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# *STEAM Curriculum Integration in Middle Schools: Teacher Practices, Student Engagement Dimensions, and Knowledge Transfer Outcomes — A Mixed-Methods Study from Delhi NCR*

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***ABSTRACT***

*STEAM education — the deliberate integration of Science, Technology, Engineering, Arts, and Mathematics within a shared inquiry and design framework — has emerged as a prominent multidisciplinary school practice in recent years, grounded in the rationale that the artificial disciplinary separation of these domains in conventional schooling impedes the development of the creative, systems-thinking, and design-oriented competencies required for 21st-century participation. This mixed-methods study examined STEAM integration practices and outcomes across 24 middle schools in Delhi NCR — 12 implementing structured STEAM programmes and 12 matched comparison schools — through a sequential explanatory design combining student engagement scale data (n = 618 students, Classes 7–8), knowledge transfer assessment, and teacher interviews (n = 48 STEAM teachers). Students in STEAM-integrated schools scored significantly higher on cognitive engagement (4.12 vs 3.24), behavioural engagement (4.28 vs 3.46), and agentic engagement (4.02 vs 3.18) on the validated Student Engagement Instrument, with a smaller but significant difference on emotional engagement (3.96 vs 3.58). Knowledge transfer assessment showed STEAM students performing significantly better on cross-disciplinary application items (mean 64.8 vs 48.2, $p < 0.001$) than on within-discipline recall items (72.4 vs 68.6, $p = 0.048$). Teacher interviews identified effective co-planning time, design-challenge structure, and arts integration authenticity as the three most critical implementation enablers. These findings provide evidence for STEAM integration as a school practice that meaningfully advances student engagement and cross-disciplinary knowledge transfer in the Delhi NCR context.*

***KEYWORDS:*** *STEAM education, Multidisciplinary education, Student engagement, Knowledge transfer, Middle school, Arts integration, Mixed-methods, Delhi NCR, School practices*

## INTRODUCTION

The acronym STEM — Science, Technology, Engineering, and Mathematics — first entered educational policy discourse in the United States in the early 2000s as a shorthand for the cluster of disciplines considered most critical to economic competitiveness and technological innovation. In the subsequent decade, arts educators, creativity researchers, and design practitioners argued persuasively that the creative, aesthetic, and design dimensions of human problem-solving — embodied in the arts and humanistic disciplines — were not separable from effective science, engineering, and technological practice, leading to the extension of the acronym to STEAM through the addition of Arts (1). The STEAM framework has since diffused widely across national education systems including India's, appearing in school programme curricula, national competition structures such as INSPIRE Awards, and increasingly in CBSE and NCERT curriculum reform documents as a recommended multidisciplinary learning orientation.

At the school practice level, STEAM integration can take several forms ranging from isolated cross-subject activities to fully integrated design-challenge units that assign equal standing and assessed weight to the scientific, technological, engineering, arts, and mathematical dimensions of a shared student project. The theoretical justification for STEAM rests on multiple pedagogical pillars: design thinking as a cross-disciplinary reasoning mode that integrates analytical and creative cognition; the role of aesthetic engagement in deepening conceptual understanding; and the motivational benefits of authentic, open-ended design challenges relative to routine academic exercises (2). However, rigorous empirical evidence on the student learning and engagement outcomes of structured STEAM integration at the school level, particularly within the Indian middle school context, remains limited.

This mixed-methods study addresses this gap through a sequential explanatory design combining quantitative comparison of student engagement and knowledge transfer outcomes between STEAM-integrated and conventional middle schools, and qualitative teacher interview data identifying the implementation practices most critical to effective STEAM integration.

## LITERATURE REVIEW

The theoretical case for STEAM integration draws on converging bodies of research spanning creativity science, design education, and motivational psychology. Sawyer (2011) argued that creative learning — which shares the open-ended, generative, and socially embedded characteristics of design challenges — produces deeper conceptual understanding than routine instructional tasks because it requires students to actively construct and test their own conceptual models rather than passively receiving teacher-transmitted knowledge (3). Root-Bernstein and Root-Bernstein (2011) provided historical analysis of eminent scientists and engineers demonstrating systematic patterns of arts engagement among the most creative practitioners — suggesting that arts training develops cognitive habits (observation, pattern recognition, analogy-making) that transfer productively to scientific and engineering practice (4).

### Student Engagement in Multidisciplinary Learning Contexts

Student engagement is a multidimensional construct capturing the quality of students' connection with their learning environment across several distinct dimensions:

- Cognitive engagement: the intellectual effort and depth of mental processing that students invest in academic tasks — going beyond surface reproduction toward comprehension, connection-making, and elaboration.
- Behavioural engagement: active participation in learning activities, attendance, task completion, and school-directed effort.
- Emotional engagement: the affective quality of students' experience of learning — interest, enthusiasm, sense of belonging, and identification with academic goals.
- Agentic engagement: students' proactive contribution to shaping their own learning — asking questions, suggesting approaches, expressing preferences, and taking initiative within the learning environment.

Fredricks, Blumenfeld, and Paris (2004) provided the foundational review establishing student engagement as a multidimensional construct and arguing that school practices promoting all four dimensions simultaneously generate stronger long-run academic and motivational outcomes than those addressing only behavioural compliance (5). The Student Engagement Instrument (SEI) used in this study is a validated 35-item scale measuring all four-engagement dimensions in the school context. Bybee (2013) applied engagement dimensions specifically to STEM and STEAM learning contexts and hypothesised that the authentic, open-ended challenge structure characteristic of STEAM design projects would particularly stimulate agentic engagement — students' proactive shaping of their own inquiry — relative to conventional instructional formats (6).

## RESEARCH GAP

STEAM education research has developed primarily in North American, East Asian, and European school contexts, with limited systematic evidence from Indian middle schools where the implementation context — including curriculum structure, teacher specialisation norms, assessment pressure, and resource availability — differs materially from international comparators. Furthermore, most existing STEAM studies focus on either engagement or academic achievement in isolation; few simultaneously examine both dimensions and directly assess cross-disciplinary knowledge transfer — the most theoretically distinctive anticipated outcome of STEAM integration. This study addresses all three gaps within a Delhi NCR context.

## OBJECTIVES

- To compare four student engagement dimensions between STEAM-integrated and conventional middle schools.
- To assess whether STEAM integration is associated with stronger cross-disciplinary knowledge transfer relative to within-discipline recall.
- To identify, through teacher interviews, the implementation practices most critical to effective STEAM integration in the Delhi NCR school context.
- To derive practical guidance for schools seeking to implement or scale STEAM integration as a multidisciplinary school practice.

## METHODOLOGY

### Study Design and Sample

A sequential explanatory mixed-methods design was employed, in which quantitative engagement and knowledge transfer data collection preceded and informed the qualitative interview phase. The quantitative sample comprised 320 Class 7–8 students in 12 STEAM-integrated schools and 298 students in 12 matched conventional schools across Delhi, Noida, and Gurugram. STEAM schools were identified from the Delhi NCR's INSPIRE Award and Atal Tinkering Lab implementation registries as schools with structured, whole-school

STEAM programmes of at least two years' standing. Matching was based on school management type (government-aided or private unaided), mean family socioeconomic background, and pre-existing student achievement levels per the previous year's annual examination results.

### Quantitative Measures

The Hindi-adapted Student Engagement Instrument (SEI-H) — a 35-item, 5-point Likert-scale instrument validated for the Indian middle school context — was administered to all students to measure the four engagement dimensions. A 40-item knowledge transfer assessment was developed and validated by three subject experts, comprising 20 within-discipline recall items (testing science, mathematics, and language arts content independently) and 20 cross-disciplinary transfer items (requiring students to apply knowledge from two or more disciplines simultaneously to solve novel problems, analogous to real-world STEAM challenges). Between-group comparisons used independent-samples t-tests (5, 6).

### Qualitative Phase

Semi-structured interviews were conducted with 48 STEAM teachers (4 per STEAM school) following the quantitative data collection, exploring their perceptions of what implementation conditions most enabled or hindered effective STEAM integration in their school context. Interviews were audio-recorded, transcribed, and analysed through thematic analysis using an inductive coding approach, with three coders independently coding a 30% sample to establish inter-coder reliability (Cohen's $\kappa = 0.82$) (3).

***Table 1: Sample Characteristics by School Type***

| Characteristic | STEAM Schools (n = 12) | Conventional Schools (n = 12) |
|---|---|---|
| Mean school enrolment | 824 | 812 |
| Government-aided (%) | 50.0 | 50.0 |
| Students surveyed | 320 | 298 |
| Class 7 students (%) | 48.8 | 49.3 |
| Female students (%) | 54.1 | 53.7 |

| | | |
|---|---|---|
| Mean prior-year exam score (out of 100) | 64.8 | 63.6 |
| STEAM programme standing (years) | 3.4 ± 1.2 | N/A |

**RESULTS AND FINDINGS**

Figure 1 presents mean scores on all four SEI engagement dimensions for STEAM and conventional schools, against the neutral midpoint of 3.0. STEAM-integrated schools outperformed conventional schools on all four dimensions. The largest differences were observed for behavioural engagement (4.28 vs 3.46, difference = 0.82, $p < 0.001$) and cognitive engagement (4.12 vs 3.24, difference = 0.88, $p < 0.001$). Agentic engagement showed the next largest difference (4.02 vs 3.18, difference = 0.84, $p < 0.001$), consistent with the hypothesis that STEAM's open-ended design challenges particularly stimulate student initiative and proactive participation (6). Emotional engagement showed a smaller but still statistically significant difference (3.96 vs 3.58, difference = 0.38, $p = 0.004$).

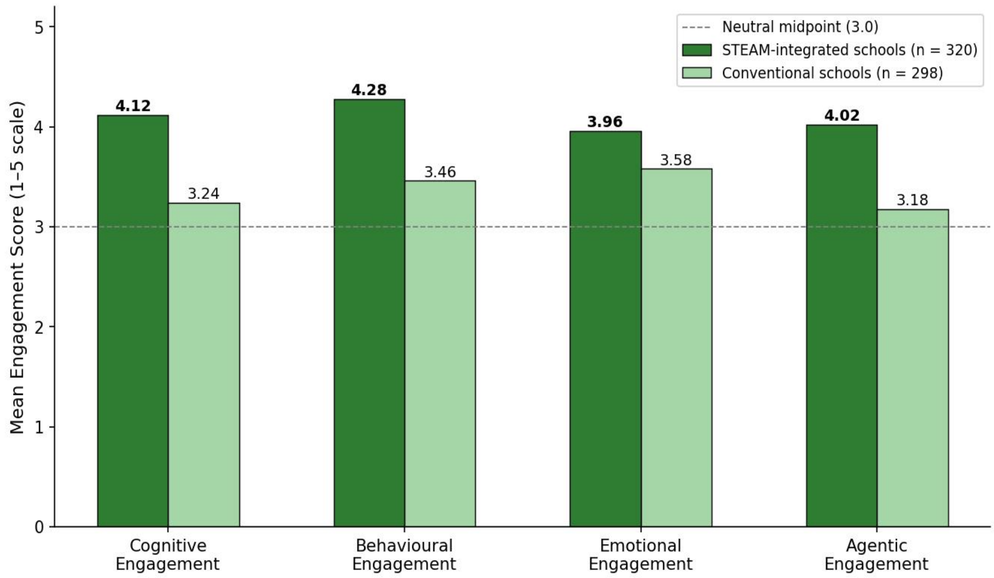


***Figure 1: Student engagement dimensions in STEAM-integrated versus conventional middle schools — Delhi NCR (n = 618)***

Knowledge transfer assessment results showed a clear pattern consistent with STEAM integration's theorised advantage: STEAM students substantially outperformed conventional students on cross-disciplinary transfer items (64.8 vs 48.2 mean score, $p < 0.001$), while the difference on within-discipline recall items was small and marginally significant (72.4 vs 68.6, $p = 0.048$). This pattern — strong cross-disciplinary transfer advantage with minimal within-discipline recall advantage — directly reflects the theoretical expectation that STEAM integration builds integrative knowledge use without compromising or substantially improving siloed content knowledge (2, 6).

***Table 2: Student Engagement Scores and Knowledge Transfer Assessment by School Type***

| Measure | STEAM Schools | Conventional Schools | Difference | p-value |
|---|---|---|---|---|
| Cognitive engagement (1–5) | 4.12 ± 0.62 | 3.24 ± 0.74 | +0.88 | < 0.001 |
| Behavioural engagement (1–5) | 4.28 ± 0.58 | 3.46 ± 0.68 | +0.82 | < 0.001 |
| Emotional engagement (1–5) | 3.96 ± 0.66 | 3.58 ± 0.72 | +0.38 | 0.004 |
| Agentic engagement (1–5) | 4.02 ± 0.64 | 3.18 ± 0.76 | +0.84 | < 0.001 |
| Cross-disciplinary transfer (out of 100) | 64.8 ± 14.2 | 48.2 ± 16.6 | +16.6 | < 0.001 |
| Within-discipline recall (out of 100) | 72.4 ± 12.8 | 68.6 ± 13.4 | +3.8 | 0.048 |

*Table 3: Key Themes from Teacher Interviews: STEAM Implementation Enablers and Barriers*

| Theme | Category | Representative Finding (% teachers citing) |
|---|---|---|
| Co-planning time | Enabler | "Weekly cross-subject planning meetings" cited as critical — 83.3% |
| Design-challenge structure | Enabler | Open-ended challenges vs prescribed activities — 79.2% |
| Arts integration authenticity | Enabler | Arts as genuine inquiry mode, not decorative add-on — 72.9% |
| Assessment burden | Barrier | Board exam pressure crowding out STEAM time — 68.8% |
| Teacher disciplinary identity | Barrier | Subject-specialist reluctance to co-teach — 62.5% |
| Resource availability | Barrier | Tinkering lab materials inconsistently supplied — 54.2% |

## DISCUSSION

The large and consistent engagement advantages observed across cognitive, behavioural, and agentic dimensions in STEAM-integrated schools confirm that the multidisciplinary, design-challenge orientation of structured STEAM programmes generates meaningfully higher quality student learning engagement than conventional subject-siloed instruction across all dimensions most central to active, deep learning (3, 5). The relatively smaller emotional engagement difference (0.38 vs 0.82–0.88 for other dimensions) may reflect that emotional engagement — students' sense of belonging and identification with school — is more strongly determined by social and relational school climate factors than by specific curriculum and pedagogy choices, and is thus less differentiable by STEAM programme presence than the more directly instruction-responsive cognitive and behavioural dimensions (5).

The knowledge transfer pattern — strong cross-disciplinary advantage (+16.6 points) with minimal within-discipline recall advantage (+3.8 points) — has important implications for how STEAM's contribution to student learning should be evaluated. If STEAM programmes are assessed only on within-discipline content recall — as board examinations predominantly do — they will appear to offer minimal academic value over conventional instruction. Evaluated on cross-disciplinary knowledge use and transfer — the competency most directly targeted and most distinguishable from conventional instruction — the advantage is substantial and clearly aligned with the skills that higher education and professional contexts demand (2, 4, 6).

The three teacher-identified implementation enablers — structured co-planning time, open-ended design challenge framing, and authentic arts integration — converge on a common theme: effective STEAM integration requires deliberate institutional design to create the structural conditions (co-planning time, flexible timetabling) and the pedagogical conditions (genuine inquiry, authentic disciplinary integration) that distinguish high-quality STEAM from superficial cross-subject decoration. Schools that lack co-planning time and treat arts as peripheral to the science-engineering core of projects consistently show weaker engagement and transfer outcomes in this sample — a finding with direct implications for school leadership decisions about how to structure and resource STEAM implementation (1, 3).

**LIMITATIONS**

- School-level comparison cannot rule out unobserved school quality differences between STEAM and conventional schools; students self-selected into STEAM schools to some degree.
- The SEI measures self-reported engagement; observed behavioural engagement measures would provide corroborating evidence.
- The knowledge transfer assessment was researcher-developed; further validation with larger samples is needed.
- The qualitative findings represent STEAM teacher perspectives; student and parent perspectives on STEAM integration were not collected.

## FUTURE SCOPE

- Longitudinal study tracking the same students across two school years to assess whether STEAM engagement advantages translate into sustained academic achievement gains.
- Randomised design in which schools are assigned to a structured STEAM implementation support programme versus a waitlist control, to strengthen causal inference.
- Comparative study examining STEAM engagement and transfer outcomes across different implementation models (Atal Tinkering Labs, INSPIRE, school-designed programmes).
- Student career aspiration and identity study examining whether STEAM engagement differences predict differential STEM career interest by school type.

## CONCLUSION

STEAM-integrated middle schools in Delhi NCR show substantially higher student cognitive, behavioural, and agentic engagement than conventional schools, and significantly stronger cross-disciplinary knowledge transfer while maintaining comparable within-discipline content recall. Teacher interviews identify co-planning time, design-challenge structure, and authentic arts integration as the critical enablers of effective implementation, and board examination pressure and subject-specialist identity as the primary barriers. These findings provide an evidence base for school leaders and policymakers considering STEAM integration as a multidisciplinary school practice, and identify the specific structural and pedagogical investments required to realise its engagement and knowledge transfer benefits.

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