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Knowing, Doing, and Embracing Local Resources and Pedagogical Shifts in Science Education through Experiments

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Abstract

This research identified significant misconceptions and a lack of practical, real-life understanding due to the strict teacher-centric approach and unavailability of teaching materials in the science teaching and learning process. This action research was conducted with five science teachers, focusing on using locally available teaching materials to teach specific science concepts. The primary assumption was that locally available materials could correct misconceptions and serve as effective tools in science education. From an ontological perspective, this paper adopted a postmodernist stance, suggesting that participants could develop new ideas and inquiries instead of a positivist viewpoint that confined learners to prescribed activities. The research methodology comprised three distinct phases: pre-intervention, intervention, and post-intervention, and it measured the effectiveness of the intervention statistically. Teachers used syringes to develop teaching materials and effective teaching methodologies to address misconceptions and strengthen the practical understanding of the working mechanisms of devices like hydraulic presses, Newton meters, and water hand pumps. Incorporating locally available materials for model-making in science education is essential for improving student engagement, fostering creativity, enhancing critical thinking skills, and developing science procedural skills.

Introduction

Science education is often perceived as a theoretical and practical aligning learning process. The practice of real-life problem-solving can be fostered early through science procedural skills (Pedrera et al., 2025). Incorporating hands-on activities for model-making and nurturing science inquiry and reasoning with tools in science education helps to enhance critical thinking and the scientific process (Faikhamta et al., 2024; Fakaruddin et al., 2023; Malik & Zhu, 2022; Shao et al., 2024). However, in many remote regions, especially in developing countries, limited resources for science education prevent hands-on experiences during the learning processes. This includes inadequate physical infrastructure, such as laboratories and libraries, as highlighted by Dhamala et al. (2021) and Koirala (2021) in Nepal.

Additionally, the inadequacy and lack of capability among human resources, as well as the prevalence of improper management practices (e.g., Belbase, 2019; Koirala, 2021) are barriers to employing activity-based science

classes. Despite these challenges, sophisticated tools are not always necessary. Employing metaphorical concepts or modeling approaches using locally available materials can be effective (Chittleborough & Treagust, 2009; Quive et al., 2020). However, students frequently miss out on opportunities for activity-based learning due to a lack of knowledge about using or assembling locally available tools and technology (Belbase, 2019; Dhamala et al., 2021; Koirala, 2021). This action research concerns teaching practices and challenges facing the learner, especially the awareness of pedagogical and content knowledge for teachers (e.g., Lieberei et al., 2024; Xue et al., 2024) and improving the learning environment with activity-based classroom settings for students (e.g., Faikhamta et al., 2024; Xue et al., 2024). This includes modeling the hydraulic piston and its mathematics, debunking common myths about Newton's 3rd law, and some syringe activities (e.g., Crawford, 2022; Winkelmann et al., 2025).

Rationale for Research

Since the 2019/20 academic year in Nepal, the science curriculum has undergone significant revisions, becoming more advanced compared to its predecessor. The recent curriculum emphasizes procedural skills and the learning process, moving away from the previously rigid, content-centered approach (Acharya et al., 2022). The evaluation system has also shifted to a formative format, assessing every science-related learning activity. However, teaching approaches remain conventional, often relying on examples and solving real-life problems orally in a teacher-centered, memorization-based, exam-oriented manner with fixed processes (Aelterman et al., 2016; Luitel & Taylor, 2006; Weegar & Pacis, 2012). These traditional methods align with Paulo Freire's "banking" concept of education, where students are seen as passive recipients of knowledge (Garavan, 2010; Weegar & Pacis, 2012). Consequently, such practices lead to the development of misconceptions and superficial memorization in students (Jansen & van der Merwe, 2015; Matsuyama et al., 2019; Mpho, 2018). Addressing these issues in science teaching and learning processes is essential to aligning with the curriculum's objectives (Saribas & Çetinkaya, 2024).

There is a push among teachers and educators in the country toward adopting student-centric teaching methods and modern classroom designs. Nonetheless, it is found that those who train teachers often promote these approaches without considering their practical implementation (Koirala, 2021). Acharya et al. (2022) highlighted the efficacy of experiential learning in school gardens for science education. However, such studies are limited in the context of science education in Nepal.

Significance of Research

The research is intended to foster transformative and enduring learning among students, aiding them in rectifying misconceptions about specific science concepts (Appendix A). The following research questions guide the research:

- 1. How do we develop the intervention curriculum for the teachers to transform their pedagogical practices using locally available materials?*
- 2. How do students learn meaningfully and overcome their misconceptions using the locally available materials?*

Theoretical Background

Locally Available Materials for Modeling

The use of locally available materials in science education has roots in the early 20th century. The work of Tao (1983) is evidence of prioritizing finding whatever local tools for science education since 1976. In addition, the demonstration using bamboo by Warren (1983) adds to the rich history of applying local resources in science education. This practice was originally motivated by the need to make science education more accessible and relevant to students, particularly in resource-limited environments. Local resources adhere to situated learning principles as guided by Lave and Wenger (1991). Using these resources for modeling cultivates meaningful and in-depth learning. Moreover, such practices foster students' cognitive, affective, and psychomotor domains (Limbu, 2024) by requiring authentic contexts and activities, access to expert knowledge, various roles and identities, collaborative knowledge construction, and self-reflection (Barak & Yachin, 2024; Faikhamta et al., 2024; Xue et al., 2024).

In science education, the model-based view is the most important to understand the nature of scientific methods and knowledge (Chittleborough & Treagust, 2009; Develaki, 2016; Engelschalt et al., 2023). Using locally available materials—whether they are local, low-cost, or no-cost—provides an excellent alternative for conducting hands-on activities and understanding scientific knowledge (Bello et al., 2023; Wenderott, 2023). For instance, a plastic water bottle can be used to demonstrate atmospheric pressure, buoyancy, variations in liquid pressure with height, and more science content. However, awareness and prior experience in using these materials are crucial (Blanco-Anaya et al., 2017; Quive et al., 2020). In this regard, Xue et al. (2024) found a positive correlation between modeling and learning outcomes, and no significant relationships exist between meta-modeling knowledge, modeling practices, and learning outcomes, which indicates that while teachers may have theoretical knowledge, it does not always translate into practical modeling skills. Employing local modeling resources enhances the sustainability of in-depth science learning and fosters psychomotor skills and awareness of their multiple uses and resourcefulness (Engelschalt et al., 2023; Winkelmann et al., 2025; Faikhamta et al., 2024). Additionally, significant science procedural skills can be developed with cost-effective, relevant, and accessible materials. Adequate knowledge of using locally available materials can overcome the barriers to activity-based science education, particularly in remote regions (e.g., Peşman et al., 2024), and Pedrera et al. (2025) identified three distinct stages of modeling: *Basic Model*-heterotrophic explaining ideas based on intuitive and naive conceptions, *Intermediate Model*-demonstrating scientific mechanism but lacking key concepts or full understanding, and *Upper model*-resembling the consensus Scientific Model. The relevance and familiarity of materials and modeling in learning processes can significantly aid in transforming scientific concepts into everyday experiences, thereby enhancing understanding and retention (Bello et al., 2023; Faikhamta et al., 2024).

Transforming Classroom Settings

The framework for this research's teaching and learning process is centered on Mezirow's transformative learning theory. It focuses on the process of change in the frame of reference, leading to transformative learning (Mezirow, 1997) where students correct their misconceptions and teachers change their teaching approach to a situated

learning-based one. Moreover, this theory is also constructivist-rooted and oriented towards how learners interpret and reinterpret their sense experience (Mezirow, 1994). Teachers can reinterpret their past experiences in different modes of reflection for various purposes (Markwick & Reiss, 2023; Zajda, 2021), leading to effective teaching approaches with the least gaps concerning knowledge, theoretical, and practical (Zajda, 2021). This research advocates situated learning settings for teaching and learning processes and competencies on meta-modeling among teachers and students (e.g., Develaki, 2016). Students are encouraged to explore, inquire, and construct their understanding through diverse activities in such a classroom or teaching approach. The teacher's role in this setting is not that of a traditional instructor but rather of a facilitator (Develaki, 2016; Shah, 2019; Taylor, 2015; Zajda, 2021). Teachers guide students through the learning process, providing support, feedback, and scaffolding when necessary. They also prepare students for the real world by developing models and essential skills such as collaboration, communication, and self-directed learning. Therefore, the situated learning approach enhances the learning experience and equips students with the skills necessary for lifelong learning (Amineh & Asl, 2015; Lave & Wenger, 1991; Schreiber & Valle, 2013). Regarding implementing such approaches, this research found misconceptions and surficial understanding and adhered to correct them under specific content (Assi & Cohen, 2023).

Transdisciplinary Stances for Research

In the twenty-first century, significant science procedural skills are essential to address complex personal, community, and global challenges (Čipková et al., 2024). The evolution of science education has emphasized the importance of hands-on experiments, which play a crucial role in enhancing students' understanding and application of scientific concepts. These practical activities improve scientific skills and foster scientific thinking habits, providing students with practical insights and opportunities to apply theoretical concepts (Malik & Zhu, 2022; Shao et al., 2024). Incorporating imagination and reasoning, supported by tangible tools, is essential for enhancing creative thinking in students (Fakaruddin et al., 2023). Moreover, collaborative invention projects for students working together to design and construct prototypes to solve real-life challenges further enhance this process. This approach fosters teamwork, communication skills, and a deeper understanding of scientific concepts through peer-to-peer learning (Malik & Zhu, 2022; Sormunen et al., 2023). This aligns with Thomas S. Kuhn's concept of paradigm shifts in scientific understanding. Kuhn's work underscores the need for a conceptual change in science education, moving from superficial knowledge with misconceptions to in-depth, real-life implications (Wray, 2023). This shift necessitates a transition from conventional, teacher-centric strategies to student-centric approaches, ensuring that learners are actively engaged in the scientific process and capable of critical thinking and problem-solving in real-world contexts (Fakaruddin et al., 2023; Zuccarini & Malgieri, 2022).

Methodology

This research is grounded in a constructivist ontology, a participatory and subjective epistemology, and is value-laden (Gelling & Munn-Giddings, 2011; Spencer et al., 2014). We socially construct and follow subjective phenomena to achieve reality, shaped by our experiences and interactions (Spencer et al., 2014). Insights were co-constructed through the active participation of mentors, researchers, and participants. This research aimed to

understand and improve the world, with the values and morals of all involved shaping the process and outcomes (Gelling & Munn-Giddings, 2011). Additionally, it addresses challenges in collaborative work (Pant et al., 2024) by understanding and fulfilling research responsibilities (Chang, Ngunjiri, & Hernandez, 2013).

Research Design

This research employed mixed methods, including qualitative and quantitative research methods. The qualitative part has an interpretive research paradigm and an action research design to align the philosophical consideration of this research. An interpretive research paradigm is used to understand participants' experiences, meanings, and social realities, emphasizing context and subjectivity (Assi & Cohen, 2023). An action research design is chosen for its practical, participatory approach, allowing us to address real-world problems collaboratively while continuously refining solutions through iterative cycles (Kivunja & Kuyini, 2017). At the same time, the quantitative part uses positivism to measure the effectiveness of the interventions. Action research is a systematic, multi-staged cyclical process to improve and transform practices through informed, progressive changes (Bradbury et al., 2019; Coghlan, 2022; Dusty, 2024). Initially conceptualized by Kurt Lewin (1840–1947), it empowers individuals to engage in reflective thought, discussion, decision-making, and action on personal and collective issues (Adelman, 2006; Crawford, 2022; Tindowen et al., 2019). This action research was completed through four phases: identifying the problem, planning for action, implementation and analysis, and reflection.

Reflecting on the implementation has been instrumental in developing knowledge (Bradbury et al., 2019; Coghlan, 2022; Dusty, 2024; Manthiram & Edwards, 2021; Tindowen et al., 2019). The development of the curriculum (Appendix B) and the implementation design were guided by mentors and participating teachers, highlighting the importance of collaborative work and mentoring in professional development (Manthiram & Edwards, 2021; Markwick & Reiss, 2023; Tenorio-Lopes, 2023). The research hierarchy consisted of three levels with respective roles (Appendix B): academic and field mentors, the researcher, and the participants (science teachers and secondary-level students).

Participants and Data Collection

Participants were purposively selected based on prior interactions and criteria, including secondary-level teachers in remote areas and their readiness for prolonged engagement (Pervin & Mokhtar, 2022). The study involved 5 teachers and 288 ninth and tenth-grade students from community schools. Teachers participated in interviews, workshops, and reflections and implemented the curriculum, while students engaged in pre- and post-tests (Appendix C). Maintaining positive relationships with participants was crucial (Gelling & Munn-Giddings, 2011), so this research's ethical considerations focused on building partnerships, recognizing power dynamics, promoting equality, and respecting diverse knowledge. Data was collected through multiple methods, including interviews, observations, and pre-and post-tests, to capture comprehensive insights (Kivunja & Kuyini, 2017; Pervin & Mokhtar, 2022). This included recorded audio, images of implementation, Google Docs tracking for teachers' progress, and test results.

Data Analysis

The collected data was analyzed using both qualitative and quantitative methods. Qualitative data from interviews, observations, and reflective sessions were transcribed, coded, and analyzed to identify themes and patterns. Quantitative pre-and post-test data were analyzed using a Wilcoxon signed-rank test in SPSS software to determine the effect size on students' learning outcomes. This research followed Lewin's Approach to Action Research, guided by the action plan and Data Collection Plan as shown in Figure 1 below:

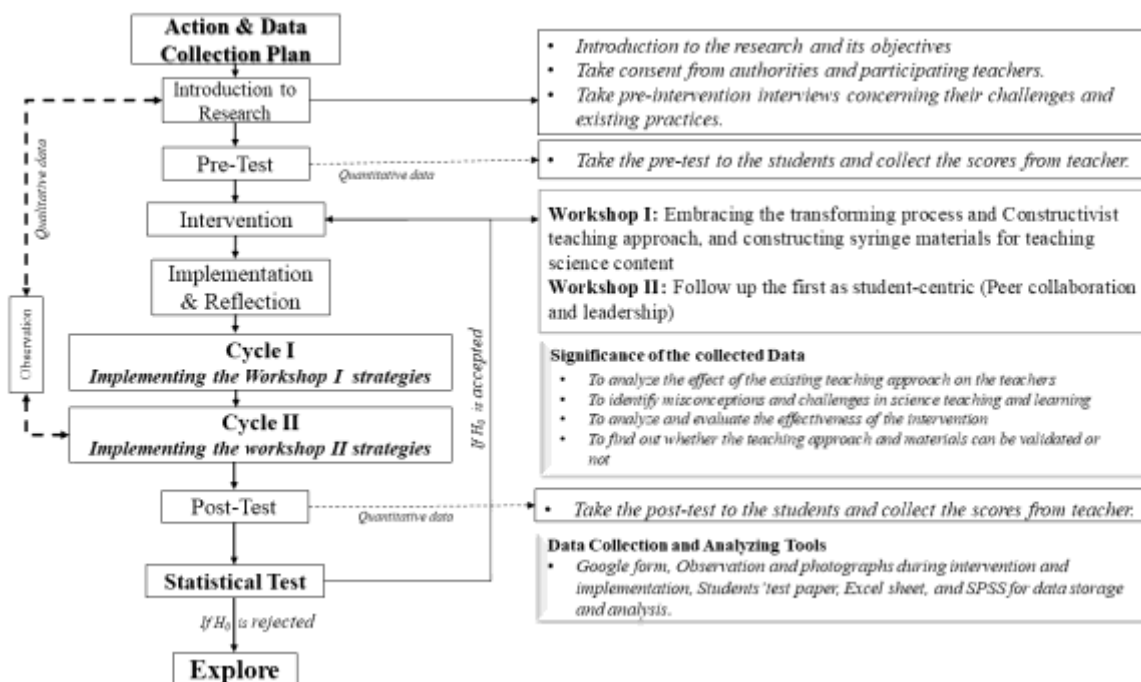


Figure 1. Conceptual Framework of the Action and Data Collection Plan

Reflection on Working with Teachers

The data collection began with a general introduction based on the prior pilot survey and a brief about us. Consent was obtained from the selected in-service science teachers and their respective administrations. All the teachers showed great enthusiasm to participate in the research. They were cooperative, dedicated, and hardworking, with high qualifications and extensive experience in the related field (Appendix D).

Initially, the objective of the curriculum regarding science content was unknown. After numerous virtual Zoom meetings, Google Forms questionnaires, and school visits, we identified the issues for the research. Based on these issues, we set the second objective to enhance scientific learning by correcting misconceptions about Newton's third law, numerical and demonstration for Pascal's law, and the working mechanism of a water pump. Through an interview, the regular teaching practice of the selected in-service science teachers, the physical conditions of their classrooms, and their existing understanding of hands-on experiments were understood. A pre-test evaluation was also conducted to assess the students' existing understanding.

Pre-Intervention Science Teaching

During the pre-intervention interview, three schools out of five were randomly selected based on time availability and visited. These visits are aimed at interacting with students to identify content-related issues and examine whether activities are done, especially in physics. These visits informed the specific science contents (Appendix A) to develop the curriculum. All the teachers involved in the instruction used very similar teaching methods when delivering this content. They primarily used conventional, lecture-based methods, attempting to explain real-life problems. Their approach was largely teacher-centered, akin to behaviorist models (Weegar & Pacis, 2012), with students acting as passive listeners and focusing on exam preparation. The teachers conducted selective experimental classes, but students had limited hands-on experimentation opportunities. None of the activity-based classes included practical activities related to Newton's third law of motion, Pascal's law, and air pressure in a hand/water pump. Instead, the concept was taught by describing and attempting to elaborate on the laws using relevant real-life examples (Luitel & Taylor, 2006), which has been the fixed process for several years.

Teachers often use real-life examples to teach Newton's third law. Mr. Rijal explained it during a picnic near a lake. Mr. Gautam used a marker and a whiteboard, and Mr. Adhikari and Mr. Katwal demonstrated it by dropping a ball. Mr. R. Katwal provided examples and practical videos to clarify the concept. However, most teachers demonstrated activities and controlled students' learning behavior. Following behaviorist beliefs that the external environment shapes individual behavior, teachers acted as motivators by influencing grades, rewards, and privileges (Aelterman et al., 2016).

Similarly, lecture-based teaching was only found to teach Pascal's law and air pressure by solving some numerical problems and labeled drawings. They linearly followed lesson objectives, supporting desired learning outcomes and using reinforcement to reinforce them. Such an approach often yields misconceptions about science content (Saribas & Çetinkaya, 2024). In contrast, Mr. Rijal's approach was more activity-based, allowing students to engage in activities and social interactions to construct their learning through rough experiences and interaction (Weegar & Pacis, 2012).

Challenges with their existing teaching approach: The research teachers all tried to teach Newton's third law effectively. However, they faced various challenges. Mr. Adhikari found it time-consuming to clarify action and reaction forces and resorted to providing notes for students to memorize key terms. Mr. P. Katwal faced challenges such as large class sizes, difficulty in determining hands-on mathematical calculations, lack of multimedia devices, and limited time for interaction with students. Mr. R. Katwal focused on teaching the theoretical aspects of the concept because he found it difficult to demonstrate and measure forces. Mr. Rijal had difficulty obtaining reliable and valid materials for experimenting in his area, indicating they didn't take any workshop related to the local materials (Dhamala et al. 2021; Koirala, 2021; Phillips et al., 2022). In contrast, Mr. Adhikari had access to all necessary equipment and used two spring balances to teach action-reaction forces, claiming to face no challenges in teaching the concept. As Dewey stated in 1938, learners construct cognitive knowledge from their experiences, and progressive education must include socially engaging learning experiences (Williams, 2017). Even though all teachers believe Dewey's concern, none of the participating teachers practiced real-life or

demonstrative measuring of the magnitude of action and reaction, effort load concerning the cross-section of pistons, and the working mechanism of a hand pump. They were also unaware of locally available materials that could be used for this purpose.

Despite these challenges, all teachers were satisfied with their students' learning outcomes. When asked about their *evaluation methods*, all teachers were satisfied with their students' performance, although some students did not perform as well as others. Pre-intervention methods of teachers in this research often involve using examples and solving real-life problems orally in a teacher-centered, memorization-based, exam-oriented approach with fixed processes (Aelterman et al., 2016; Luitel & Taylor, 2006; Weegar & Pacis, 2012). Such conventional teaching approaches align with Paulo Freire's "banking" conception of education, where students are viewed as passive recipients of knowledge (Garavan, 2010; Weegar & Pacis, 2012). Moreover, pre-intervention interactions with teachers and students have revealed that such teaching practices contribute to developing misconceptions and surficial memorizations (Jansen & van der Merwe, 2015; Matsuyama et al., 2019; Mpho, 2018).

Identification of Issues and Pre-test

Based on the content, potential misconceptions and issues related to Newton's third law, Pascal's law, and air pressure were reviewed in the literature, and this information framed the interactions with the students. Thus, a pre-test of the students was taken upon these visits. This research focused on two prime misconceptions: "*greater mass implies greater force*" and "*Only active agents exert reaction*", and was demonstrative with hands-on activities teaching and learning processes which were not in practice. To cover the content with similar locally available instruments, we (the researcher and participating teachers) selected Newton's third law, Pascal's law, and air pressure using syringes.

A pre-test for the students was taken with structured objective questions. There were seven multiple-choice questions for ninth graders concerning Newton's third law of motion only and examined the misconceptions. Some numerical-based and diagrammatic conceptual-based objectives for tenth graders concern Pascal's law and the working mechanism of the water pump (Appendix E). For this pre-test, teachers acted as facilitators to make the questions clearer if students did not get the ideas. Altogether, one hundred and thirty-five students from five teachers. All teachers selected one section only for this test. The test result is represented through the spider web (Figure 2) below.

In this web representation, the blue area represents the total number of participants, and the orange area represents those who provided correct answers. It reflects the gap between teachers' desired outcomes and the effectiveness of their existing practices. The orange area represents the actual learning achieved by students. The gap between the orange and blue areas is referred to as the self-discrepancy of teachers: the larger the gap, the more changes are needed to achieve the desired outcomes. This indicates that teachers need to change their teaching practices and become critically reflective practitioners (Phillips et al., 2022). To facilitate this change, we (Field mentor, Researcher, and Teachers) collaboratively developed a curriculum that included an introduction to new teaching practices, workshops, and implementation (Appendix C).



Figure 2. Web Representation of the Pre-Test Result

Intervention: Teaching Profession Development Workshop

Teachers were informed about situated learning-based science teaching to facilitate transformative learning through active knowledge construction and participation. They designed lesson plans that encourage students to construct knowledge through hands-on activities and personal experiences. These plans included developing situations, grouping, bridging, questioning, exhibiting, and reflecting (Shah, 2019; Zajda, 2021). Teachers were encouraged to interact openly with students to develop and implement their plans. To implement these plans, teachers have to facilitate the learning process by modeling, coaching, and scaffolding (Chen et al., 2022). The first step of the intervention was to mentor teachers in enhancing activity-based classroom settings and then introduce and conduct activities using locally available materials (Manthiram & Edwards, 2021; Lozano & Solbes, 2021; Tenorio-Lopes, 2023).

Workshop I and Cycle I

Based on the needs of the teachers, we conducted a workshop. Since the teachers participating were in different areas, a physical workshop was not possible. Instead, we conducted Workshop I virtually via Zoom meetings, demonstrating how to make a Newton meter and model of a hydraulic press and water hand pump. We used syringes and measured action, reaction, and transmitted forces using scales on the syringes. Moreover, the opening and closing of valves during the upstroke and downstroke were observed through the bearing balls used. All teachers responded positively to the workshop and gained an understanding of how to use syringes to correct misconceptions (Appendix G: Making Teaching Materials). During the workshop, Mr. Gautam and Mr. R. Katwal expressed concerns about the procedure and its effectiveness. Additionally, they asked for already-made materials,

reasoning that the administration takes a longer time to provide such materials. It was found that some teachers couldn't make a water pump and hydraulic pump even after a week (e.g., Blanco-Anaya et al., 2017). We reconducted the workshop and guided them.

After implementing Cycle I, all teachers were pleased with their students' satisfaction. Mr. Adhikari noted that students engaged with the material by discussing both the actions and reactions involved. However, they frequently asked, "How is this related to a vehicle collision case?" In response, he made efforts to connect the activities to real-life accident scenarios. Teachers explained and demonstrated the activities, with or without volunteer students, while the rest of the class observed. Meanwhile, Mr. R. Katwal reported that his instrument was functioning properly but failed during the demonstration. As a result, he had to revise it the following day. They conducted at least four activities inside the classroom using different states of collision in the ninth (1 and 2) and two activities on separate days in the tenth class (3 and 4).

1. Colliding the pistons of two syringes:
 - a. One student is pushing, and the next remains stationary
 - b. Both students are pushing
 - c. One is pushing gently, and the next is moving backward simultaneously
2. Two objects are placed on the stretched rubber, and the heavier one is suddenly removed
3. Pushing any piston of the hydraulic press model and measuring the displacement of pistons
4. Demonstrating upstroke and downstroke to observe the opening/closing of the suction and piston valve in the water hand pump model



Figure 3. A Representative Activity of Cycle I & II

Note:1. Two volunteers are colliding with pistons of syringes, and the observer is accounting for action and reaction through the displacement of the piston. 2. Students are measuring the transmitted force considering 1 division is equal to 1 unit force. 3. Demonstrating model of a water hand pump.

Workshop II and Cycle II

According to the curriculum, we planned a second cycle of activities for the teachers. After a brief reflection, we discussed and changed the approach to the activities. In Cycle II, teachers acted as facilitators rather than directly conducting and explaining the activities (instructor). Students were allowed to learn collaboratively and through peer leadership. Teachers reported that their Cycle II implementation went well and that students were supportive

and collaborative. Mr. Rimal reported that his students were surprised to use syringes to demonstrate action and reaction forces during collisions and modeling of magnifying force and hand pump, which is in their home for regular use. The remaining teachers also expressed their joy at seeing students actively engaged in learning when allowed to do so themselves, despite the noise from group discussions. During the cross-observation, it was found that some students were teaching and demonstrating to their peers the working mechanism of those instruments as prototypes of the real one. All teachers believed that most students had corrected misconceptions, achieved in-depth concepts using syringes, and were ready to take post-tests. Following Cycle II implementation, a post-test was organized for students. The evaluating questions were linked with the pre-test questions in advanced form.

Statistical Data Analysis

The population for this statistical analysis consists of ninth and tenth-grade students. Out of 156 ninth-grade students, 135 participated in the pre-test, 115 in the post-test, and a total of 109 students participated in both tests. Similarly, out of 132 tenth-grade students, 128 participated in the pre-test, 130 in the post-test, and a total of 127 students participated in both tests. In this study, pre-test and post-test scores were assessed to measure the impact of the intervention. Both tests were conducted within 15 minutes for the ninth and 20 minutes for the tenth to ensure consistency in testing conditions. The post-test was conducted after two weeks. The analysis was carried out at a 99% confidence level, providing a high degree of certainty that the observed changes in scores are statistically significant. Before assessing the effectiveness of the intervention, we conducted a test of assumptions (Appendix I) to identify the appropriate statistical test (Rey & Neuhauser, 2011). The Test of Normality revealed a p-value of .000, indicating that none of the data is normally distributed.

Based on the results of the Test of Normality, it is appropriate to use the Wilcoxon Signed-Rank test rather than the student's t-test (Rey & Neuhauser, 2011; Imam et al., 2014). The Wilcoxon signed-rank test is a non-parametric test that can be used when the data does not follow a normal distribution (Imam et al., 2014). Additionally, the one-tailed hypothesis for the Wilcoxon Signed-rank test is set as:

Table 1. Wilcoxon Signed-rank Test Statistics
Null Hypothesis (H_0): The proposed intervention is not positively effective.

Grade	Assessment concerned to:	Exact Sig. (1-tailed)	Z	No. of students (N)	Effect size: $r = \left \frac{z}{\sqrt{N}} \right $
Nine	Misconception1 (post – pre) test score	.000	-9.077 ^b	109	0.869
	Misconception2 (post – pre) test score	.000	-9.699 ^b	109	0.928
Ten	Pascal's law (Post - Pre) test score	.000	-9.958 ^b	127	0.883
	Hand pump (Post - Pre) test score	.000	-10.057 ^b	127	0.829

b. Based on negative ranks.

*For 99% of confidence interval, if the p-value (Sig.) is less than 0.01, we reject the null hypothesis.

From Table 1, all p-values are 0.000 ($p < 0.01$), indicating significant differences between pre-test and post-test scores for all assessments. Consequently, we rejected the null hypothesis and concluded that our intervention was positively effective. The effect sizes (r) are all very large, ranging from 0.829 to 0.928. According to the standards set by Tomczak and Tomczak (2014) and Bhandari (2020) using Cohen's (1988) criteria, these values are considered large effect sizes, indicating that the interventions had a very strong impact on students' scores in all cases.

Research Findings and Discussion

Upon implementing the curriculum, we gained valuable insights and observed significant changes in modeling-based science education, the importance of mentorship, and participant engagement (e.g., Bradbury et al., 2019; Coghlan, 2022; Dusty, 2024; Tindowen et al., 2019). We shifted to informal communication as suggested by Pant et al. (2023), to address dialogical tension during collaborative work (Chang et al., 2013; Pant et al., 2023). This approach facilitated a smoother implementation of the action plan and curriculum (Chang et al., 2013).

Challenges of Research

Since this research's objectives were complex, one must be aware of the teaching approach, students' learning experience, and use of low-cost materials. Despite enough support, we experienced dialogical tensions even after becoming aware of informal relationships (Pant et al., 2023). Therefore, this research highly advocates communication skills and ease among stakeholders in collaborative research. The difficulty in having regular group discussion sessions due to the busy schedules of teachers (Gelling & Munn-Giddings, 2011; Tindowen et al., 2019) resulted in extending the time and made us go through them patiently, as experienced by Pant et al. (2023) in collaborative work. The inertial notion of their existing teaching practices was so inconvenient that they demanded the prepared model instead of self-preparing. Teachers had to be convinced to move out of their comfort zone for model-making and implement Cycle I and II by highlighting the significance of participating students in learning activities (e.g., Tindowen et al., 2019). Although the modeling instructions were standardized, some teachers needed to reconstruct their models multiple times, while others did not work during their first class. This indicates that having habitual and effective experiences in model-making and model-based science teaching is essential, as noted by Quive et al. (2020).

Some other hindrances included low student participation, diverse student backgrounds, introverted teacher personalities, limited access to ICT tools and applications, and a strong attachment to comfort zones. However, these limitations extend beyond the scope of the research. Despite these limitations and challenges, the research accounted for significant changes and outcomes through the two cycled interventions.

Transforming the Teaching Approach

Teachers initially used to employ a traditional approach, leading to misconceptions, low student engagement, and superficial understanding (Mpho, 2018; Matsuyama et al., 2019). Transforming teachers' perspectives was

challenging, but this research played a pivotal role in this transformation (Coghlan, 2022; Dusty, 2024), aligning with Gravett's (2004) and Peşman et al. (2024) findings on interactive teaching methods. Despite time and resource constraints, teachers successfully implemented the proposed approach by adhering to the action plan and reflecting on their experiences (Bagatrishvili, 2024; Coghlan, 2022). This transformation can be seen as a paradigm shift in the educational context (Wray, 2023) and an answer to the first research question.

Mentoring part of the intervening teachers to integrate situated teachings and learnings—collaborative methods, hands-on activities, and real-life modeling using local materials (Chittleborough & Treagust, 2009; Develaki, 2016)—was essential, particularly in science education (Crawford, 2022; Lozano & Solbes, 2021). This research further signifies Mezirow's (1997) transformative processes and Lewin's model of action research (Adelman, 2006) as a method to cultivate Lave and Wenger's (1991) situated learning. Initially, teachers faced dilemmas between their methods and the intervention, but after the second cycle, they indicated the adoption of student-centric practices using low-cost materials. Teachers instructing their students to use and construct the model show they achieved meta-modeling concepts using syringes, as highlighted by Develaki (2016) and Xue et al. (2024). Further, such capabilities indicate the enhancement of content and pedagogical knowledge and their resemblance among teachers (Blanco-Anaya et al., 2017; Markwick & Reiss, 2023). The significant changes in learning outcomes concerning in-depth scientific methods and knowledge in selected content inspired teachers and us to continue the model-based science teaching approach. Additionally, this research supports the continued use of situated learning-based teaching, emphasizing model-making activities, student engagement, and low-cost resources (e.g., Shah, 2019; Zajda, 2021).

Enhancement of in-Depth Science Learning

The initial pre-test results revealed that only 30.07% of responses were correct, indicating a significant level of misconceptions and low conceptualization of principles and working mechanisms. However, the effectiveness of the transformation was demonstrated by the post-test results (Table 1). In addition to the qualitative improvements, statistical analysis further supports the effectiveness of the intervention and responds to the second research question. The rejection of the null hypothesis suggests that the intervention is an effective approach to teaching with an extreme impact size of 0.829 to 0.928 (e.g., Assi & Cohen, 2023; Bhandari, 2020; Rey & Neuhäuser, 2011). The primary findings of this research revolve around the reconceptualization of Newton's third law of motion, an in-depth understanding of Pascal's application and mechanism of water hand pump by students, and the strengthening of content knowledge (Malik & Zhu, 2022). Their new concepts regarding Newton's third law of motion include *"the force exerted by the truck on the car is equal to the force exerted by the car on the truck"* and *"when a book is placed on a bench, it is indeed experiencing a force"*. The difference in damage is not due to the force but due to the difference in mass of the truck and car. The truck is more massive, so it withstands the impact better than the car, conserving the linear momentum; this reconceptualization can be referenced by Gerjuoy (1949), Haber-Schaim (1981), and Zuccarini and Malgieri (2022).

Similarly, in the case of the rest object, the reaction can be accounted for by an experiment involving two objects of different weights placed on stretched rubber bands. The sudden removal of the heavier object causes the lighter

object to jerk or shoot upwards, demonstrating the reaction force in action (Home, 1968). The multiplication of force in hydraulic presses and the mechanism of water hand pumps are effectively understood and reinforced through real-life applications using syringes. Additionally, these model-based teaching and learning opportunities enhanced cognitive and psychomotor aspects and the practical application of theoretical concepts in both teachers and students (Fakaruddin et al., 2023; Limbu, 2024; Shao et al., 2024). This means they can now transform their theoretical understanding into hands-on activities in the intermediate or upper stage of modeling (Pedrera et al., 2025), where they can demonstrate in-depth science procedural skills and meta-modeling (Xue et al., 2024). Significant collaboration and mutual understanding between students and teachers were the hidden uplifting hands for such impacts (Sormunen et al., 2023; Hofkens and Pianta, 2022). These findings underscore the transformative impact of situated learning in science education.

Validation of Tools

The pedagogical transformation and improved science learning confirm that using low-cost, locally available materials, such as syringes, for experiments can effectively facilitate and enhance science education, even with limited resources (e.g., Bello et al., 2023; Engelschalt et al., 2023; Winkelmann et al., 2025; Tao, 1983; Warren, 1983). Moreover, this research has led to insightful learning outcomes, with a focus on the professional development of teachers and the academic growth of students. Reflecting on experiences following the action cycle and utilizing low-cost resources, as highlighted by Wenderott (2023) and Fakaruddin et al. (2023), have emerged as significant factors in this process. These tools can be effectively used to demonstrate real-life situations and foster creativity and the ability to assemble locally available tools (Čípková et al., 2024; Malik & Zhu, 2022). This approach is a powerful tool for enhancing teaching and learning in education.

Limitations of the Research

While the research improved pedagogical practices and promoted the use of local materials, it did not address the need for social skills mentorship, which is crucial for adopting progressive learning approaches (Hofkens & Pianta, 2022). Additionally, there was limited awareness of using local teaching tools and low student participation in content-specific activities, partly due to minimal administrative support for science projects (Romina et al., 2019). Time constraints also prevented addressing broader issues- identifying diverse local materials, defining administrative roles to provide materials, and encouraging regular co-curricular projects.

Conclusion

*Soulja is an innocent girl
Science is an interest, and she questions for
Soulja perturbs about why this is so
She gets a reply, "This is how I learned so"
Soulja acquires; science is great
She sets her mind to misconceptions even though*

...

Soulja meets the model-based learning viewpoint

She feels odd and falls into the dilemma of being disoriented

Soulja continues to raise multiple critical queries

She develops and sets new perspectives

Soulja is an innocent girl

Science is an interest, and she questions for...

[Theme: Students and participating teachers identified issues in them and got intervened to be transformed.

Now they accommodate the new knowledge in their frame of reference.]

In conclusion, this prolonged engaged mixed-action research method illuminates the transformative impact on teachers' perceptions and practices and students' learning (Wray, 2023). In the qualitative part, challenging entrenched teaching methods and despite hindrances and limitations, teachers adopted the situated learning approach to teaching by introducing low-cost and locally available resources. In the quantitative part, the correct responses from 26.03% at pre-intervention to a high range of effect size post-intervention were further strengthened by statistical tests. Additionally, it underscores the power of local materials in modeling science education and further emphasizes the role of action research in facilitating this transformation. This research effectively addressed situated learning by fixing misconceptions and superficial understandings. It validated the use of syringes as an effective tool to demonstrate action-reaction, magnifying forces with a hydraulic press, and the mechanism of a hand pump.

Recommendation

This research recommends developing continuous professional development programs to equip teachers with the necessary skills to integrate situated learning-based teachings and meta-modeling concepts into their practice. These programs should focus on activity-based and interactive teaching methods and use low-cost, locally available materials (e.g., Bello et al., 2023; Chittleborough & Treagust, 2009; Engelschalt et al., 2023; Gravett, 2004; Wenderott, 2023). A mentorship program should be established to guide teachers in their transformation process, providing support and encouragement for teachers to step out of their comfort zones and experiment with new teaching approaches (e.g., Amineh & Asl, 2015; Schreiber & Valle, 2013; Taylor, 2015). School administrations should support science-based projects, provide resources, facilitate collaborations, and recognize and reward innovative teaching practices (Romina et al., 2019; Shao et al., 2024).

Strategies should be developed to increase student participation in content-specific activities, making the activities more engaging, relevant, and real-life problem-solving to be qualified as the citizen of 21st century (Čipková et al., 2024; Wenderott, 2023; Shah, 2019; Zajda, 2021). Future action research should explore the role of social skills in effective teaching and learning, and training programs could be developed to enhance teachers' social skills, improving student engagement (Crawford, 2022; Hofkens and Pianta, 2022). Additionally, finding other local or low-cost materials like syringes for modeling is highly recommended (Tao, 1983; Warren, 1983).

Future Direction

Future studies could investigate the long-term impact of a transformed teaching approach on students' understanding and application of scientific concepts (Bagatrishvili, 2024; Coghlan, 2022), as exemplified by the works of Gerjuoy (1949), Haber-Schaim (1981), and Home (1968). The use of low-cost, locally available materials, such as those suggested by Wenderott (2023) and this research, could be explored in other areas of science education, making science education more accessible and affordable. Future research could examine the role of social skills in teaching and how improving these skills, as proposed by Hofkens and Pianta (2022), can enhance student engagement and learning outcomes. Further research is needed to understand the role of school administration in facilitating innovative teaching practices and science-based projects, as discussed by Romina et al. (2019), and the impact of regular co-curricular projects on students' understanding and interest in science.

In light of the insights, challenges, and limitations identified in this research within the Nepalese school environment, implementing these recommendations and exploring these future directions are crucial. We believe this will not only enhance the quality of science education but also cultivate a more profound understanding and appreciation of science among students. Thus, it is imperative to address these recommendations and investigate these future directions to further the advancement of science education.

Ethical Considerations

This study adhered to ethical guidelines for educational research involving human participants as outlined by the Tata Institute of Social Sciences (TISS), India. Formal written permission was obtained from the administrations of the five participating schools, and written informed consent was secured from the teachers. For students, assent was obtained along with consent from the school's administration. Participation was voluntary, and participants were assured of their right to withdraw at any time without consequences. Confidentiality and anonymity were maintained by using pseudonyms and securely handling all data. The study was designed to be harmless and to ensure fairness, transparency, and beneficence.

Data Organization

All photographs, handwritten data, informed consent, and ethical approvals are securely stored and can be made available on request.

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