

Levels of Reflective Thinking Among Student Teachers: A Descriptive Study

Gagandeep Kaur¹ and Manpreet Kour^{*}

¹Guru Nanak Dev University, Amritsar, Punjab, India.

^{*}manpreet15021995@gmail.com (Corresponding Author)

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ABSTRACT

Background: It is well known that reflective thinking is a major aspect of efficient teaching and career development. Reflective capacity as developed in the pre-service phase plays an important role in equipping student teachers to respond to issues in the classroom.

Purpose: The objective of the current study was to analyze the levels of reflective thinking among student teachers with respect to the specific variables, including gender, locale, academic stream, and academic achievement.

Methodology: The research design was a descriptive survey design. The random sampling method was used to sample 360 student teachers in the teacher education institutions of Amritsar district in Punjab. A self-developed reflective thinking scale was used with four dimensions, viz., ability to self-assess, awareness of own teaching skills, developing lifelong learning skills, and belief about self and self-efficacy, to gather data. Percentage analysis and chi-square tests were used to examine the distribution and association of reflective thinking levels across demographic variables.

Findings: The results indicated that most of the student teachers had a moderate level of reflective thinking, with only a relative few having high or low levels of reflective thinking. The findings show that the student teachers have reflective thinking, which needs to be systematically reinforced by the teacher education programs.

Conclusions: The study concludes that reflective thinking in student teachers is still in its developing stage; there is a need to make deliberate and organized pedagogical interventions in teacher education programs. This research also notes the importance of incorporating reflective practices like reflective journaling, reflective mentoring, and guided self-reflection into pre-service teacher training to promote professional readiness.



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1. Introduction

Higher-order thinking skills such as problem-solving, critical thinking, creative thinking, learning to learn, and reflective thinking have become essential competencies in today's world. In the rapidly changing educational environment of the 21st century, teachers and educational professionals are increasingly required to develop reflective thinking for effective performance and professional growth. Dewey (1933) defined reflective thinking as a deliberate, active, and persistent way of thinking. Schön (1983) described that reflection can be through "reflection-for-action," "reflection-in-action," and "reflection-on-action." These views highlight the significance of reflective thinking for professional practice and continuous learning in

teacher education. Contemporary educational settings demand that teachers be equipped with not only subject knowledge and pedagogical competence but also critical reflection on their teaching practices, students' learning experiences, and the classroom contexts. Reflective thinking enables teachers to evaluate their beliefs, instructional decisions, and classroom experiences, thus improving professional practice and strengthening the relationship between theory and practice. The development of reflective thinking is crucial, particularly at the pre-service stage when student teachers are still developing their professional identity and teaching competence. Rodgers (2002) says reflective teachers improve student evaluation, revise instructional techniques and strategies, develop independent conclusions, and remain open to self-

improvement. Hence, there is a need for systematic pedagogical practices to promote reflective thinking of student teachers.

Reflective thinking is considered to be a central aspect of teacher education and is based on Dewey's concept of reflection as an active and deliberate cognitive process. Reflection is also emphasized as a process of transforming experience into meaningful learning and professional knowledge in Schön's (1983) reflective practice framework and Kolb's (1984) experiential learning theory. Reflective thinking has been defined in recent literature as the process of moving from descriptive reflection to critical reflection that significantly contributes to the professional competence, effectiveness in class, and problem-solving ability of student teachers (Wahyuni & Putra, 2021; Indrašienė *et al.*, 2023; Voulgari & Koutroumpa, 2026). The present study is theoretically grounded in Dewey's theory of reflective thought (1933), Schön's framework of reflective practice (1983), Kolb's theory of experiential learning (1984), and Hamilton's multidimensional model of reflective thinking. Dewey (1933, 1934) defined reflection as an active and careful consideration of beliefs and experiences. Schön (1983) broadened this definition to include the value of reflection during and after professional action. Reflection was defined by Kolb as a vital stage of experiential learning, where experience is transformed to knowledge. Based on these perspectives, Hamilton's model conceptualizes reflective thinking in several dimensions like self-assessment, awareness of teaching competencies, orientation towards lifelong learning, and self-efficacy beliefs (Choy *et al.*, 2019). This multidimensional framework forms the conceptual basis for the evaluation of reflective thinking among student teachers in the present study.

Previous studies have found that reflective teaching practices have positive effects on classroom teaching and professional competence. Ahmad *et al.* (2013) demonstrated that reflective practice training for educators has a significant effect on improving their competence as teachers. Similarly, differences in reflective thinking skills of teacher candidates were discussed by Rahmadhani *et al.* (2020), which were seen in their reflective interpretations and analytical behaviors. However, a significant proportion of pre-service teachers do not engage in deep reflective thinking, as indicated by several studies (Hatton

& Smith, 1995; Kember *et al.*, 2008; Wahyuni & Putra, 2021; Voulgari & Koutrouba, 2026). These findings indicate that reflective competence may not be developed automatically and thus needs systematic pedagogical support and structured interventions. Reflective thinking is not a uniform construct but is on a continuum from descriptive reflection to dialogic and critical reflection (Hatton & Smith, 1995). Descriptive reflection is mainly about remembering and describing what happened in the classroom. Critical reflection involves challenging assumptions, analyzing contextual factors, and thinking about the ethical and social implications of teaching practices. The transition from surface-level reflection to critical reflection is considered a significant process for the development of reflective practitioners in teacher education programs.

Recent studies have increasingly redefined reflective thinking as a complex metacognitive process that develops gradually through organized learning experiences. Studies conducted between 2020 and 2025 show that student teachers' level of reflective thinking is generally moderate, and it needs support from experiential learning, guided reflection, and cooperative activities (Colomer *et al.*, 2020; Anselmann, 2023; Sheridan *et al.*, 2025; Liu *et al.*, 2025). The importance of reflective practice is broadly recognized as a central element of professional teacher development. For instance, Alshammari and Alrashidi (2025) found that teachers reported moderate levels of reflective practice and generally held positive attitudes toward reflection. Their study also demonstrated that there were no significant differences in reflective practice based on teaching level or gender, indicating that reflection is more of a professional competency than as a demographic characteristic. Chaseley & Abercrombie (2025) also highlighted how those reflective prompts and critical incident analysis assist in moving beyond surface-level reflection to deeper critical reflection. Metacognitive awareness has also been linked with reflective thinking in recent studies. Greater self-regulation and professional learning capacity (Pousi *et al.*, 2025) have been associated with higher levels of reflection. In the literature, reflective thinking is identified as a core professional competence in teacher education in general. However, research has also shown that in the absence of systematic guidance and structured opportunities for reflection, reflective

thinking tends to be descriptive rather than critical in nature (Voulgari & Koutrouba, 2026).

The development of competent and responsible teachers is a matter of reflective thinking. Assessing the levels of reflective thinking of student teachers can assist teacher educators to identify the areas in which support and intervention are needed. The assessment of reflective thinking at the pre-service stage is particularly important because teacher education programs seek to develop reflective practitioners (NCTE, 2009). The study contributes to the existing literature by studying the level of reflective thinking in student teachers in the Indian context, specifically Punjab. Furthermore, the study investigates the effect of academic and demographic variables to establish whether professional training or background characteristics have an effect on reflective thinking. The findings could help teacher education institutions in designing instructional practices and professional development activities for the improvement of the reflective competence of future teachers. Although previous research has extensively examined reflective thinking among teachers and pre-service teachers, several gaps still remain in the literature. First, research on reflective thinking among student teachers in the Indian context and especially in teacher education institutions in Punjab is limited. Second, although many studies have conceptually discussed reflective practice, they have not examined the multidimensional nature of reflective thinking through frameworks such as Hamilton's model. Thirdly, research on the role of academic and demographic variables in reflective thinking of student teachers is insufficient. Hence, the present study intends to fill these gaps by exploring the levels of reflective thinking in student teachers through a multidimensional framework.

1.1. Objectives of the Study

- To examine the distribution of student teachers across different levels (low, moderate, and high) of reflective thinking.
- To analyze the level of reflective thinking among student teachers with respect to locale (urban and rural).
- To analyze the level of reflective thinking among student teachers with respect to gender (male and female).
- To analyze the level of reflective thinking among student teachers with respect to academic stream (medical, non-medical, and humanities).

- To analyze the level of reflective thinking among student teachers with respect to academic achievement (high, average, and low).

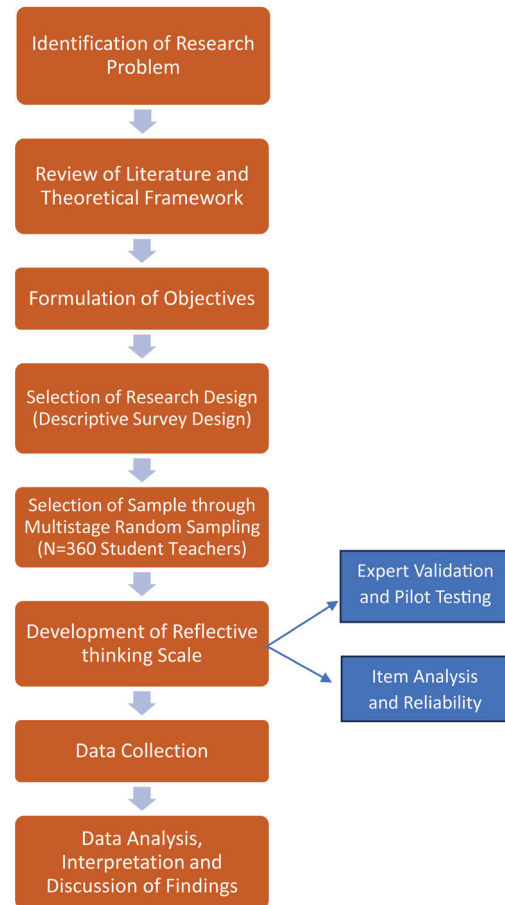


Figure 1: Process Flow Chart of the Study

2. Methodology

2.1. Research Design

A descriptive survey design was employed to describe the existing levels of reflective thinking among student teachers without manipulating any variables.

2.2. Sample

The sample included 360 student teachers from teacher education institutions in the Amritsar district of Punjab. A multistage simple random sampling technique using the lottery method was employed to select teacher education institutions in the Amritsar district of Punjab. Lists of enrolled student teachers were obtained from participating institutions, and participants were randomly selected to ensure equal representation. The sample was drawn from teacher

education institutions affiliated with Guru Nanak Dev University. To ensure representation, the participants came from a variety of academic disciplines and had varying degrees of academic achievement. The purpose of the study was explained to the participants, and their participation was entirely voluntary. Anonymity and confidentiality were ensured.

2.3. Tools Used

2.3.1. Reflective Thinking Scale

A reflective thinking scale developed by the investigators was used to assess reflective thinking among student teachers. The scale was based on Hamilton's multidimensional model of reflective thinking, which conceptualizes reflective thinking through dimensions such as self-assessment, awareness of teaching competencies, lifelong learning orientation, and self-efficacy beliefs. The Hamilton Model was adopted as the conceptual framework for the present study because it provides a comprehensive understanding of reflective thinking relevant to teacher education and professional development.

2.3.2. Dimensions of the Scale

The scale consisted of four dimensions:

- Ability to self-assess
- Awareness of own teaching skills
- Developing lifelong learning skills
- Belief about self and self-efficacy

2.3.3. Scale Development Process

- Item pool generation: The development of the Reflective Thinking Scale was carried out systematically in multiple stages. Initially, a pool of 40 statements was generated through a review of literature related to reflective thinking, reflective practice, metacognition, and teacher professional development, particularly based on Hamilton's theoretical framework. The items were designed to reflect the four dimensions of reflective thinking identified in the model.
- Expert Review/Screening of items: The preliminary draft of the Reflective Thinking Scale was reviewed by experts in teacher education and educational psychology to assess the relevance, clarity, and representativeness of the items. The items were examined for redundancy, ambiguity, overlap, and clarity. After careful screening and revision, 35 items were retained in the revised version of the scale. Items with ambiguous wording were revised or removed.

- Item Analysis: Item analysis was conducted to determine the discriminating power of the items included in the Reflective Thinking Scale. The preliminary scale was administered to a pilot sample of 100 student teachers. Kelly's extreme group method was employed by selecting the upper 27% and lower 27% groups based on total scores (Kelley, 1939). Independent sample t-tests were computed to determine the discriminating power of each item. Items with non-significant t-values were revised or removed from the scale. Following item analysis, three additional items were removed, resulting in a final scale of 32 items.
- Validity Testing: To establish content and face validity, the revised scale was further reviewed by five experts in teacher education and educational psychology. The experts examined whether the items adequately represented the dimensions of reflective thinking. Based on their suggestions, necessary modifications were made to improve conceptual precision and language clarity.
- Reliability Testing: The reliability of the scale was established using test-retest reliability and internal consistency measures. The test-retest reliability coefficient was found to be 0.82, indicating satisfactory stability of the scale over time. Cronbach's alpha coefficient was calculated to assess internal consistency and yielded a value of 0.94, suggesting a good degree of internal consistency among the items. The final scale consisted of 32 items distributed across the four dimensions of reflective thinking.

2.3.4. Sample Items

Examples of items included in the scale are:

- I review my performance to identify areas for improvement.
- I make changes to my instructional methods based on self-evaluation.
- I take an active role in constructing my knowledge rather than passively receiving information.
- I look forward to developing skills that will be useful throughout my life and career.
- I am confident in my ability to plan and organize tasks effectively.
- I can critically evaluate the impact of my teaching on student learning.

2.3.5. Scoring Procedure

Data was collected using a 5-point Likert scale, with 1 denoting "strongly disagree" and 5 denoting "strongly agree." Before analysis, items with negative wording were reverse coded. Higher scores indicated higher levels of reflective thinking, and the total score ranged from 32 to 160.

Participants were categorized into three levels of reflective thinking:

- Low
- Moderate
- High

The classification was carried out using percentile cut-off scores.

2.3.6. Academic Achievement

Academic achievement was determined based on the marks obtained by the students in their previous class examination. These scores were used for classifying them into different academic levels for analysis using Kelly's criteria. Kelly's 27% criterion was used to classify students into high, average, and low academic achievement categories.

2.4. Statistical Techniques

Percentage analysis was used to analyse the data. Since the objectives focused primarily on describing the distribution of reflective thinking levels across categories, percentage analysis and chi-square techniques were considered appropriate. Chi-square analysis was employed because the variables were categorical in nature and the study aimed to examine associations between reflective thinking levels and demographic variables. Student teachers were classified into low, moderate, and high levels of reflective thinking on the basis of percentile cut-off scores. Participants scoring below the 25th percentile were categorized as low reflective thinkers, those between the 25th and 75th percentile as moderate reflective thinkers, and those above the 75th percentile as high reflective thinkers. Percentile-based classification has commonly been used in educational and psychological research for categorizing levels of psychological constructs.

3. Analysis and Interpretation

Table 1: Levels of Reflective Thinking among Student Teachers

Levels of Reflective Thinking	Frequency (N)	Percentage (%)
Low	81	22.5 (%)
Moderate	173	48.1 (%)
High	106	29.4 (%)
Total	360	100.0 (%)

According to the findings, 48.1% of the student teachers thought reflectively at a moderate level, followed by

high levels of reflective thinking 29.5% and low levels of reflective thinking 22.5%. According to this distribution, most student teachers have an average ability to think reflectively. The moderate category's predominance indicates that although student teachers are able to reflect on their experiences, they may not have reached the full potential of deeper or more critical levels of reflection.

Table 2: Distribution of Student Teachers According to locale (Urban/Rural)

Locale		Levels of Reflective Thinking			Total
		Low	Moderate	High	
Urban	Count	33	74	49	156
	% within Locale	21.2%	47.4%	31.4%	100.0%
Rural	Count	48	99	57	204
	% within Locale	23.5%	48.5%	27.9%	100.0%
Total	Count	81	173	106	360
	% within Locale	22.5%	48.1%	29.4%	100.0%

Table 3: Chi-Square Test for Association between Locale and Reflective Thinking

Test	Value	d.f	p-value
Pearson Chi-Square	.605 ^a	2	.739
N of Valid Cases	360		

In terms of locale, student teachers in urban areas exhibit a moderate degree of reflective thinking at 47.4%, while those in rural areas exhibit a moderate level at 48.5%. For both urban and rural groups, the distribution across low, moderate, and high levels is very comparable. According to the chi-square value ($\chi^2 = 0.605$, $p > .05$), the observed differences are not statistically significant. This indicates that student teachers from both urban and rural backgrounds exhibit similar reflective capacities, indicating that locale has little impact on the degree of reflective thinking. The effect size was negligible (Cramer's $V = 0.04$), which means that locale has very little practical impact on student teachers' reflective thinking.

Table 4: Levels of Reflective Thinking with Respect to Gender (Male/Female)

Gender		Levels of Reflective Thinking			Total
		Low	Moderate	High	
Male	Count	6	23	12	41
	% within Gender	14.6%	56.1%	29.3%	100.0%

Female	Count	75	150	94	319
	% within Gender	23.5%	47.0%	29.5%	100.0%
Total	Count	81	173	106	360
	% within Gender	22.5%	48.1%	29.4%	100.0%

Table 5: Chi-Square Test for Relationship Between Gender and Reflective Thinking

Test	Value	df	p-value
Pearson Chi-Square	1.896 ^a	2	.388
N of Valid Cases	360		

According to the gender-wise analysis, 56.1% of male student teachers and 47.0% of female student teachers have a moderate level of reflective thinking. Males and females had about identical levels of reflective thinking (29.3% and 29.5%, respectively). The distribution of reflective thinking levels is similar across genders, according to the chi-square test ($\chi^2 = 1.896$, $p > .05$). This suggests that there is little gender difference in reflective thinking among student teachers and that educational experiences may have a greater impact than biological or social gender disparities. Effect size was small (Cramer's $V = 0.07$), suggesting that gender has minimal practical influence on reflective thinking levels.

Table 6: Distribution of Student Teachers According to Stream (Medical/Non-Medical/Humanities)

Academic Stream		Levels of Reflective Thinking			Total
		Low	Moderate	High	
Humanities	Count	51	86	56	193
	% within Academic Stream	26.4%	44.6%	29.0%	100.0%
Non-Medical	Count	18	65	38	121
	% within Academic Stream	14.9%	53.7%	31.4%	100.0%
Medical	Count	12	22	12	46
	% within Academic Stream	26.1%	47.8%	26.1%	100.0%
Total	Count	81	173	106	360
	% within Academic Stream	22.5%	48.1%	29.4%	100.0%

Table 7: Chi-Square Test for Association Between Academic Stream and Reflective Thinking

Test	Value	df	p-value
Pearson Chi-Square	6.355 ^a	4	.174
N of Valid Cases	360		

With respect to analysis based on academic stream, 47.8% of medical students, 53.7% of non-medical students, and 44.6% of humanities students have a moderate level of reflective thinking. The general trend suggests that the moderate level is still prevalent across all academic backgrounds, regardless of considerable variation shown across streams. These differences are not significant, according to the chi-square value ($\chi^2 = 6.355$, $p > .05$). This suggests that reflective thinking is not limited to a particular academic stream but rather is a general professional trait that develops across disciplines. The effect size was small (Cramer's $V = 0.09$), indicating a weak association between academic stream and reflective thinking.

Table 8: Distribution of Student Teachers According to Academic achievement (High/Average/Low)

Academic Achievement		Levels of Reflective Thinking			Total
		Low	Moderate	High	
High Academic Achievement	Count	16	46	36	98
	% within Academic Achievement	16.3%	46.9%	36.7%	100.0%
Average Academic Achievement	Count	42	78	44	164
	% within Academic Achievement	25.6%	47.6%	26.8%	100.0%
Low Academic Achievement	Count	23	49	26	98
	% within Academic Achievement	23.5%	50.0%	26.5%	100.0%
Total	Count	81	173	106	360
	% within Academic Achievement	22.5%	48.1%	29.4%	100.0%

Table 9: Chi-Square Test for Relationship between Academic Achievement and Reflective Thinking

Test	Value	df	p-value
Pearson Chi-Square	4.949 ^a	4	.293
N of Valid Cases	360		

Regarding academic performance, the moderate level of reflective thinking is exhibited by 50.0% of low scorers, 47.6% of average performers, and 46.9% of high achievers. The overall pattern is consistent across achievement levels, despite the fact that a somewhat higher proportion of high achievers (36.7%) fall into the high reflective-thinking category than ordinary and low performers. According to the chi-squared result ($\chi^2 = 4.949$, $p > .05$), there is no meaningful variance. This implies that reflective thinking could not be only based on exam results and could operate independently of academic achievement. The effect size was small (Cramer's $V = 0.08$), suggesting that academic achievement has limited practical influence on reflective thinking.

4. Discussion

This study aimed at finding out the level of reflective thinking among the student teachers in terms of gender, locale, academic stream, and academic achievement. The findings revealed that most of the student teachers had a moderate level of reflective thinking, whereas fewer participants were categorized at high and low levels. This suggests that while student teachers do have some reflective awareness, their reflective engagement may primarily remain at a descriptive or surface level rather than progressing towards a deeper critical reflection. These findings are consistent with Dewey's (1933) and Schön's (1983) conceptualization of reflective thinking as a developmental process that develops in a sequential manner, facilitated through systematic inquiry, experience, and professional engagement. Likewise, previous research has indicated that pre-service teachers tend to reflect at technical or descriptive, rather than transformative or critical levels of reflection (Larrivee, 2008; Kember *et al.*, 2008). This suggests that reflective thinking does not occur as an automatic consequence of teacher preparation and that it may require additional formal pedagogical support and reflective opportunities in teacher education programs.

The effect size values (Cramer's V range from 0.04 to 0.09) showed weak to negligible association between reflective thinking and demographic variables such as gender, locale, academic stream, and academic achievement. The findings suggest that reflective thinking may be more influenced by professional training and pedagogical experiences than by background characteristics. The small effect sizes support the idea that reflective thinking is a learnable and context-specific competency acquired in the profession, rather than an innate characteristic determined by demographic or academic variables. Reflective capacity therefore seems to develop primarily through professional and reflective experiences.

The absence of significant gender differences also supports Dewey's idea of reflection as a conscious and learned process of learning, rather than an innate ability. Likewise, the absence of substantial variation across academic streams suggests that reflective thinking is an educational disposition that cuts across disciplines and can be developed in different subject specializations. The findings also correspond to Schön's notions of reflection-in-action and reflection-on-action, which stressed the significance of experiential learning and professional practice in the development of reflective competence. The results also suggest that reflective thinking may be more related to metacognitive functions such as planning, monitoring, and evaluation than academic performance outcomes, with little difference across academic achievement levels. Thus, instead of academic success, reflective thinking seems to be a separate professional competence linked to critical inquiry, pedagogical awareness, and self-evaluation. This underlines the importance of systematic and theoretically based interventions in teacher education programs to improve higher levels of reflective competence in student teachers.

These findings also have important implications for teacher education programs. The dominance of a moderate level of reflective thinking implies the need to include structured reflective practices such as reflective journals, peer discussions, guided practicum experiences, mentoring, and critical self-evaluation activities in teacher education curricula. Such practices could assist student teachers to move beyond descriptive reflection into deeper critical and transformative reflection. Without systematic opportunities for reflective inquiry, student teachers may remain at

the technical or superficial levels of reflection instead of developing the reflective competence required for effective and adaptable teaching. The findings of the present study are also aligned with recent national and international research demonstrating that pre-service teachers often possess moderate levels of reflective thinking and need structured reflective support to enhance higher-order professional thinking skills (Wahyuni & Putra, 2021; Anselmann, 2023; Sheridan *et al.*, 2025). The consistency of the studies suggests that the development of reflective competence remains a continuing challenge in teacher education worldwide. This means that teacher education institutions may need to move away from transmissive pedagogical approaches and to include opportunities for reflective and experiential learning that will systematically develop the reflective competence of prospective teachers.

The findings generally contribute to the growing body of literature that highlights the role of reflective thinking as a facilitator of teacher professional competence, adaptive expertise, and lifelong learning. The results support the perspective that reflective thinking is a developmental and professional competence that needs systematic pedagogical support in teacher education programs. Teacher education institutions can enhance future teachers' ability to respond effectively to the dynamic and complex nature of today's classrooms by promoting higher levels of reflection.

5. Suggestions for Future Research

Future research may extend the present investigation by using qualitative or mixed-method approaches to better understand the reflective processes of student teachers. Longitudinal studies may also be conducted to examine the development of reflective thinking over time during teacher preparation programs. In addition, experimental and intervention-based studies focusing on reflective training practices such as mindfulness, reflective journaling, and mentoring may further contribute to understanding how reflective competence can be systematically enhanced among future teachers.

6. Conclusion

The study analyzed the levels of reflective thinking among student teachers. The results of this study are especially relevant in the context of the growing

emphasis on reflective practice as a fundamental professional competency in India's present teacher education system. The findings indicated that the existence of reflective thinking among student teachers is at a moderate level, which means that reflective capacity is present with the necessity to enhance it. Teacher education programs should therefore make deliberate efforts to cultivate the skill of reflection with the help of curricular and pedagogical innovations. Strengthening reflective thinking in student teachers can contribute to improving the overall quality of education. The study reinforces the view that reflective thinking should not be treated as an incidental outcome of teacher education but as a deliberately cultivated professional competency essential for adaptive and reflective teaching.

7. Limitations

- **Lack of qualitative data:** Qualitative techniques that could offer deeper and more complex insights into reflective thinking processes—like interviews, reflective journals, and classroom observations—are not included in this study.
- **Limited Generalizability:** The sample was selected from a particular area; the results may not be as applicable to other settings, establishments, or student-teacher populations.

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Authors' Contribution

Both authors contributed equally to the conceptualization, design, writing, and editing of the paper.

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Conflict of Interest

The authors declare no conflict of interest related to this study.

Declarations

The authors declare that this work is original and has not been submitted elsewhere for publication. All data, methodologies, and system components have been developed and reported in adherence to academic standards. All referenced materials have been duly cited, and the authors accept full responsibility for the integrity and accuracy of the findings presented.

Ethical Approval

The ethical principles of voluntary participation, informed consent, confidentiality, and anonymity were strictly followed throughout the study.

Figure Permissions

The authors declare that the entirety of this work, including the text, figures, and tables, is original, has not been previously published, is in the public domain, or is exclusively copyrighted by the authors.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author, M. Kour.

Human and Animal Rights

Informed consent was obtained from all participants prior to data collection. No animals were involved in this research.

AI Disclosure Statement

The authors declare that artificial intelligence (AI)-assisted tools were used only for language improvement, grammar refinement, and formatting assistance during manuscript preparation. All scientific content, literature interpretation, critical analysis, conclusions, and final manuscript review were performed by the authors. The authors take full responsibility for the accuracy, originality, and integrity of the manuscript and confirm that it complies with the journal's plagiarism and publication ethics policies.

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