life and contribute meaningfully to society. Higher-order thinking encompasses creativity, problem-solving, analysis, and critical thinking skills considered essential for innovation and economic progress (Komarudin et al., 2020; Hughes et al., 2018).

HOT skills enable individuals to apply knowledge in new contexts, deduce complex information, and arrive at logical solutions (Albrecht, 2009). Educators categorize HOT into three main areas: transfer, critical thinking, and problem-solving (Ullman, 2000). These competencies are key to academic achievement and lifelong learning (Miri et al., 2007).

Higher-Order Thinking in Bloom’s Taxonomy

Bloom’s Taxonomy provides a widely accepted framework for understanding and developing higher-order thinking skills. The taxonomy divides learning objectives into three domains i.e. cognitive, affective, and psychomotor. Cognitive domain further categorized into six levels:

remembering, understanding, applying, analyzing, evaluating, and creating (Abosalem, 2016; Niazi, 2020).

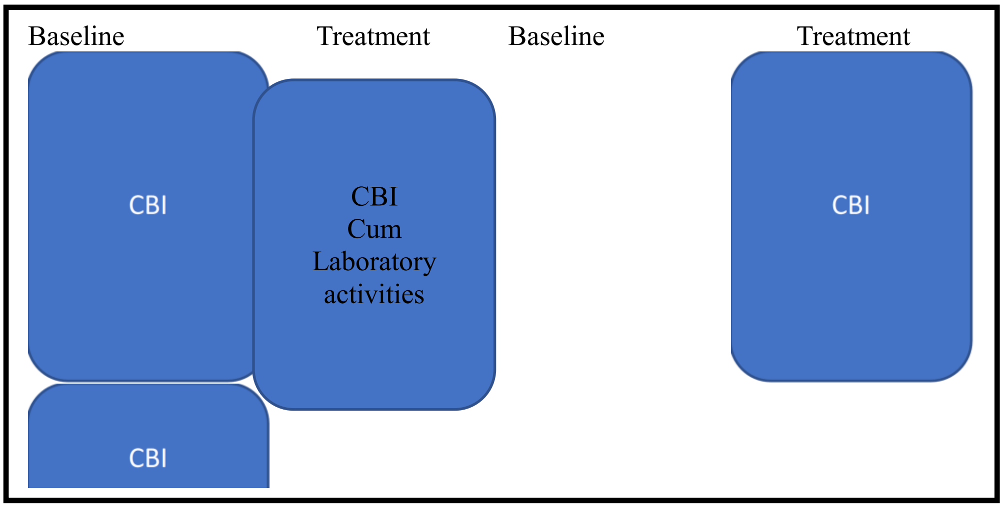
This hierarchical model helps educators structure lessons that go beyond knowledge recall and promote deep understanding and creative thinking. Each level builds on the previous one, guiding students from foundational knowledge to advanced reasoning (Bhagyalakshmi & Seshachalam, 2015). Bloom’s Taxonomy is thus an invaluable tool in curriculum development and instructional planning, especially in science education where critical and creative thinking are essential.

Education serves as the primary tool for preparing students to become active and responsible members of our modern society (Rinjaya & Halimi, 2022). Therefore, to foster higher-order thinking skills, schools at all levels should keep this as a focal point. Accordingly, a most important purpose of science education should be the expansion of such skills from the perspective of both the specific content of science and interrelated disciplines. However, classrooms often fail to accurately implement educational theories (Elmas et al., 2020). There is a gap between theory and practice. Science subjects are not taught through practical activities; just theory and content are delivered to students, and not conducting any practical activities along with the delivery of content and students remain unable to understand the basic and complex concepts of science subjects (Oliveira, & Bonito, 2023). That’s why the current study finds out that engaging students in laboratory activities may be helpful to develop higher-order thinking in students.

Materials and Methods

The purpose of the present study is to examine the effect of laboratory activities on secondary level students’ higher-order thinking in the subject of physics. The research is experimental in nature and follows a single-subject research design known as the ABAB design. The detailed steps for implementing this design and other related procedures are described below.

Figure 2: Design of Study



Previously the design of the study was presented in figure 2, whereas the following table presents specifications of the two tests conducted at the pre and post of CBI and Practical based interventions, during the four stages and two phases of the study. The test was developed to assess students’ higher order thinking, of which specifications are presented in the following table.

Table 1: Test Specifications

Sr. No	Content Topics	Learning Outcomes			Total
		Analysis	Evaluation	Creation	
1	Venire caliper	1	2	2	5
2	Screw gauge	3	0	2	5
3	Free fall method	2	2	1	5
4	Simple pendulum	5	1	3	9
5	Helical Spring	1	4	1	6
	Total	12	9	9	30

Table 1 presents the distribution of test items developed to assess students' higher-order thinking skills specifically analysis, evaluation, and creation across five content topics covered during the study. Each topic was selected from the secondary level physics curriculum and aligned with the processes and observation of the practical performed mutually by the teacher and students during the two different phases of interventions.

The content validity ratio (CVR) for higher order thinking items, which ranges from 0.6 to 0.86. which is according to Lawshe (1969) is acceptable for being greater than 0.49. Therefore, we retained 15 out of 17 items and dropped two items from instrument-II on higher-order thinking. The overall cumulative content validity index (CVI) value to represent the validity of the instrument, being 0.81, where CVI > 0.7, is sufficient to declare the tests valid.

Results

Following are the results of quantitative data analysis, to present effect of practical work of science lab, on students' higher-order thinking while teaching physics a science subject at the secondary level. A repeated measure ANNOVA for data analysis was applied on the collected data from a single group over four time periods: 1st, 3rd stages while taught through CBI, and at 2nd, and 4th stage where taught through CBI cum Practical lab work, respectively. and collected repeated measures. Firstly, the descriptive analysis for broader mental frame is presented graphical representation of mean scores at the four stages in 2 phases of the study.

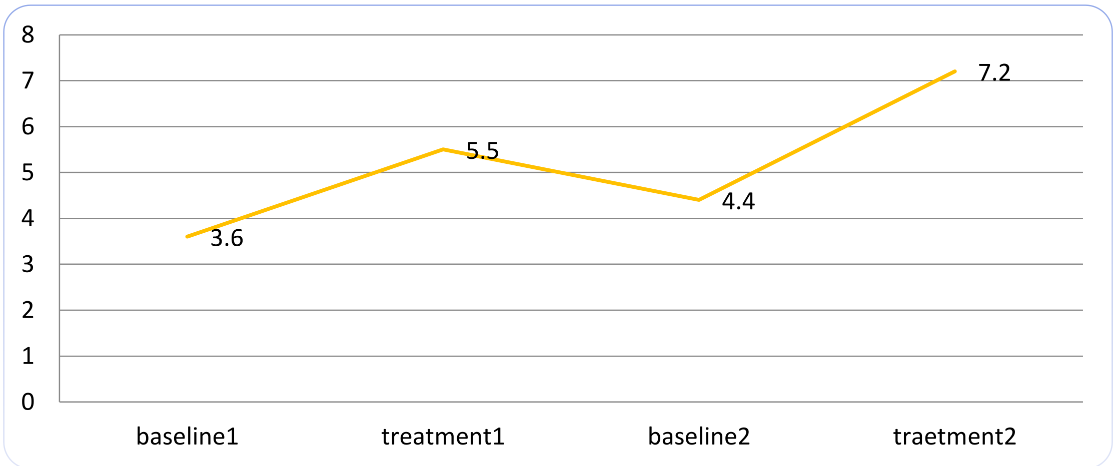


Figure-3: Visual Representations of Learners' Scores on Pre-Post 4 Tests in 2 Phases

Figure 3 shows an increasing trend through pre and post-test scores, while in phase 1, at two different stages, i.e., content-based instruction (M=3.6, 4.4) and CBI with lab-practicals (M=5.5, 7.2) as treatment in the phase 2. Hence there is visible enhancement in higher order thinking among the learners' where they are engaged in practical activities as compared to their thinking levels, where taught through CBI.

Having found the increasing trends through descriptive data representations, the more sophisticated inferential analysis is presented to pose more confidence level in the results of the study.

Table 2: Repeated Measures ANOVA on Four Measurements of Higher Order Thinking

Time Period	Mean	S.D	N	F	Sig.	η^2
Baseline1	3.6	1.17	10			
Treatment1	5.5	1.08	10	51.09	.00	.95
Baseline2	4.4	1.07	10			
Traetment2	7.2	1.47	10			

The results in table 2 show that F ratio is significant at (p<.10), hence there are increased significant variations in students' scores on HOT tests, over four time periods, i.e., whereas F = 51, and p<.10 and partial eta saqured =.95 shows a large effect size because, according to Cohen, if the value of partial eta saqured is.14 or greater, the effect size is large. Hence, there is a significant improvement in the HOT scores of students over four time periods, from baseline 1 to treatment 1, and from baseline 2 to treatment 2.

Table 3: POST HOC on Four Measurements of Higher Order Thinking

Factors	Comparative Factors	Mean Difference	Std. Error	Sig.
1	2	-1.90*	.18	.00
	3	-.80*	.20	.01
	4	-3.60*	.27	.00
2	3	1.10*	.23	.00
	4	-1.70*	.21	.00
3	4	-2.80*	.25	.00

Table 3 presents the results on students' higher order thinking test during time 2 and time 4, when they participated in practical activities, compared to time 1 and time 3, when they received instruction using the CBI method. Furthermore, the above results in table 3, based on post hoc analysis, show a significant mean difference in the HOT scores of the entire group of students from time 1 to time 2, time 3, and time 4, hence there is visible upwards change in students' scores on the higher order thinking test during time 2 and time 4, when they participated in practical activities, as compared to time 1 and time 3, when they received instruction using the CBI method.

Table 4: Repeated Measures ANOVA on Four Measurements of Higher Order Thinking at Analysis Level

Time Period	Mean	S.D	N	F	Sig.	η^2
Baseline1	1.6	.69	10			
Treatment1	2.2	.42	10	26.56	.000	.91
Baseline2	1.8	.42	10			
Traetment2	2.8	.63	10			

Table 4 depicts the change in students analytical thinking skills over four time periods, where F ratio 26.56is significant at (p<.10). Table 4.3 presents the means and standard deviations of scores in four time periods. At the analysis level, there is a significant change in HOT scores over four time periods. Wilks' Lambda=.081, F (1,9)=26.55, and p<.10 and partial eta saqured.91 show a large effect size. Therefore, we find a statistically significant change in the HOT scores of students over four time periods, from baseline 1 to treatment 1, and from baseline 2 to treatment 2.

Table 5: POST HOC on Four Measurements of Higher Order Thinking at Analysis Level

Factors	Comparative Factors	Mean Difference	Std. Error	Sig.
1	2	-6.0*	-1.00	.00
	3	-2.0*	-.20	.01
	4	-1.20*	-1.20	.00
2	3	-4.00*	.16	.00
	4	-6.00*	-.60	.00
3	4	-1.00*	.14	.00

Table 5 shows a significant mean difference in the HOT analysis scores of the entire group of students from time 1 to time 2, time 3, and time 4. Hence there is meaningful improvement is students' learning on the test based on analytical thinking tasks after they have participated in practical activities, as compared to time 1 and time 3, when they received instruction using the content-based teaching

Table 6: Repeated Measures ANOVA on 4 Measurements of HOT at creation level

Time Period	Mean	S.D	N	F	Sig.	η^2
Baseline1	1.1	.56	10			
Treatment1	1.7	.58	10	6.71	.00	.74
Baseline2	1.5	.70	10			
Traetment2	2.1	.56	10			

Table 6 shows F ratio 6.71 which is significant at (p<.10), thus the results on HOT test improved over four time periods at creative thinking level therefore students learning regarding their creative thinking upgraded from baseline 1 and treatment 1, to baseline 2 and treatment 2. Hence developmental increase in contents novelty and practical lab work support students' learning significantly.

Table 7: POST HOC on Four Measurements of Higher Order Thinking at creating Level

Factors	Comparative Factors	Mean Difference	Std. Error	Sig.
1	2	-.60*	.16	.00
	3	-.40	.22	.10
	4	-1.00*	.21	.00
2	3	-.20	.24	.44
	4	-.40*	.16	.03
3	4	-.60	.30	.00

Table7, results of the post hoc analysis show a significant mean difference in the HOT synthesis scores of the entire group of students from time 1 to time 2 and time 4. However, the change in scores at time 3 in both the phases, is not significant even the practical activities did not work well for students' creative learning abilities. Where as it might not worked effectively due to drawbacks in teaching etc.

Table 8 : Repeated Measures ANOVA on Four Measurements of HOT at Evaluation Level

Time Period	Mean	S. D	N	F	Sig.	η^2
Baseline1	0.9	.31	10			
Treatment1	1.6	.51	10	25.35	.00	.91
Baseline2	1.0	.66	10			
Traetment2	2.3	.67	10			

Table 8 presents data analysis results at evaluation level, HOT scores have significantly changed over four time periods, where is the F value 25.35, p<10, and the partial ETA score is.91, hence an empirical improved change in the students' HOT, over four time periods, from baseline 1 to treatment 1, and from baseline 2 to treatment 2 are higher than earlier.

Table 9: POST HOC on Four Measurements of HOT at Evaluation Level

Factors	Comparative Factors	Mean Difference	Std. Error	Sig.
1	2	-.70*	.15	.00
	3	-.10*	.23	.57
	4	-1.40*	.22	.00
2	3	.60*	.22	.02
	4	-.70*	.21	.00
3	4	-1.30*	.15	.00

The results of Table 9 presents the results of post hoc analysis where mean difference in the HOT at evaluation level of the group of students from time 1 to time 2, time 3, and time 4 is significantly increased.

Thus students' scores on the higher order thinking at evaluation level where they may make value based judgements is better between time 2 and time 4, when they participated in practical activities, compared to time 1 and time 3, when they were taught through content based teaching practices.

Discussion

There is significant change in the HOT scores of students over four time periods, from baseline 1 to treatment 1, and from baseline 2 to treatment 2. It means that the study comprising small sample, provide empirical evidence on the basis of repeated interventions, at stage 2, and 4, through lab activities, regarding enhanced learning especially their overall HOT skills. The similar stance was reported by Zakor,2022, that the students learning in physics, needs them to have mastery over various kinds of representations through experiments, graphs interpretations and inference from mathematical symbols. Students would have understood and learnt the transformation of all these representations, as supported by the results of the present study based on repeated measure ANOVA. The results provide base to determine the visible enhancement in learners' overall higher order thinking skills which they developed through maximizing the use of their senses during the laboratory activities. Therefore, a statistically significant raise in the post test scores, based on practical intervention, confirmed that there is developmental change upwards in students' cognitive performance on the given tests related to higher order thinking. Conclusively the results allow to claim significant support of lab based practical activities in developing students' higher order thinking skills while passing through the experiential learning in phase 2, and 4, as compared to their learning experience, exclusively dependent on classroom CBI.

Similarly, the results of repeated measure ANOVA with F ratio = 25.35, at the varying higher order levels like analysis (F=26.55, sig., .000), creation, (F=6.718, sig., .000), and evaluation being significant support that students' synthesis/ creation skills also upward changed during the experiment time period, from baseline 1 to treatment 1, and from baseline 2 to treatment 2 through upward and developmentally integrated content through practical activities in the science laboratory.

Contrary to the above results, no significant change occurred in students' cognitive abilities in creative thinking skills while gone through content-based instruction. F ratio = 6.718 is significant at p-value = 0.000 <.05 shows that the null hypothesis H04 is rejected and found that there is significant change in HOT Scores over four time periods baseline 1 and treatment 1, and between baseline 2 and treatment 2, at synthesis level. The partial ETA squared =.742 shows that there is strong and significant change in the analysis score of 9th graders over four time periods through hierarchical implementation of content-based instruction and then laboratory activities integrated. To check the magnitude of the difference post hoc test Bonferroni was applied the significant results are presented in the table below.

This experimental study explored the impact of integrating laboratory activities with content-based instruction on the higher-order thinking (HOT) abilities of 9th-grade physics students. the study measured students' HOT skills—analysis, evaluation, and creation—across four different instructional phases. The results revealed a significant improvement in students' HOT scores when practical activities were included, highlighting that hands-on learning enhances cognitive engagement and leads to deeper understanding compared to traditional content-only teaching methods.

The consistent increase in HOT performance across all phases of the study confirms that laboratory activities play a vital role in fostering analytical thinking, critical evaluation, and creative application in physics education. The study concludes that combining theoretical instruction with laboratory activities offers a more effective approach to teaching science, especially in resource-constrained educational environments. Therefore, integrating laboratory activities should be prioritized to ensure meaningful learning outcomes and better prepare students for academic success and real-life problem-solving.

The discussion is concluded that the science teachers at secondary level needs to integrate laboratory activities and they might have to take a paradigm shift from content-based instruction, being traditionally followed, to lab work in science teaching for potential results regarding student higher order thinking. But the following challenges as explored by an in depth study that identified certain factors affecting the teaching of physics through practicals.

Some of the factors are: a) the knowledge of teachers on physics Practicals is inadequate, b) the willingness of the teachers to teach physics practicals, c) no laboratory technician, d) not indicated on the regular time table, e) teachers are not motivated, f) non-availability of apparatus, and g) large number of students (Zakor, M.E. & Karim,S., 2022).

The challenges in the way of practicals in science teaching needs to be addressed by the the schools' leadership being instructional leader and supervisors, through facilitation and encouragement of the science teachers to promote the culture of laboratories in teaching science, geography and computers etc., for the quality education assurance at school level.

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