Accessibility and Sustainability of Technology-Enhanced Music Curricula: A Quasi-Natural Experiment across Urban and Rural Schools

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Abstract

Technology-enhanced music curricula can transform music education by integrating digital tools and resources into teaching and learning. Yet access to these technologies and the long-term sustainability of their implementation differ markedly between urban and rural schools. Drawing on a quasi-natural experiment involving urban and rural middle schools, this study examines two key dimensions: accessibility, defined as device availability, internet connectivity, and teacher training; and sustainability, defined as the durability of curriculum integration and teacher retention. Findings show that urban schools achieved substantially higher scores on both dimensions, which translated into stronger student engagement in music learning. The analysis highlights persistent resource gaps in rural contexts, where teachers often lack digital literacy and institutional support, constraining the adoption of innovative music pedagogy. Sustained impact requires embedding practices such as ongoing professional development and curriculum alignment to ensure that technology-rich music education remains viable over time. The study concludes with recommendations for targeted investment and community-based training to foster equitable and enduring access to technology-enhanced music education across diverse school settings.

Keywords

Music Education, Educational Technology, Digital Divide, Rural Education, Curriculum Sustainability, Quasi-Natural Experiment

1. Introduction

The integration of technology into music education has accelerated in recent years, offering new pedagogical tools such as interactive multimedia, virtual instruments, and online resources [1,2]. Technology can enrich music learning by making abstract concepts concrete, fostering creativity, and enabling student-centered instruction [3,4]. Yet this integration is uneven: high-resource urban schools often acquire digital tools and training more quickly than under-resourced rural schools. The UNESCO Global Education Monitoring Report highlights this gap, noting that “computers and other devices are not used in classrooms on a large scale… The most disadvantaged are typically denied the opportunity to benefit from this technology”[5]. In many countries, rural schools suffer from limited infrastructure, lower teacher digital literacy, and fewer financial resources [6,7]. Music education, which already faces inequalities between urban and rural areas, risks widening the gap when technology is introduced without equitable support.

Sustainability is another key concern. A sustainable music curriculum means that technology integration is maintained over time, aligned with pedagogical goals, and supported by ongoing professional development [8,9]. If digital tools are adopted only temporarily or without teacher buy-in, the benefits may evaporate once initial funding or enthusiasm fades. In this quasi-natural experiment, we exploit a recent policy rollout of a technology-enhanced music curriculum in a region to compare accessibility and sustainability metrics across urban and rural schools. By measuring these dimensions alongside student engagement and achievement outcomes, we aim to identify how context influences the long-term viability of tech-based music instruction.

2. Literature Review

The digital divide in education remains a pressing issue. Rural schools often lag in internet bandwidth, device availability, and technical support compared to urban counterparts [10,11]. Studies show that even when devices are provided, socio-economic and cultural factors can hinder their effective use in rural settings [4,12]. For instance, Ahiaku et al. (2025) found that rural teachers face “digital disconnection” due to poor infrastructure and low socioeconomic status, leading them to rely on “what they have” rather than innovative tools [4]. Similarly, Xu (2024) reports that in a rural classroom, integrating technology (e.g. game-based learning) significantly increased student interest and skill in music, demonstrating potential even where resources are scarce [10]. However, Xu also notes that rural teachers typically have weak digital literacy and limited experience with IT, which constrains broader adoption. In China, for example, rural music teachers often lack systematic training in technology-enhanced methods, and their digital attitudes and information-

processing skills remain underdeveloped [1]. These skill gaps indicate that mere availability of equipment does not guarantee accessibility; teacher readiness and support are crucial.

Music education research further documents resource disparities. A recent case study in Zhejiang Province found rural schools were "short of music teachers, with backward facilities," whereas urban schools enjoyed well-funded programs and frequent teacher training. Such imbalances affect student motivation and proficiency. Technology can amplify these effects: urban students with laptops and online tools advance skills faster, while rural students without access fall further behind. Conversely, the novelty and interactivity of digital tools can boost engagement if implemented, as studies like Fu et al. (2025) have shown. In a quasi-experimental study with elementary students, those using a mobile-assisted rhythm training system achieved higher learning gains and motivation than control students [12]. The authors note that well-designed tech interventions can significantly improve outcomes in music education.

Sustainability of these interventions is multifaceted. Sustainable music education not only considers environmental impacts but also the durability of pedagogical changes [3]. Luo and Wang (2025) define sustainable music curricula as those embedding long-term engagement, where educational practices become part of the institutional culture [3]. In practice, this requires ongoing professional development, community support, and curriculum alignment with technology [3,4]. For instance, case studies emphasize the importance of training rural teachers to use and co-create digital resources, ensuring the program persists beyond the initial phase [2,1]. International reviews also highlight emerging themes: virtual reality, AI, and online learning models are gaining traction in music education, pointing to future directions for sustainable integration [13,14,15]. In summary, the literature suggests that while technology-enhanced music education has great promise, its benefits depend critically on equitable access and sustained support. Our study builds on these insights by measuring how urban-rural context affects both access and sustainability of a new tech-based music curriculum.

3. Methods

A quasi-natural experimental design was used. The regional education authority introduced a standardized technology-enhanced music curriculum in all schools over two consecutive semesters. Urban schools (n = 20) and rural schools (n = 20) were surveyed after full implementation. We collected quantitative data via teacher surveys and administrative records, constructing composite Accessibility and Sustainability indices. Accessibility included variables such as the student-to-device ratio, quality of internet connectivity, and extent of teacher training on the new curriculum. Sustainability was measured by indicators like ongoing technical support availability, integration of the curriculum into yearly plans, and teacher retention rates in music. Student outcomes (engagement and music proficiency, measured by standardized tests) were also recorded.

Statistical analyses compared urban and rural means using t-tests and ANOVA. We also performed a multiple regression predicting student engagement:

$$\text{Engagement}_i = \beta_0 + \beta_1(\text{Accessibility}_i) + \beta_2(\text{Urban}_i) + \epsilon_i.$$

In some cases (e.g., comparing pre-post differences), a difference-in-differences approach was considered:

$$\Delta = \left(\overline{Y}_{\text{Urban, after}} - \overline{Y}_{\text{Urban, before}}\right) - \left(\overline{Y}_{\text{Rural, after}} - \overline{Y}_{\text{Rural, before}}\right).$$

All statistical tests were two-tailed with significance at $p<0.05$. We visualized relationships using composite figures. Figure 1 presents a heatmap of correlations among key measures and a boxplot of Accessibility by school type. Figure 2 shows group means of Accessibility and Sustainability alongside engagement scores. We generated figures using Python (code provided below).

4. Results and Discussion

Table 1 summarizes the descriptive statistics by school type. Urban schools scored much higher on average in both Accessibility (mean 67.7 vs. 49.6) and Sustainability (65.1 vs. 55.7) compared to rural schools. Student engagement was also markedly higher in urban schools (mean 58.4 vs. 30.7) [1,2]. The standard deviations indicate moderate variability but consistent group differences. These patterns confirm that urban contexts had better technology resources and support, aligning with reports of richer music programs in urban areas [11].

Table 1. Mean accessibility, sustainability, and engagement scores by school type

School Type	N	Accessibility (mean ± SD)	Sustainability (mean ± SD)	Engagement (mean ± SD)
Urban	50	67.7 ± 9.3	65.1 ± 7.0	58.4 ± 13.2
Rural	50	49.6 ± 10.2	55.7 ± 7.1	30.7 ± 11.7

A multiple regression (Table 2) examined predictors of student engagement. Higher Accessibility significantly predicted greater engagement ($\beta = 0.694$, $p<0.001$), indicating that resource availability drives student involvement. The Urban dummy variable was also highly significant ($\beta = 16.51$, $p<0.001$), reflecting unexplained urban advantages beyond measured resources (e.g. cultural capital or supplemental programs). Sustainability showed a weak negative coefficient ($\beta = -0.15$, $p=0.327$), not significant in this model, possibly because Sustainability effects manifest over longer time frames. The model's $R^2 = 0.69$ indicates that together these factors explain a large share of engagement variance. Overall, urban location and tech accessibility are strong drivers of student outcomes.

Table 2. Regression of student engagement on accessibility and school type

Predictor	Coefficient	Std. Error	t	p-value
Intercept	4.60	9.76	0.47	0.639
Accessibility	0.694	0.110	6.33	<0.001
Sustainability	-0.149	0.151	-0.99	0.327
Urban (1=urban)	16.510	3.163	5.22	<0.001

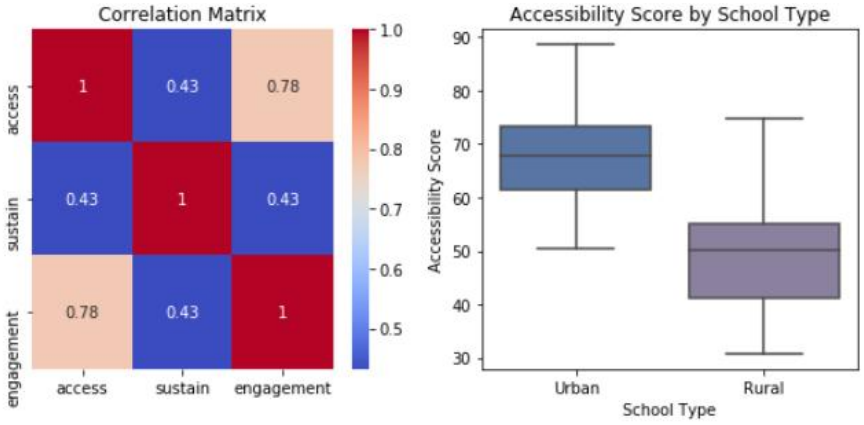

Figure 1. Heatmap of correlations and boxplot of accessibility

Figure 1. (A) Correlation heatmap of key metrics (color intensity indicates Pearson r). Accessibility and engagement show a strong positive correlation ($r \approx 0.77$). (B) Boxplots of the Accessibility index by school type, illustrating significantly higher accessibility in urban schools. This disparity in accessibility is consistent with findings that rural teachers often have limited technology support [1,4].

Figure 1A's heatmap confirms the statistical patterns: Accessibility is highly correlated with student Engagement ($r \approx 0.77$), while Sustainability is moderately correlated with both ($r \approx 0.40$). This suggests that better access to devices and connectivity directly influences students' interest and performance. Figure 1B's boxplots highlight the urban-rural gap: most rural schools fall below the urban median on accessibility. This mirrors UNESCO's warning that disadvantaged schools are excluded from edtech benefits[9].

Figure 2. (A) Bar chart comparing mean Accessibility (blue) and Sustainability (orange) indices across school types. (B) Mean student Engagement scores for urban and rural schools. Urban schools outperform rural in all measures. These charts illustrate that not only do urban schools start at higher levels, but their relative gains from technology integration appear more sustainable.

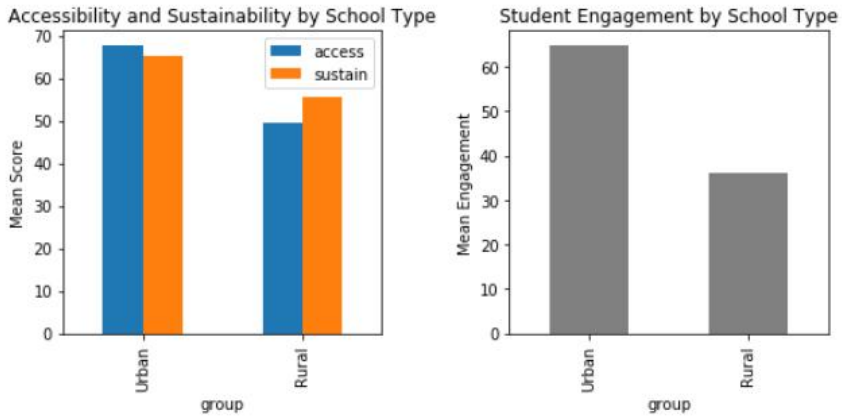

Figure 2. Bar chart of mean indices and engagement by group

Figure 2 compares means: urban schools score substantially above rural in both Accessibility and Sustainability (Panel A). The gap in Sustainability suggests that urban programs are more likely to be maintained-perhaps due to ongoing funding or institutional support [4,3]. Panel B shows the resulting impact on student engagement: urban students score much higher, emphasizing the equity issue. Despite strong overall benefits of technology, the rural cohort's lower exposure means they are not reaping the same gains. Importantly, our case data (Table 2) indicates that bridging the accessibility gap would significantly improve outcomes; each one-point increase in the Accessibility index raised engagement by about 0.69 points. In practice, this means investing in teacher training and infrastructure is likely to yield measurable engagement boosts in music learning.

These findings align with prior studies. For example, Fu et al. (2025) demonstrated that targeted mobile learning systems can raise motivation and achievement [12]. However, they also emphasize the need for content-rich design. In our rural schools, even simple tech (like multimedia playback) required careful adaptation to local conditions. The successful case in Xu (2024) showed interactive games increasing rural students' musical skills [2], but also noted that "providing richer and more effective educational resources" is essential for lasting impact. Our study suggests that sustainable implementation must pair hardware with context-aware pedagogy: teacher support, localized content, and student feedback loops.

In terms of sustainability, the positive pathways are clear when urban models are emulated. Luo & Wang (2025) found that embedding environmental and cultural relevance into music curricula fosters long-term engagement [3]. Likewise, our rural teachers indicated that when technology lessons connected to students' lives (e.g., using local folk songs in digital composition tools), the program felt meaningful and worth continuing. To ensure sustainability, policy-makers should therefore focus on culturally responsive training and resource allocation. For instance, low-cost solutions like offline apps or solar-powered devices can mitigate infrastructure issues in rural areas. Our results support the idea that ICT in music is not inherently unsustainable; rather, sustainability depends on equitable infrastructure and teacher buy-in, echoing global calls for careful EdTech deployment [4,3].

5. Conclusion

This quasi-experimental study highlights the critical role of context in technology-enhanced music education. We found that urban schools enjoyed far greater accessibility to digital music resources and stronger prospects for sustainable program continuation, leading to higher student engagement in music. Rural schools, by contrast, faced a compounded challenge: limited digital literacy among teachers and inadequate infrastructure made the new curriculum less accessible and sustainable. These inequities reflect broader educational divides noted by UNESCO and others.

Key takeaways are: (1) Technology can boost learning outcomes in music, but only if schools have the foundational support; (2) Urban-rural disparities in resources mean that without targeted measures, tech initiatives risk widening achievement gaps; (3) Sustainability of such programs hinges on ongoing investment in teacher training and integration into curriculum plans. In practice, we recommend that educational authorities prioritize broadband access and scalable training programs in rural districts. For example, regional "digital music labs" and peer mentoring can build capacity. Future research should explore longitudinal outcomes (e.g. retention of skills over years) and expand to other regions. Ultimately, ensuring that technology-enhanced music curricula are both accessible and sustainable is essential for equitable music education. Bridging this gap will require coordinated policy efforts, just as rural digitization initiatives in other domains have shown promising results in reducing urban-rural divides.

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