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Integrative Inquiry: A Cross-Pollination Approach to teaching M.Ed Sciences and Mathematics Programmes at Samtse College of Education

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Abstract

This study examined how Integrative Inquiry, a cross-pollination approach within Place-Based Education (PBE) that grounds learning in local and authentic contexts, enhances teaching and learning in the Master of Education (M.Ed) programmes at Samtse College of Education, Royal University of Bhutan. The project engaged M.Ed students specializing in Biology, Chemistry, Physics, and Mathematics in ecological investigations of the Dhamdum Stream, Samtse district. Working in interdisciplinary teams, students designed research proposals, *conducted* field data collection (e.g. macroinvertebrate sampling, physicochemical testing, and stream profiling), and assessed stream ecosystem health using Simpson's Diversity Index and the Hindu Kush-Himalayan Biotic Score (HKHBios). Students' learning outcomes were measured through survey questionnaires covering seven domains: interdisciplinary integration, collaboration and communication, real-world application, scientific inquiry, motivation and engagement, critical thinking, and sense of accomplishment - rated on a 5-point Likert scale. Additional evidence was drawn from facilitator observations and project reports. Quantitative data were analysed in SPSS using descriptive statistics and paired-samples *t* tests, with statistical significance set at $p < .05$. The analyses revealed significant improvements across seven domains: interdisciplinary integration ($M = 3.25, 4.17$; $t(47) = 5.67$, $p < .001$), scientific inquiry and problem solving skills ($M = 3.28, 4.15$; $t(47) = 5.12$, $p < .001$), motivation and engagement ($M = 3.42, 4.27$; $t(47) = 6.23$, $p < .001$), and critical thinking ($M = 3.12, 4.05$; $t(47) = 3.45$, $p < .01$). High levels of collaboration and communication skills (M = 4.32), real-world application (89.6%), and sense of accomplishment (87.5%) were also reported. Overall, the study demonstrates that Integrative Inquiry fosters interdisciplinary approach, problem-solving skills, and professional competencies by embedding learning in authentic contexts, highlighting its potential as a transformative pedagogical model for teacher education programmes.

Keywords: Integrative Inquiry, Interdisciplinary Learning, Real-World Problem-Solving, Scientific inquiry, Place-Based Education, M.Ed Programmes, River Study

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Introduction

The landscape of higher education is undergoing a significant transformation, driven by the complexities of the 21st century. The increasing interconnectedness of global issues, rapid technological advancements, and the growing need for sustainable solutions have created a pressing demand for innovative approaches to learning, teaching and assessment (Grey & Morris, 2024). In response, higher education institutions are shifting focus toward interdisciplinary approaches, critical thinking, problem-solving and collaboration-skills increasingly recognised as essential in navigating modern world challenges (Blessinger & Carfora, 2014). This paradigm shift is particularly relevant in the field of education, where challenges are multifaceted and require interdisciplinary insight. Master of Education (M.Ed) programmes at Samtse College of Education, particularly those designed for in-service teachers, play a vital role in preparing educators, policymakers, and leaders to address complex, context-specific issues. These programmes offer a unique opportunity to directly impact classroom practice, as students are concurrently engaged in professional work and academic study. Tailored to support the continuous professional development of practicing teachers, the in-service M.Ed Sciences and Mathematics programmes aim to bridge theory and practice. However, traditional teaching methodologies often fall short in equipping teachers with the tools needed for responsive and innovative teaching (Archer-Kuhn & MacKinnon, 2020).

In response, *Integrative Inquiry: A Cross-Pollination-Based Interdisciplinary Approach to Teaching M.Ed Sciences and Mathematics Programmes at Samtse College of Education* emerges as a promising framework for module design and delivery. It aligns with Place-Based Education (PBE) principle, which situates learning within local ecological and cultural contexts, fosters ecological literacy, and employs integrative inquiry-based investigations as a central element (Deringer, 2017; Norbu & Chayanuvat, 2020; Attard et al., 2021). At the same time, it draws upon Inquiry-Based Learning (IBL), which emphasises the investigation of authentic, complex questions through critical thinking, collaboration, and problem-solving (Attard et al., 2021). By synthesising the contextual focus of PBE with the investigative practices of IBL, Integrative Inquiry enables interdisciplinary engagement across Biology, Chemistry, Physics, and Mathematics.

The present study illustrates the application of this approach through a river study conducted along the Dhamdum Stream in southwestern Bhutan. By examining the ecological health of the stream, students engaged in interdisciplinary learning, applying knowledge from Biology, Chemistry, Physics, and Mathematics to real-world environmental issues. Grounded within the PBE principles, where inquiry-based investigations serve as a key strategy, students collected and analysed local environmental data, cultivating critical thinking, problem-solving, and collaborative skills, while strengthening their ecological literacy and connection to place (Deringer, 2017; Norbu & Chayanuvat, 2020; Attard et al., 2021).

By exploring the potential of Integrative Inquiry in-service M.Ed Sciences and Mathematics programmes, this study contributes to the wider discourse on innovative pedagogical models in higher education. It offers insights into how such programmes can be designed to prepare teachers more effectively for the complexities of twenty-first-century teaching and learning.

Aim, Objectives and Research Questions

This study aimed to evaluate the effectiveness of *Integrative Inquiry: A Cross-Pollination Approach* in enhancing interdisciplinary and field-based learning within the context of in-service M.Ed Sciences and Mathematics programmes at Samtse College of Education, Royal University of Bhutan.

Specific objectives of the study:

(i) To assess M.Ed students' ability to synthesise and apply concepts from Biology, Chemistry, Physics, and Mathematics in addressing real-world tasks.

(ii) To evaluate students' ability to collaborate effectively and communicate clearly within interdisciplinary teams during classroom activities and field-based tasks.

(iii) To examine students' ability to transfer theoretical knowledge into practical application within authentic field-based contexts.

(iv) To determine the extent to which Integrative Inquiry enhances students' competencies in scientific inquiry, including data collection, analysis, reasoning, and interpretation.

(v) To investigate the impact of Integrative Inquiry on students' motivation, engagement, critical thinking, and sense of accomplishment.

Research questions

Based on the above objectives, the following research questions guide the study:

(i) How effective is Integrative Inquiry in enhancing students' capacity to integrate knowledge across Biology, Chemistry, Physics, and Mathematics?

(ii) In what ways does Integrative Inquiry strengthen students' collaboration and communication skills in team-based problem solving?

(iii) How does Integrative Inquiry enhance students' ability to apply knowledge to real-world problems?

(iv) How does participation in Integrative Inquiry impact scientific inquiry and problem-solving skills?

(v) To what extent does Integrative Inquiry foster motivation, engagement, critical thinking, and a sense of achievement among M.Ed students?

Literature Review

In the evolving landscape of higher education, there is a growing consensus on the necessity for pedagogical innovation that prepares learners for complex, interdisciplinary, and real-world challenges. Traditional models of instruction, often siloed within disciplinary boundaries, are increasingly being questioned for their limited capacity to nurture critical thinking, collaboration, and application of knowledge to authentic contexts (Holley, 2009; Grey & Morris, 2024). In response, scholars and educators have turned towards frameworks such as Integrative Inquiry, IBL, interdisciplinary approach as educational innovation, and experiential pedagogy to foster deeper student engagement and learning outcomes.

Integrative Inquiry: A Cross-Pollination-Based Interdisciplinary Approach

Integrative Inquiry, as explored in this study, offers a cross-pollination-based interdisciplinary approach to teaching M.Ed Sciences and Mathematics programmes at Samtse College of Education, Royal University of Bhutan. At its core, the approach promotes dialogue between disciplines, enabling students to draw connections across Biology, Chemistry, Physics, and Mathematics rather than treating them as isolated domains. Rooted in interdisciplinary integration, critical reflection, and place-based engagement, Integrative Inquiry aligns closely with the goals of in-service teacher education, which seeks to strengthen professional competence while advancing innovative pedagogical practice.

By encouraging students to synthesise disciplinary perspectives and apply them to authentic, context-specific issues, this approach addresses the limitations of traditional compartmentalised methods of instruction. It also reinforces the ecological and cultural relevance of learning by embedding inquiry within the lived experiences and environments of students. Through such engagement, Integrative Inquiry fosters intellectual agility, adaptability, and the capacity to navigate complexity—qualities indispensable in the face of twenty-first century educational challenges. More importantly, it cultivates a mindset of continuous inquiry, critical responsiveness, and collaborative problem-solving, positioning teachers as both learners and change agents within their professional contexts (Holley, 2009; Grey & Morris, 2024).

Inquiry-Based Learning and Critical Thinking

IBL is a foundational pillar of Integrative Inquiry. It positions learners as active participants in their own knowledge construction through questioning, investigating, and problem-solving (Hmelo-Silver et al., 2007). Archer-Kuhn and MacKinnon (2020) characterise it as a "pedagogy of trust," wherein students are empowered to take intellectual risks within a supportive environment. Blessinger and Carfora (2014) further argue that IBL nurtures intellectual curiosity and lifelong learning by engaging students with complex, open-ended questions that demand creative and critical engagement.

Critical thinking, closely intertwined with inquiry, forms the second essential strand of Integrative Inquiry. Abrami et al. (2015), in a comprehensive meta-analysis, demonstrate that

explicit instruction in critical thinking significantly strengthens learners' analytical and evaluative capacities. They emphasise the value of embedding such instruction within content-rich, inquiry-oriented contexts—a principle central to Integrative Inquiry. Brookfield (2012) adds practical strategies to develop learners' ability to question assumptions, analyse perspectives, and engage in reflective judgement. Together, these dimensions highlight the transformative potential of pedagogies that deliberately integrate inquiry and critical thinking, preparing educators to navigate complexity, challenge orthodoxy, and foster reflective professional practice.

Interdisciplinary Learning

A defining feature of Integrative Inquiry is its emphasis on interdisciplinary learning. It draws on the understanding that contemporary issues cannot be adequately addressed within disciplinary silos. Interdisciplinary learning integrates knowledge and methodologies from various fields, encouraging students to explore complex problems holistically (Borrego & Newswander, 2010; Newell, 1990). Within the M.Ed Science and Mathematics programmes, this approach is particularly relevant, as students often come from Biology, Chemistry, Physics, and Mathematics specialisations and engage collaboratively on educational challenges.

Holley (2009) argues that interdisciplinary strategies in higher education act as transformative agents, enabling students to construct integrated understandings of knowledge. Grey and Morris (2024) similarly advocate for interdisciplinary and sustainable pedagogies as necessary to address complex societal and ecological challenges. These frameworks are central to the design and delivery of modules in Integrative Inquiry, promoting reflective practice and systemic thinking among in-service educators.

Collaboration and Communication in Learning

The collaborative nature of Integrative Inquiry facilitates peer-to-peer learning and knowledge co-construction. As demonstrated by Brindley et al. (2009), effective group learning relies on structured collaboration, mutual accountability, and shared purpose. These elements are cultivated in the Integrative Inquiry framework, particularly during interdisciplinary fieldwork projects where teams must negotiate diverse disciplinary perspectives.

Attard et al. (2021) demonstrate that IBL enhances engagement in STEM education by promoting real-world relevance and teamwork. These aspects are mirrored in Samtse College of Education's Integrative Inquiry initiative as cross-pollination approach – a new educational innovation to teaching M.Ed programmes, where collaboration and team work not only enhance learning outcomes but also builds communication competencies critical for professional teachers.

Scientific Inquiry and Problem-Solving Skills

River and stream investigations provide authentic contexts for enhancing students' Scientific Inquiry and problem-solving skills while simultaneously assessing stream health. Through inquiry-based approaches, learners engage in questioning, hypothesis formation, data

collection, and interpretation using both physicochemical indicators (e.g., dissolved oxygen, turbidity, pH) and biological measures such as macroinvertebrate diversity, particularly the Ephemeroptera-Plecoptera-Trichoptera (EPT) index, which serves as a reliable proxy for water quality (U.S. Environmental Protection Agency [EPA], 1999). Studies highlight that PBE using local rivers fosters environmental literacy, systems thinking, and evidence-based reasoning, as students connect scientific methods to real-world ecological issues (Lin & Huang, 2024). Moreover, citizen-science programmes such as stream monitoring initiatives demonstrate that community participation not only yields credible water-quality data but also strengthens inquiry skills, collaborative problem-solving, and stewardship behaviours (McFadden et al., 2023). Systematic reviews further affirm that inquiry-based science education (IBSE) enhances motivation, scientific understanding, and critical thinking when structured around authentic fieldwork such as river studies (Tsai et al., 2023). Collectively, the literature indicates that river-based studies are powerful pedagogical tools that integrate rigorous environmental assessment with the development of essential 21st century competencies.

Place-Based Education and Experiential Learning

Integrative Inquiry is closely aligned with PBE and experiential learning, both of which provide essential grounding for authentic and meaningful inquiry. PBE encourages learners to connect academic knowledge with local contexts, fostering a sense of place and community (Deringer, 2017). Norbu and Chayanuvat (2020) provide evidence from Bhutanese classrooms showing that place-based inquiry enhances environmental understanding, engagement and a sense of accomplishment.

Eyler (2009) and Kuh (2008) emphasise the value of experiential learning in fostering civic engagement, personal growth, and real-world application. In the M.Ed context at Samtse College of Education, students engage with local ecological systems. For example, the river study, where they apply scientific concepts and interdisciplinary methods to contemporary environmental issues, embodying the principles of experiential and place-based learning.

Motivation, Engagement, and Professional Identity

Integral to the success of Integrative Inquiry is its impact on motivation, engagement and identity development. Deci and Ryan's (2000) self-determination theory underlines the importance of autonomy, competence, and relatedness-all of which are supported through Integrative Inquiry's collaborative, inquiry-driven model. The relevance and authenticity of tasks increase learner motivation, while the interdisciplinary and place-based nature of the projects fosters a deep sense of engagement and professional identity.

Loughran (2006) and Mezirow (2000) stress that reflective practice and transformative learning are central to developing teachers' professional identity. Integrative Inquiry offers in-service M.Ed students opportunities to reflect critically on their teaching, explore multiple

perspectives, and refine their professional purpose. In doing so, it cultivates educators who are both contextually grounded and pedagogically innovative.

Methodology

Study Context and Educational Framework

This study was conducted as part of an in-service M.Ed programme at Samtse College of Education, which implemented an Integrative Inquiry approach to promote interdisciplinary learning, collaboration, and real-world problem-solving across Biology, Chemistry, Physics, and Mathematics specialisations. The river study along the Dhamdum Stream served as the primary field-based, place-based learning activity where students applied disciplinary knowledge to examine ecological health and environmental challenges. This approach aligns with the principles of PBE and IBL, fostering scientific inquiry, critical thinking, and collaboration through authentic investigation.

Study Design

This study employed a mixed-methods, interdisciplinary, field-based design to evaluate the effectiveness of *Integrative Inquiry: A Cross-Pollination Approach* in enhancing collaborative and real-world learning among in-service M.Ed students. The approach was grounded within the principles of PBE and IBL**,** focusing on authentic environmental problem-solving through a river study conducted along sections of Dhamdum Stream, southwestern Bhutan. Quantitative measures (paired samples *t*-tests, descriptive statistics, and frequency distributions) were used to assess learning outcomes, while qualitative observations supported insights into collaboration, engagement, and application of interdisciplinary knowledge.

Participants and Group Composition

Participants were in-service M.Ed students enrolled in subject-specific modules on contemporary scientific issues. Using purposive sampling, students were organised into six to eight mixed-interdisciplinary groups, each comprising 7-8 students representing Biology, Chemistry, Physics, and Mathematics. The groups collaboratively designed research proposals, conducted fieldwork, and prepared integrative scientific reports as part of the river study project.

Collaborative Planning and Role Allocation

The initial phase of the project involved collaborative planning, during which each interdisciplinary group developed a robust research proposal that integrated disciplinary perspectives and methodologies. This planning stage enabled students to identify a common field-based research focus, design field data collection strategies, and establish individual subject contributions toward a shared investigative goal. The proposal development process not only reinforced interdisciplinary dialogue but also laid the foundation for structured, student-led inquiry in authentic field conditions.

Within each group, leadership roles were assigned based on disciplinary expertise to ensure effective task execution. For instance, Biology representatives led the identification and evaluation of sampling sites along stream or river sections, facilitated macroinvertebrate collection, and oversaw field sorting, specimen preservation, and laboratory identification techniques. Like-wise, Chemistry representatives were responsible for the collection and analysis of key physicochemical parameters of water quality, ensuring methodological precision and data reliability. Similarly, Physics students managed the quantification of stream characteristics, including depth, width, velocity, and elevation, as well as the deployment and calibration of field instruments. Mathematics students directed data processing, statistical analysis, and the synthesis and visualisation of findings, thereby supporting the integration of disciplinary outputs into a cohesive interpretation.

This organisational structure fostered collaborative inquiry, distributed leadership, and authentic engagement with complex environmental phenomena. It also enabled students to apply subject-specific knowledge in a real-world context while contributing to a shared interdisciplinary research agenda.

Study Area

The study was conducted along the sections of Dhamdum Stream (26.8935° N, 89.0968° E) located approximately two kilometres from the Samtse Dzongkhag headquarter in southwestern Bhutan. The site was purposively selected due to its ecological significance and accessibility of freshwater resources, providing a suitable setting for interdisciplinary, field-based investigations. As a stream impacted by various anthropogenic activities and landscape changes due to ongoing development of industrial parks and extraction of boulders for export to third countries, Dhamdum Stream offered valuable opportunities to examine the status of water quality, assess biodiversity, and evaluate aquatic ecosystem health within a dynamic of real-world context.

This location was chosen particularly because of observable environmental pressures linked to human-induced activities. The stream banks were increasingly influenced by the ongoing establishment of industrial infrastructure nearby, presenting a distinct context to investigate the interaction between development and ecological integrity. Additionally, the stream experienced sediment deposition from upstream land erosion induced by monsoon rains and physical disturbances caused by boulder extraction from the riverbed. These cumulative impacts made the site especially relevant for exploring environmental degradation, sustainability, and the complex relationships between natural and human systems through an interdisciplinary approach.

From the learners' perspective, engaging with the site enabled them to directly observe and critically analyse the consequences of human-induced activities on freshwater ecosystems. Students developed a deeper understanding of ecological processes and environmental challenges, fostering skills in scientific inquiry, data collection, and interdisciplinary problem-solving.

Sampling Sites

Two sampling sites (upstream and downstream) in different sections of the Dhamdum stream were selected for macroinvertebrate sampling. The upstream site (Site 1) (26.8950° N, 89.0950° E) served as the reference site (Figure 1), and the downstream site (Site 2) (26.8920° N, 89.0985° E) as the disturbed site (Figure 2), to examine the degree of growing impacts on the water quality and stream ecosystem. The reference site was chosen for its minimal human disturbance, whereas the downstream site showed evidence of growing anthropogenic activities in the vicinity of the sampling area, including industrial sites development and operations, human settlements, and boulder extraction practices.

Figure 1

Upstream site 1 (Reference site)

Figure 2

Downstream site 2 (Disturbed site)

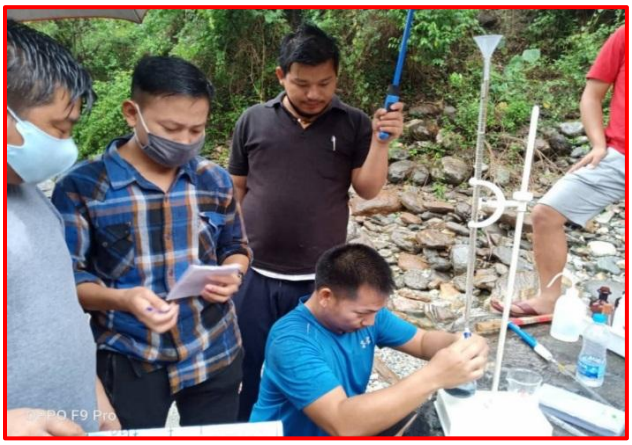
Sampling Techniques

At each sampling site, three samples were collected from three different positions along a 50-metre stretch of the stream using a Surber sampler. Separate containers were used to store macroinvertebrates from each position. Each container was labelled with the stream name, site name and code, date of sampling, investigator's name, and the corresponding sample unit number.

In addition, physicochemical parameters were measured on site. These included stream depth and width (Figure 3), velocity, pH, air and water temperature, electrical conductivity, hardness, and dissolved oxygen. Measurements were taken using water quality testing kits and multi-parameter meters (Figure 4).

Figure 3
Sample site measurement

Figure 4
Field-based physicochemical experiment



Field Sorting and Preservation

The samples collected were transferred into a white tray filled with river water to a depth of a few centimeters and debris were sorted out (Figure 5). All macroinvertebrates were picked with the forceps using hand lenses without damage. The samples collected were preserved in 70% ethanol (Figure 6) prior to counting and identification in the laboratory.

Figure 5
Field sorting

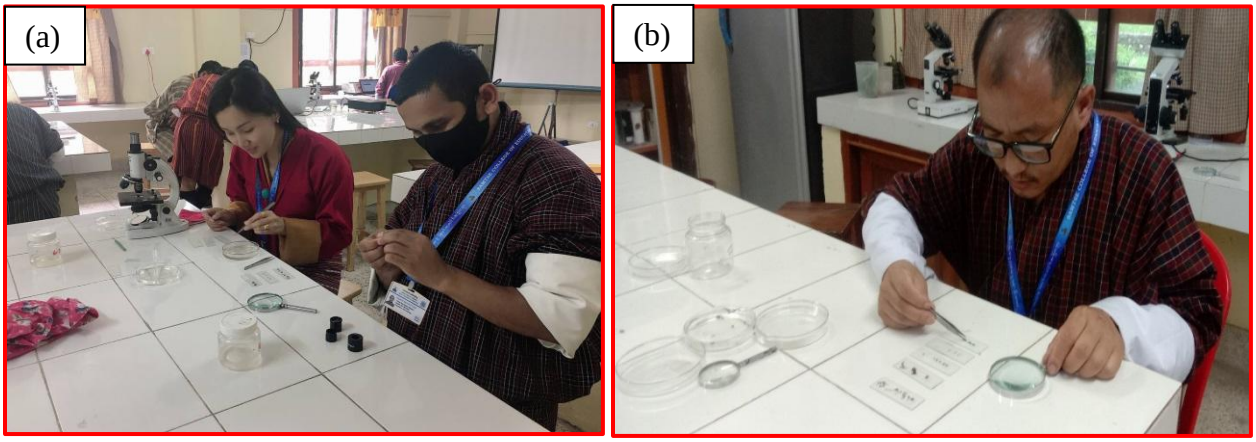
Figure 6
Field samples preservation

Laboratory Sorting and Identification

In the laboratory benthic macroinvertebrates were identified to family level (Figure 7a & b). A binocular compound microscope and HKH macroinvertebrate identification manuals (Nesemann *et al.*, 2011) were used during identification of organisms.

Figure 7a & b

Lab sorting and identification of samples



Students' Data Analysis

Abundance (number of individuals belonging to the same family), taxa richness (number of families found in sample) and Simpsons' diversity index was used to measure family biodiversity using the formula below:

Simpsons' diversity index was calculated using the formula:

$$D = 1 - \frac{\sum n(n-1)}{N(N-1)}$$

n = the total individuals of a particular species
N = the total individuals of all species

Additionally, the Hindu Kush-Himalayan Biotic scores (HKHBios) was used to determine the current status of water quality and stream health by indicating the types of organisms present in it.

Survey Tools Used to Evaluate Students' Learning Outcomes

The study employed tools aligned with the specific objectives and research sub-questions, using 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) survey questionnaires to capture participants' perceptions and self-reported competencies. The survey questionnaires were structured around seven thematic areas (domains) corresponding to the intended learning outcomes of the Integrative Inquiry project:

(i) ***Interdisciplinary Integration****:* Measured through a structured questionnaire using a 5-point Likert scale, assessing students' ability to synthesise concepts and methods from Biology, Chemistry, Physics, and Mathematics in addressing the river study tasks.

(ii) ***Collaboration and Communication Skills****:* Evaluated using a 5-point Likert scale survey alongside facilitator observations. The tool comprised two subscales: Collaboration (4 items) and Communication (4 items). Items evaluated students' ability to work effectively in interdisciplinary teams, share knowledge, negotiate ideas, communicate findings clearly, and carry out scientific inquiry tasks collaboratively, including data collection, analysis, and laboratory procedures.

(iii) ***Real-World Application of Knowledge****:* Assessed via a 5-point Likert scale survey that measured students' perceptions of their ability to apply theoretical knowledge to authentic, field-based environmental problems during the river study.

(iv) ***Scientific Inquiry and Problem-Solving Skills****:* Measured using a 5-point Likert scale questionnaire and assessment of project report to capture students' self-reported competencies in data collection, analysis, evidence-based reasoning, and interpretation of stream health.

(v) ***Motivation and Engagement****:* Evaluated through a 5-point Likert scale survey addressing students' enthusiasm, persistence, and active involvement in interdisciplinary field investigations.

(vi) ***Critical Thinking****:* Measured with a 5-point Likert scale questionnaire, capturing students' perceptions of their analytical reasoning, evaluation of evidence, and ability to draw informed conclusions from interdisciplinary data.

(vii) ***Sense of Accomplishment****:* Assessed via a 5-point Likert scale survey, which captured participants' self-reported satisfaction and perceived achievement after completing the Integrative Inquiry river study.

Data Analysis

Quantitative data were analysed using SPSS, including paired samples *t*-tests to evaluate pre-and post-intervention differences in understanding interdisciplinary integration, real-world application of skills, scientific inquiry and problem-solving skills, motivation and engagement, and critical thinking. Descriptive statistics (mean, standard deviation) and frequency distributions were used for measuring collaboration and communication skills, real-world application and sense of accomplishment. A significance level of $p < 0.05$ was applied for all inferential tests.

Results and Discussion

The findings of this study demonstrate the effectiveness of Integrative Inquiry in promoting student learning outcomes in M.Ed programmes. The areas of assessment included:

(i) Interdisciplinary Integration

A paired samples *t*-test was conducted to evaluate the impact of the Integrative Inquiry approach on students' understanding of interdisciplinary integration before and after the project. Data revealed a statistically significant improvement in students' understanding, with the mean value increasing from 3.25 before the project to 4.17 after the project, $t(47) = 5.67$, $p < 0.001$ (Table 1). The mean difference of 0.92 indicates a substantial gain in students' ability to integrate knowledge across disciplines such as Biology, Chemistry, Physics, and Mathematics. These findings suggest that the Integrative Inquiry approach effectively enhanced students' interdisciplinary thinking within the context of a real-world environmental study.

Table 1

Paired Samples t-test Results for Understanding of Interdisciplinary Integration

Variable	N	Mean	SD	*t*	*df*	*p-value*	*Mean Difference*
Pre-Project Understanding	48	3.25	0.85	5.67	47	< 0.001	0.92
Post-Project Understanding	48	4.17	0.67				

The significant improvement in students' understanding of interdisciplinary integration following the Integrative Inquiry approach underscores the effectiveness of real-world, cross-disciplinary learning experiences. Engaging with environmental challenges through collaborative, integrated tasks helped students connect concepts across Biology, Chemistry, Physics, and Mathematics-a finding consistent with Newell's (1990) emphasis on how interdisciplinary courses promote holistic thinking and creative problem-solving. Holley (2009) further argues that true interdisciplinary strategies, involving boundary-crossing collaboration, can transform higher education by reshaping both institutional culture and student learning. Combining these approaches with PBE, which situates learning in local contexts and encourages ecological literacy, enhances students' abilities to investigate and respond to real-world problems (Norbu & Chayanuvat, 2020). This aligns with your findings and reinforces the value of Integrative Inquiry in preparing educators for interdisciplinary and place-rooted pedagogies.

(ii) Collaboration and Communication Skills

The descriptive statistics (Table 2) indicate a clear improvement in students' collaboration and communication skills following the Integrative Inquiry project, with the overall mean increasing from 3.45 ($SD = 0.75$) pre-project to 4.32 ($SD = 0.59$) post-project. This improvement across all eight items, along with a reduced post-project standard deviation, suggests more consistent performance and enhanced interpersonal competencies among students.

Table 2

Descriptive Statistics for Individual and Overall Composite Mean of Collaboration and Communication Skills (n = 48)

Item Code	Item Statement	Pre-Mean	Pre-SD	Post-Mean	Post-SD
C1	I actively contribute ideas when working in a group.	3.4	0.8	4.35	0.6
C2	I respect and consider the opinions of all group members.	3.5	0.7	4.4	0.55
C3	I work towards common goals rather than personal recognition.	3.42	0.75	4.3	0.58
C4	I take responsibility for my assigned tasks in a team project.	3.48	0.78	4.38	0.57
M1	I express my ideas clearly and confidently.	3.44	0.74	4.31	0.59
M2	I actively listen to others without interrupting.	3.46	0.76	4.33	0.6
M3	I adjust my communication style depending on the audience.	3.43	0.73	4.28	0.58
M4	I give and receive constructive feedback effectively.	3.49	0.77	4.34	0.56
	Overall Mean	**3.45**	**0.75**	**4.32**	**0.59**

Improvements were observed across all eight individual items, reflecting growth in specific behaviours such as contributing ideas, listening actively, negotiating roles, and providing constructive feedback (Table 2). These findings align with other research that states project-based, and inquiry-driven learning promotes collaboration and communication skills by requiring students to negotiate roles, co-construct knowledge, and engage in joint problem-solving (Brindley et al., 2009). Specifically, interdisciplinary group work has been shown to foster these competencies by exposing students to diverse perspectives and requiring them to communicate effectively across specialisations (Shih & Pan, 2023). Furthermore, when students from diverse disciplinary backgrounds work together on complex, real-world problems, they are required not only to share knowledge but also to listen, negotiate, and co-construct understanding—a process that strengthens interpersonal and collaborative skills (Borrego & Newswander, 2010).

The context of the Integrative Inquiry project, which involved joint planning (e.g., collaborative research proposals), fieldwork, and interpretation of gathered data, naturally promoted such engagement. Moreover, the structure of interdisciplinary group work reflects Vygotsky's (1978) sociocultural theory, wherein learning is mediated through social interaction and dialogue. Overall, these findings reinforce the pedagogical value of integrating purposeful collaborative and inquiry-based tasks into in-service M.Ed programmes to strengthen essential 21st century skills, particularly communication and teamwork, in authentic, interdisciplinary learning contexts.

(iii) Real-World Application of Knowledge

The frequency distribution for the real-world application of knowledge indicates a strongly positive perception among participating M.Ed students regarding the relevance and transferability of disciplinary knowledge to authentic environmental contexts. Specifically, 66.7% of respondents (frequency = 32, n = 48) strongly agreed and a further 22.9% (frequency = 11) agreed that the Integrative Inquiry project enabled them to apply theoretical concepts to real-world problems. Only 10.4% (frequency = 5) reported a neutral stance, with no students expressing disagreement (Table 3).

This favourable response suggests that the field-based interdisciplinary investigation, situated in a real ecological setting, provided students with meaningful opportunities to apply academic learning directly in practice. Such alignment between theory and practice reflects the aims of PBE, which advocates for learning embedded in local contexts to enhance ecological literacy and civic responsibility (Deringer, 2017; Norbu & Chayanuvat, 2020). Moreover, the integrative design of the activity, which required students to analyse water quality, biodiversity and ecosystem health using domain-specific skills, embodies the core principles of IBL, which centres on active investigation and the construction of knowledge through authentic tasks (Attard et al., 2021). The absence of any negative responses further highlights the pedagogical strength of the Integrative Inquiry approach in fostering applied learning outcomes within tertiary level teacher education programmes.

Table 3

Frequency Distribution for Real-World Application of Skills

Likert scale categories	N	Frequency	Percentage
Strongly Agree	48	32	66.7
Agree	48	11	22.9
Neutral	48	5	10.4
Disagree	48	-	-
Strongly Disagree	48	-	-

(iv) Scientific Inquiry and Problem-Solving Skills

The paired samples *t*-test indicates a statistically significant improvement in students' scientific inquiry and problem-solving skills following participation in the Integrative Inquiry project. The mean score increased from 3.28 (SD = 0.81) pre-project to 4.15 (SD = 0.64) post-project, $t(47) = 5.12$, $p < 0.001$, with a mean difference of 0.87 (Table 4). This suggests that the field-based interdisciplinary investigation effectively enhanced students' ability to collect, analyse, and interpret data, as well as apply evidence-based reasoning to real-world environmental challenges.

Table 4

Paired Samples t-test Results for Scientific Inquiry and Problem-Solving Skills

Variable	N	Mean	SD	*t*	*df*	*p-value*	*Mean Difference*
Pre-Project Scientific Inquiry & Problem-Solving	48	3.28	0.81	5.12	47	<0.001	0.87
Post-Project Scientific Inquiry & Problem-Solving	48	4.15	0.64				

The statistically significant improvement in students' scientific inquiry and problem-solving skills post-project underscores the efficacy of the Integrative Inquiry approach in fostering higher-order cognitive abilities. This finding aligns with recent meta-analytic research indicating that inquiry-based science teaching significantly enhances scientific inquiry and problem-solving skills across various educational levels (Soomro et al., 2023). The development of these skills is further supported by the constructivist learning environments promoted by inquiry-based science teaching, where students actively engage in formulating research questions, hypothesis, conducting investigations, and interpreting data. Such environments facilitate the transition from rote memorization to analytical reasoning, which is essential for scientific literacy (Antonio & Prudente, 2024).

Moreover, the interdisciplinary nature of the Integrative Inquiry approach mirrors the growing emphasis on interdisciplinary science education. Recent discussions highlight the necessity of breaking down academic silos to address complex global challenges, suggesting that interdisciplinary research is crucial for significant scientific breakthroughs (Baty, 2023).

In summary, the observed enhancement in students' scientific inquiry and problem-solving skills supports the integration of inquiry-based, interdisciplinary pedagogies in science education. These approaches not only improve cognitive skills but also prepare students to tackle real-world scientific challenges effectively.

(v) Motivation and Engagement

The analysis of the paired samples *t*-test revealed a statistically significant enhancement in students' motivation and engagement following their participation in the Integrative Inquiry project. As presented in Table 5, the mean score increased from 3.42 (*SD* = 0.78) pre-project to 4.27 (*SD* = 0.59) post-project. The paired samples *t*-test yielded a *t*-value of 6.23**,** with 47 degrees of freedom and a *p*-value <.001**,** indicating a highly significant difference. The mean difference of 0.85 reflects a meaningful shift in how students perceived their own involvement and enthusiasm during the learning process.

Table 5

Paired Samples t-test Results for Motivation and Engagement

Variable	N	Mean	SD	*t*	*df*	*p-value*	*Mean Difference*
Pre-Project Motivation & Engagement	48	3.42	0.78	6.23	47	<0.001	0.85
Post-Project Motivation & Engagement	48	4.27	0.59				

This finding affirms the capacity of integrative, inquiry-driven pedagogies to stimulate learners' motivation by situating academic inquiry within authentic, contextually rich experiences. Motivation and engagement, particularly in adult and professional learners such as in-service M.Ed students, are significantly influenced by the relevance of learning tasks, the degree of autonomy provided, and the opportunities for collaborative exploration (Deci & Ryan, 2000). The river study at the Dhamdum Stream offered a learning environment grounded in the students' lived context, requiring them to investigate ecological health using disciplinary tools in Biology, Chemistry, Physics, and Mathematics. This approach resonates strongly with the principles of PBE, which has been shown to enhance both emotional and cognitive investment by linking learning to community and environmental issues (Deringer, 2017).

Moreover, the inquiry-driven structure of the project supported key elements of self-determined learning autonomy, competence, and relatedness, thereby reinforcing the motivational foundations proposed in self-determination theory (Ryan & Deci, 2000). Students were not passive recipients of knowledge; instead, they were positioned as investigators and collaborators, actively constructing understanding through real-world engagement. Such experiences not only deepen content mastery but also foster a sense of purpose and personal connection to learning-critical outcomes in teacher education, where internalised motivation often translates into sustained professional commitment and innovation (Hmelo-Silver et al., 2007). The substantial improvement in motivation and engagement observed in this study underscores the pedagogical potential of Integrative Inquiry as a transformative model for in-service teacher education programmes.

(vi) Critical Thinking

The findings from the paired samples *t*-test indicate a statistically significant improvement in students' critical thinking abilities as a result of their participation in the Integrative Inquiry project. As shown in Table 6, the mean score increased from 3.12 (*SD* = 0.85) before the intervention to 4.05 (*SD* = 0.67) afterwards. The *t*-test yielded a *t*-value of 3.45 (*df* = 47), and the p-value < .01 confirms that the improvement is statistically significant. The mean difference of 0.65 indicates a moderate, yet meaningful, gain in students' ability to reason analytically, evaluate evidence, and draw informed conclusions from data.

Table 6

Paired Samples t-test Results for Critical Thinking

Variable	N	**Mean**	**SD**	***t***	***df***	***p-value***	***Mean Difference***
Pre-Project Critical Thinking	48	3.12	0.85	3.45	47	<0.01	0.65
Post-Project Critical Thinking	48	4.05	0.67				

This improvement is consistent with a growing body of literature emphasising the efficacy of inquiry-based and experiential pedagogies in cultivating critical thinking, especially in higher education and teacher preparation contexts (Abrami et al., 2015). The design of the Integrative Inquiry project, which requires students to investigate water quality, analyse biodiversity indices, and interpret ecosystem health using data from real-world settings, provided sustained opportunities for engaging in higher-order thinking. Through field observations, data analysis, and interdisciplinary dialogue, students were not only acquiring knowledge but also evaluating its relevance and synthesising insights across disciplinary boundaries. Such experiences are central to the development of critical thinking, as they involve navigating ambiguity, challenging assumptions, and constructing evidence-based arguments (Brookfield, 2012).

Furthermore, the findings align with the theoretical underpinnings of IBL, which positions students as active investigators in the learning process. IBL environments inherently require learners to formulate questions, design investigations, interpret results, and critically reflect on their conclusions, all of which are essential components of critical thinking (Hmelo-Silver et al., 2007). When embedded within PBE, as in this study, such inquiry is grounded in local contexts, making the questions more meaningful and the reasoning more relevant (Deringer, 2017). Importantly, these outcomes demonstrate that Integrative Inquiry not only enhances content mastery but also develops cognitive dispositions necessary for reflective and responsible educational practice - skills that are particularly vital for in-service M.Ed students preparing to become educational leaders and change agents.

(vii) Sense of Accomplishment

The survey data analysis of frequency distribution presented in Table 7 suggests that students in the Integrative Inquiry project significantly contributed to students' sense of accomplishment. A total of 58.3% (frequency = 28, n = 48) of the students strongly agreed**,** and 29.2% (frequency = 14, n = 48) agreed that the experience gave them a meaningful sense of achievement. Only 12.5% (frequency = 6, n = 48) responded neutrally, and notably, there were no negative responses**.** This affirmative trend of students' responses confirms that the integrative inquiry-based approach, interdisciplinary concepts, and contextually grounded nature of the project provided not only cognitive gains but also affective satisfaction.

Table 7

Frequency Distribution for Sense of Accomplishment

Likert scale categories	N	Frequency	Percentage
Strongly Agree	48	28	58.3
Agree	48	14	29.2
Neutral	48	6	12.5
Disagree	48	-	-
Strongly Disagree	48	-	-

Such positive outcomes are essential in at the tertiary level education, where professional relevance and personal fulfilment are critical motivators for learning (Loughran, 2006; Mezirow, 2000). The structure of the Integrative Inquiry project that anchored in the ecological exploration of the Dhamdum Stream allowed students to witness the tangible outcomes of their collaborative efforts, reinforcing their sense of agency and purpose. When learners see their knowledge applied meaningfully in real-world contexts, a sense of accomplishment often follows, which in turn strengthens professional identity and intrinsic motivation (Eyler, 2009; Kuh, 2008).

This outcome also affirms the broader value of experiential and PBE frameworks. By embedding learning in authentic, community-oriented contexts, such approaches foster both academic engagement and personal investment. For in-service student-teachers, this dual impact-cognitive challenge coupled with emotional reward has the potential to reinforce commitment to lifelong learning and innovation in classroom practice. As such, the sense of accomplishment reported by students is not a peripheral outcome, but rather a central indicator of the pedagogical success of the Integrative Inquiry model.

Conclusion and Significance

This study demonstrated the pedagogical efficacy of Integrative Inquiry: A Cross-Pollination Approach in teaching M.Ed programmes, fostering interdisciplinary collaboration, critical thinking, and professional competence among in-service teacher educators. Situated within the ecological context of Dhamdum Stream, students applied knowledge from Biology, Chemistry, Physics, and Mathematics in a field-based investigation, enhancing both cognitive and professional development. Quantitative results showed significant gains in understanding interdisciplinary integration, motivation, critical thinking, and collaboration, while assessments of scientific inquiry and problem-solving highlighted improvements in designing investigations, analysing data, and constructing evidence-based solutions.

The study highlights the value of place-based, inquiry-driven pedagogy in bridging theory and practice in postgraduate education. By immersing learners in authentic, real-world challenges, Integrative Inquiry promotes deeper engagement, reflective thinking, and an embodied understanding of sustainability and ecological responsibility. Future applications across other subject areas could benefit from longitudinal tracking of learning outcomes and integration of local

community knowledge, enhancing the contextual relevance and long-term impact of teacher education in Bhutan.

Significantly, this research contributes to Bhutan's educational goals by aligning teacher preparation with the principles of Education for Gross National Happiness and the global agenda for Education for Sustainable Development. It offers valuable insights for educators, policymakers, and researchers seeking scalable, contextually relevant, and transformative pedagogical models for professional learning.

Recommendations

Building on the findings of this study, several recommendations are proposed to strengthen the application of Integrative Inquiry as a pedagogical innovation in teacher education:

1. **Institutional Adoption:** Teacher education programmes under the Royal University of Bhutan should consider formally integrating Integrative Inquiry into postgraduate curricula, particularly within science and environmental education modules, to promote interdisciplinary collaboration and real-world problem solving.
2. **Capacity Building:** Faculty development workshops are needed to equip teacher educators with the skills to design and facilitate inquiry-based, cross-disciplinary learning experiences, ensuring consistency and effectiveness in implementation.
3. **Curriculum Innovation:** The approach should be adapted for other subject areas beyond the sciences, thereby fostering interdisciplinary integration across the wider spectrum of teacher education.
4. **Community Engagement:** Future initiatives should incorporate local community knowledge systems and traditional ecological practices, enriching place-based education and strengthening cultural relevance.
5. **Longitudinal Research:** Further studies should employ longitudinal tracking of learning outcomes to evaluate the sustained impact of Integrative Inquiry on teacher competence, professional growth, and student outcomes in schools.
6. **Policy Alignment:** Policymakers and curriculum developers may use this model to align teacher education more closely with Bhutan's national priorities for Education for Gross National Happiness and global Education for Sustainable Development goals.
7. **School Implementation:** Schools should integrate inquiry-driven, interdisciplinary learning projects that connect classroom lessons with real-world contexts, fostering critical thinking, collaboration, and practical problem-solving skills among students.

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