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Impact of Hands-on Learning Activities on Students' Understanding of Biological Concepts

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Abstract
This study examined the impact of hands-on learning activities on Grade 10 students' understanding of biological concepts in a Bhutanese higher secondary school. Guided by the Constructivist Theory and the AIR (Authentic, Intentional, and Reflective) framework, the research employed a quasi-experimental mixed-methods design. A total of 78 students were assigned to control and experimental groups. Data were collected using pre-tests, post-tests, Likert-scale questionnaires, focus group discussions, and open-ended responses. Quantitative findings showed no significant difference in pre-test scores between the two groups, confirming comparable starting levels. However, post-test analysis revealed a statistically significant improvement in the experimental group ($p = 0.044$), demonstrating that hands-on learning positively influenced academic achievement. Students also expressed highly favourable perceptions toward the approach, with an overall mean score of 4.51. A moderate positive correlation was found between student perception and academic performance ($r = 0.501$, $p < 0.001$), suggesting that students who valued the learning experience tended to achieve better results. Qualitative findings reinforced the statistical results, identifying key themes such as stronger conceptual understanding, higher engagement, improved collaboration, practical skill development, and better connections between classroom learning and real-life experiences. Although minor challenges such as time limitations and unequal participation were noted, the study concludes that well-structured hands-on learning significantly improves student understanding, motivation, and participation in biology education.

Keywords: Hands-on learning, conceptual understanding, biology education, student engagement, experiential learning.

Introduction

Science Education plays a vital role in helping learners understand natural phenomena through inquiry, observation, and experimentation. Modern education systems increasingly promote learner-centered pedagogies that encourage active participation, critical thinking, and experiential learning. In Bhutan, this direction aligns with the philosophy of Gross National Happiness (GNH), which emphasizes holistic development, meaningful learning, and the connection between knowledge, values, and real-life experiences.

Biology often requires students to understand complex and abstract processes such as osmosis, diffusion, and cell division. Because these processes are microscopic and not directly visible, many learners struggle to conceptualize them through traditional lecture-based instruction. As a result, misconceptions and low achievement are common, especially when teaching methods rely heavily on passive learning.

Hands-on learning activities offer an effective solution by engaging students directly in experiments, model construction, observation, and collaborative problem-solving. Through learning by doing, students connect theory with practice, making abstract biological concepts more concrete and understandable.

This study investigated the impact of hands-on learning activities on Grade 10 students' understanding of biological concepts in a Bhutanese higher secondary school. It explored how experiential learning influences academic performance, engagement, and student perceptions, while contributing evidence for improving science teaching practices in Bhutan.

Objectives:

a) Examine the impact of hands-on learning activities on students' understanding of biological concepts.
b) Assess the effectiveness of hands-on learning activities in improving academic performance.
c) Explore students' perceptions toward hands-on learning activities.
d) Determine the relationship between students' perceptions and their academic performance.

Literature Review

Hands-on learning activities are widely recognized as effective pedagogical approaches in science education because they promote active participation, inquiry, and experiential understanding. Rooted in Constructivism, these approaches assume that learners build understanding through interaction, reflection, and meaningful engagement rather than passive reception of facts. In science classrooms, hands-on learning may include experiments, model construction, observation tasks, simulations, field investigations, and collaborative problem-solving. Such strategies are especially valuable in biology, where many concepts such as osmosis, diffusion, and cell division are invisible to the naked eye.

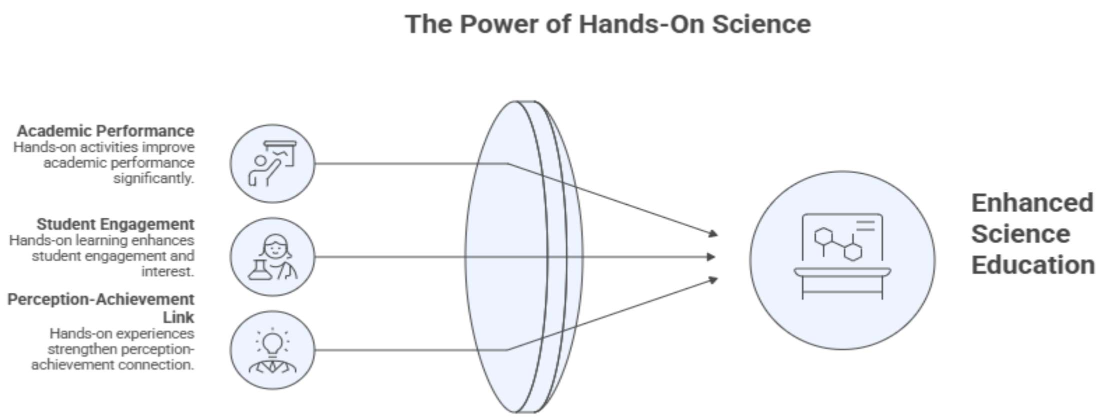
International studies consistently report positive outcomes from hands-on learning. In Canada, Hasni et al. (2016), through a synthesis of science education studies, found that inquiry-based and practical approaches improved conceptual understanding and student attitudes. In Jamaica, Thompson and Soyibo (2002) reported that students performed better in biology when taught through activity-based methods rather than lecture-only instruction. Similarly, Blair-Walters and Soyibo (2004), in the Caribbean context, found stronger understanding of complex biology concepts when learners engaged in practical tasks. In Portugal, Oliveira and Bonito (2023) concluded that well-designed practical science activities improved both skills and conceptual learning. All these studies suggest that experiential learning can strengthen achievement when appropriately structured.

Research also shows that students generally respond positively to hands-on learning. In Taiwan, Shyr (2010) observed that practical engagement increased student motivation and classroom participation in science. Rodríguez (2022), in a Latin American context, found that demonstrations, experiments, and real-life applications improved learners' attitudes toward science. In the context of Ireland, Donnelly, O'Reilly, and McGarr (2013) argued that hands-on learning develops both practical competence and conceptual confidence. Collectively, these findings indicate that when students are active participants, they are more motivated, collaborative, and willing to persist with challenging scientific ideas.

However, educational practices are culturally shaped, and direct transfer of findings from other countries should be approached carefully. Bhutanese classrooms operate within unique linguistic, social, and philosophical traditions. The national education system is influenced by the philosophy of GNH, which values balanced development, ethical citizenship, environmental awareness, and meaningful learning. These principles naturally align with learner-centered and reflective pedagogies. Yet, Bhutanese schools also face contextual realities such as syllabus pressure, examination orientation, mixed-ability classrooms, limited laboratory resources in some schools, and time constraints for practical work. Therefore, evidence from highly resourced or differently structured systems cannot simply be assumed to apply without local investigation.

In Bhutan, curriculum frameworks encourage inquiry, values education, and active learning. However, studies and practitioner observations indicate that classroom teaching can still remain teacher-centered due to workload, assessment pressure, and limited preparation time. In such conditions, abstract biology topics may be taught theoretically, leaving students to memorize processes they cannot visualize. This challenge is particularly relevant for Grade 10 students, where biology concepts become more demanding and examinations carry high stakes.

Consequently, there is a need to test whether or not hands-on learning can function effectively within ordinary Bhutanese classroom conditions as opposed to idealized external settings. Hands-on learning may be especially suitable in Bhutan because it resonates with local cultural ways of learning. Bhutanese communities have long traditions of learning through observation, apprenticeship, collective participation, and practice—whether in agriculture, crafts, rituals, environmental stewardship, or community service. Students often learn skills by doing alongside others. This cultural pattern suggests that experiential methods are not foreign imports but compatible with indigenous learning habits. When science lessons use practical tasks, group discussion, and reflection, they may connect modern curriculum goals with familiar cultural modes of participation.



The present study was guided by the AIR (Authentic, Intentional, and Reflective) framework of Flanagan et al. (2024). While authentic learning emphasizes relevance to real situations, intentional design ensures that activities are purposefully aligned to outcomes. Reflective learning enables students to connect action with understanding. This framework is particularly appropriate in Bhutan, where education seeks not only examination success but also thoughtful, capable, and socially responsible learners.

Although global literature strongly supports hands-on learning, a clear research gap remains: limited empirical evidence exists from Bhutanese higher secondary science classrooms. Most cited studies come from Canada, Portugal, Ireland, Taiwan, Jamaica, and other international contexts with different resources, class cultures, and assessment systems. Therefore, local research is necessary to determine whether similar benefits occur in Bhutan. This study addresses that gap by examining the impact of structured hands-on learning activities on Grade 10 students' understanding of biological concepts, engagement, and perceptions within a Bhutanese higher secondary school context.

Method and Approaches

This study employed a quasi-experimental mixed-methods research design to examine the impact of hands-on learning activities on grade 10 students' understanding of biological concepts. A quasi-experimental approach was selected because intact classroom groups were used rather than randomly assigning students, which is common in school-based educational research where administrative and ethical constraints limit full experimental control. The mixed-methods approach enabled the integration of quantitative and qualitative evidence, thereby providing both measurable outcomes and contextual understanding of learner experiences (Creswell & Creswell, 2018).

The quantitative strand included pre-tests, post-tests, and Likert-scale questionnaires to measure academic achievement and student perceptions. The qualitative strand included focus group discussions and open-ended responses to capture student reflections, engagement, and perceived challenges. The combination of methods strengthened triangulation, credibility, and interpretive depth.

The study was conducted in a Bhutanese higher secondary school with Grade 10 students studying biology under the national curriculum. Bhutanese curriculum policy encourages inquiry-based and learner-centered teaching aligned with holistic educational goals. However, practical implementation often varies because of time pressure, examination demands, class size, and resource constraints. This context made the school an appropriate setting for investigating whether structured hands-on learning could improve conceptual understanding within realistic classroom conditions.

A total of 78 Grade 10 students participated in the study, including 38 males and 40 females. Students were divided into an experimental group ($n = 39$) and a control group ($n = 39$). Purposive allocation was used based on existing class sections, while pre-test scores were examined to ensure baseline comparability between groups. Pre-test analysis confirmed no statistically significant difference in prior knowledge, supporting group equivalence before the intervention.

Intervention Design: AIR Framework

The intervention was guided by the AIR (Authentic, Intentional, and Reflective) framework (Flanagan et al., 2024). AIR informed the structure of each lesson in the experimental group. Students engaged in real and observable biology tasks such as osmosis experiments using potato strips, diffusion demonstrations using colored liquids, microscope observation, model construction of cells, and simulation of mitosis stages. These activities linked abstract concepts to visible experience.

Each activity was explicitly aligned to lesson objectives, curriculum standards, and assessment targets. Worksheets, guiding questions, and teacher prompts were used to maintain conceptual focus rather than unstructured activity. Students completed short written reflections, peer discussions, and teacher-led debriefing after each activity. Reflection questions focused on what happened, why it happened, and how the activity explained the biological concept. The intervention lasted four instructional weeks.

Control Group Condition

The control group studied the same biology topics during the same time period through regular teacher-led instruction commonly used in the school context. This included textbook explanation, note-taking, question-answer sessions, board illustrations, and teacher demonstrations where relevant. Both groups covered the same syllabus content, used the same assessment schedule, and were taught for similar instructional time. To reduce teacher-effect bias, the same teacher-researcher taught both groups using planned lesson sequences.

Instruments and Data Collection

The researcher developed a 20-item multiple-choice test to assess understanding of osmosis, diffusion, and cell division. Items were aligned to curriculum outcomes and reviewed for face validity by experienced biology teachers. The same test format was used for pre-test and post-test with reordered items. A 5-point Likert-scale questionnaire measured engagement, motivation, confidence, collaboration, and perceived understanding. Students described what helped their learning, difficulties experienced, and suggestions. Small-group interviews were conducted with volunteer students from the experimental group to explore in-depth perceptions. To address equity concerns, the control group received access to the same hands-on learning materials and activities after completion of data collection, ensuring they were not permanently disadvantaged. To reduce the Hawthorne effect (where students improve because they know they are being studied), activities were embedded within normal teaching routines and the emphasis on “special treatment” was minimized. Teacher effect was also controlled through use of the same teacher for both groups.

Data analysis

Data analysis was conducted using a convergent mixed-methods approach, where quantitative and qualitative data were analyzed separately and later integrated during interpretation (Creswell & Creswell, 2018). This design enabled the study to generate statistical evidence of academic outcomes while also exploring students’ perceptions and experiences of hands-on learning activities.

Quantitative data were analyzed using descriptive and inferential statistics. Prior to conducting parametric tests, assumptions of normality were examined using the Shapiro–Wilk test, as presented below.

Table 1

Normality Test (Shapiro–Wilk)

Variable	W Statistic	p-value
Pre-Test Score	0.982	0.343
Post-Test Score	0.976	0.148

The Shapiro–Wilk results showed that both pre-test and post-test scores were normally distributed (p > .05). Therefore, parametric statistical tests were considered appropriate.

To determine whether both groups were comparable before the intervention, an independent samples t-test was conducted on pre-test scores.

Table 2

Independent Samples t-Test for Pre-Test Scores

Group	N	Mean	SD	Mean Difference	Effect Size (d)	Sig. (2-tailed)
CG	39	2.38	1.18	0.02	0.02	0.918
EG	39	2.36	1.01			

The findings indicate no statistically significant difference between the two groups at baseline (p = .918), confirming equivalence prior to the intervention.

A second independent samples t-test was conducted on post-test scores to examine the effect of the intervention.

Table 3

Independent Samples t-Test for Post-Test Scores

Group	N	Mean	SD	Mean Difference	Effect Size (d)	Sig. (2-tailed)
CG	39	4.62	2.27	-0.87	-0.46	0.044
EG	39	5.49	1.39			

A statistically significant difference was found between groups (p = .044), with the experimental group outperforming the control group. The moderate effect size suggests that the hands-on learning intervention had a meaningful positive impact on students' academic performance.

Likert-scale questionnaire responses were analyzed using means, standard deviations, standard errors, and confidence intervals.

Table 4

Students' Perception of Hands-on Learning Activities

Item No.	Statement	N	Mean	SE	SD	Level of Perception	95% CI Lower	95% CI Upper
1	Learning activities helped to understand concepts	39	4.37	0.10	0.69	High	4.15	4.59
2	I enjoyed carrying out the activities	39	4.61	0.09	0.58	Highest	4.42	4.79
3	Learning activities kept me engaged	39	4.44	0.11	0.70	High	4.22	4.66
4	I feel a greater sense of satisfaction when taught through this approach	39	4.40	0.10	0.67	High	4.19	4.61
5	Learning activities provide opportunities to interact	39	4.54	0.09	0.63	Highest	4.34	4.74
6	Learning activities made me think critically	39	4.71	0.08	0.58	Highest	4.55	4.87
7	Learning activities developed curiosity	39	4.51	0.09	0.61	Highest	4.33	4.69
Overall	Overall Perception	39	4.51	0.09	0.63	Highest	4.28	4.60

Students reported highly positive perceptions toward hands-on learning, with all items rated high to highest. This suggests strong engagement, satisfaction, curiosity, and perceived conceptual understanding.

To examine whether perception was associated with achievement, a Pearson product-moment correlation was conducted.

Table 5

Correlation Matrix between Students' Perception and Scores

Variables	Students' Perception	Scores
Students' Perception	1	0.501**
Scores	0.501**	1
N	39	39
p-value	—	0.001

*Note. *p < .05, **p < .01, ***p < .001*

The results revealed a statistically significant moderate positive correlation ($r = .501$, $p = .001$), indicating that students with more positive perceptions of hands-on learning tended to achieve higher academic scores.

Qualitative Data Analysis

Qualitative data from focus group discussions and open-ended responses were analyzed manually using thematic analysis, following the six-phase framework of Braun and Clarke (2006). The six steps included: familiarization with the data, initial coding, searching for themes, reviewing themes, defining and naming themes, and producing the report.

Themes identified included: conceptual understanding, active engagement, collaboration, skill development, real-life connection, and practical challenges.

Findings from both strands were integrated through triangulation. Quantitative data showed improved achievement and highly positive perceptions, while qualitative findings explained these outcomes through student accounts of better visualization, increased motivation, productive teamwork, and meaningful learning experiences. This convergence strengthened the overall validity of the study and confirmed the effectiveness of hands-on learning activities in improving biology learning outcomes.

Results and Discussion

The results are presented according to the three research questions to ensure clarity and direct alignment with the research objectives.

Research Question 1: Is there a significant difference in academic performance between students taught through hands-on learning activities and those taught through conventional methods?

The quantitative findings showed that both the control group and experimental group started from a comparable baseline. As shown in Table 2, there was no statistically significant difference in pre-test scores between the two groups ($p = .918$). This confirms that the groups had similar prior knowledge before the intervention, strengthening internal validity.

However, post-test results in Table 3 revealed a statistically significant difference between the two groups ($p = .044$), with the experimental group ($M = 5.49$, $SD = 1.39$) outperforming the control group ($M = 4.62$, $SD = 2.27$). The effect size ($d = -0.46$) indicates a moderate practical impact. The lower standard deviation of the experimental group suggests that hands-on learning not only improved achievement but also produced more consistent outcomes across learners.

These findings indicate that structured hands-on learning activities were more effective than conventional lecture-based instruction in improving students' understanding of biological concepts. This supports previous studies by Oliveira and Bonito (2023) and Fowler (2008), who reported that experiential learning strengthens conceptual understanding and skill development.

Research Question 2: What are students' perceptions toward hands-on learning activities?

Students demonstrated highly positive perceptions toward the intervention. As shown in Table 4, all questionnaire items recorded mean scores above 4.0, with an overall mean of 4.51, indicating the highest level of perception. Students particularly rated enjoyment (M = 4.61), opportunities for interaction (M = 4.54), curiosity development (M = 4.51), and critical thinking (M = 4.71) very highly.

These results suggest that students viewed hands-on learning as engaging, enjoyable, interactive, and intellectually stimulating. Such findings are consistent with Musharrat (2020), who found that practical learning approaches improve motivation and participation by engaging multiple senses.

The qualitative findings further support this result. Students reported that lessons were more interesting, less monotonous, and easier to understand when they actively participated in experiments and model-making. They described feeling more alert, curious, and involved compared to traditional note-based lessons.

Research Question 3: To what extent does students' perception influence their academic performance?

This research question was addressed through correlation analysis. As presented in Table 5, a statistically significant moderate positive relationship was found between students' perceptions and academic scores ($r = .501$, $p = .001$). This indicates that students who reported more positive perceptions of hands-on learning tended to achieve higher post-test scores.

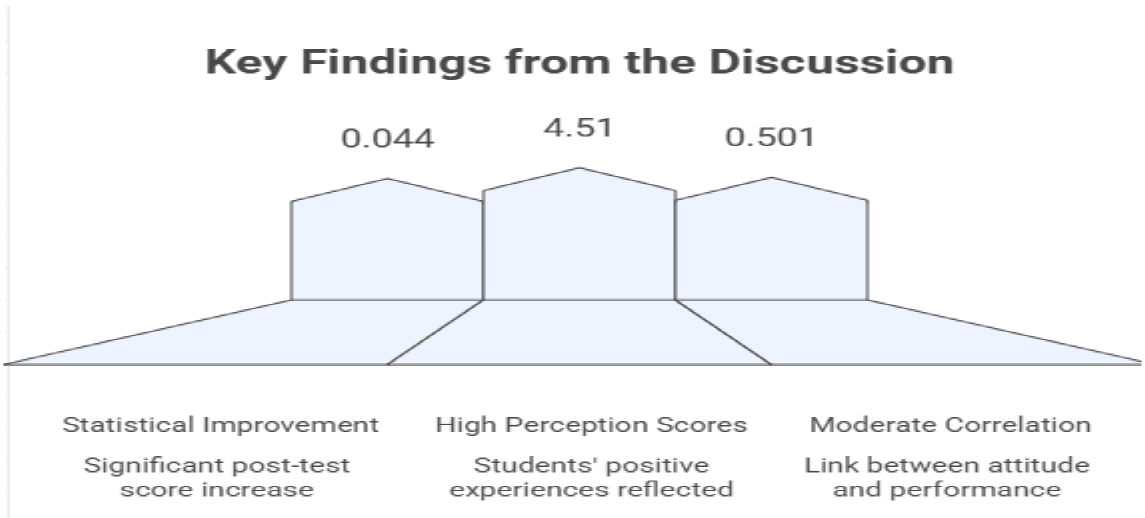
The coefficient suggests that perception had a meaningful influence on performance. In practical terms, when students enjoyed learning, felt engaged, interacted with peers, and believed activities helped understanding, they were more likely to perform better academically. This finding confirms that affective factors such as motivation, confidence, and engagement are strongly connected to achievement.

Qualitative evidence helps in explaining this relationship. Students stated that enjoyable activities increased their concentration, teamwork built confidence, and reflection helped them remember concepts. Therefore, positive perception was not merely an attitude outcome—it functioned as a learning mechanism that supported achievement.

The findings demonstrate strong convergence between quantitative and qualitative data. Statistical improvements in achievement were supported by student narratives describing better visualization of abstract concepts such as osmosis, diffusion, and cell division. High perception scores were reinforced by reports of increased motivation, enjoyment, and participation.

Hands-on learning appears especially valuable in biology because many biological processes are invisible or abstract. Activities such as experiments, models, and guided reflection enabled students to transform theoretical ideas into observable experiences. This aligns with constructivist theory, where learners actively construct understanding through experience and

reflection.
Although overall findings were positive, some students noted challenges such as limited time, unequal participation in groups, and the need for clearer instructions. These practical issues suggest that hands-on learning is effective when carefully planned and well managed.



Based on the findings, the following recommendations are proposed:
Integrate hands-on learning in biology classrooms: Teachers should regularly incorporate experiments, models, simulations, and collaborative tasks when teaching abstract biological concepts.
Professional development for teachers: Schools and education authorities should provide training on designing structured hands-on lessons aligned with curriculum goals.
Use reflection as part of activities: Teachers should include guided reflection after practical tasks so students connect experience with scientific understanding.
Improve resource support: Schools should strengthen access to low-cost laboratory materials and teaching aids for practical science learning.
Promote inclusive group work: Teachers should assign clear roles in group activities to reduce unequal participation.
Future research: Further studies should examine long-term retention through delayed post-tests, inclusion of larger samples, and exploration of hands-on learning in other science subjects.

Conclusion

This study provides strong evidence that hands-on learning activities significantly enhanced students’ conceptual understanding, engagement, and attitudes toward learning biology. Quantitative findings showed that students in the experimental group achieved significantly higher post-test scores than those in the control group, with more consistent learning outcomes. Qualitative findings further revealed that students valued active participation, collaboration, experimentation, and real-life connections, all of which supported deeper understanding and intrinsic motivation. These combined findings indicate that hands-on learning was effective not only in improving academic performance but also in creating meaningful and enjoyable learning experiences.

The findings also validate the AIR (Authentic, Intentional, and Reflective) framework as an effective guide for designing experiential science instruction. Authentic elements of the intervention involved students engaging in practical biology tasks such as experiments on osmosis and diffusion, model-making of cells, and observing biological processes through demonstrations. These experiences helped students visualize concepts that are normally abstract and invisible. Intentional design was reflected in the careful alignment of each activity with lesson objectives, curriculum standards, and assessment goals. Activities were sequenced with teacher guidance, worksheets, questioning strategies, and collaborative structures to ensure that learning remained purposeful rather than merely entertaining. Reflective components were incorporated through post-activity discussions, written reflections, explanation tasks, and peer sharing, where students analyzed what they observed, explained scientific reasons, and connected theory to practice. These three AIR dimensions worked together to strengthen conceptual learning, engagement, and critical thinking.

The findings have important implications for science instruction and curriculum design in Bhutan. Teachers are encouraged to integrate structured hands-on learning activities into regular classroom practice, particularly when teaching abstract scientific concepts. Reflection should be embedded after activities so that experience leads to understanding. Careful team composition, scaffolding, and classroom monitoring are necessary to address challenges such as unequal participation and time limitations.

Future research may examine long-term retention through delayed post-tests, compare results across grade levels and science subjects, and investigate strategies for improving participation, resource use, and time management. Such studies would further strengthen the implementation of activity-based learning in Bhutanese schools.

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