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HyFlex-Lite in Palestinian schools: Classroom orchestration strategies and equity in low-connectivity environments

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Abstract

This study examines an adapted Hybrid-Flexible ("HyFlex-Lite") model for Palestinian K–12 schools with limited connectivity. HyFlex-Lite structures each lesson for three concurrent modes—in-person, synchronous low-bandwidth online, and asynchronous low-bandwidth—while targeting equivalent objectives, activities, and assessments. A sequential explanatory mixed-methods design was used. In the quantitative phase, 310 East Jerusalem teachers completed a survey of modality equivalence, orchestration load, student interaction, educational equity, technical constraints, and institutional support; EFA/CFA validated the scales, and SEM tested hypothesized relations. The qualitative phase comprised semi-structured interviews, classroom observations, and document analysis with twenty teachers, examining orchestration strategies, infrastructure challenges, access-bridging practices, and professional-development needs. Findings show that higher modality equivalence is associated with greater perceived fairness, while interaction and equity are hampered by infrastructure limitations. Teachers employed pragmatic, low-data tactics (e.g., WhatsApp voice notes, printed packets) to include learners with poor connectivity, but reported heavy workload and a need for stronger institutional support. The study proposes a Modality-Equivalence Rubric to evaluate and refine HyFlex-Lite designs. Overall, the results suggest that context-appropriate strategies, coupled with technology provision and teacher training, can foster more equitable learning in resource-constrained environments; contributions include a validated modality-equivalence measure, a practitioner guide, and policy recommendations.

Keywords: HyFlex-Lite, digital equity, low-bandwidth learning, classroom orchestration, K–12 education

Introduction

Across low-resource schooling systems—particularly in East Jerusalem—routine infrastructure and connectivity constraints shape day-to-day instruction; the present study

focuses on these structural conditions rather than any single historical disruption. Within higher education, one flexible instructional approach that gained prominence is the Hybrid-Flexible (HyFlex) design, which allows students to participate in person, online synchronously, or online asynchronously while aiming for equivalence in learning across modes. HyFlex was originally conceptualized by Beatty (2006, 2019) to maximize student choice and access under the principle that outcomes should be equivalent regardless of modality. Research in higher education suggests HyFlex can improve engagement and performance when well implemented, while also surfacing challenges around equity and the added complexity of teaching across modes (Binnewies & Wang, 2019). Most empirical work to date has focused on universities and adult learners; a recent systematic review by Barr and Luo (2025) identified relatively few rigorous studies and found that nearly all were conducted in post-secondary contexts, leaving a notable gap for K–12 settings. Emerging school-level evidence indicates potential benefits alongside distinct implementation challenges for younger learners and their teachers. For example, a Turkish K–12 HyFlex pilot reported that well-prepared teachers could foster interaction and higher-order thinking, yet serving asynchronous students still demanded careful design (Filiz et al., 2024). Similarly, Mahande et al. (2024) showed that students' cognitive styles were associated with preferences for different HyFlex modalities, and that students' preferred modalities supported their perceptions of learning equity.

Collectively, these studies support the feasibility and promise of HyFlex-like models in primary and secondary education while underscoring the need to document teacher strategies and supports in under-resourced systems—such as many Palestinian schools—where infrastructure and connectivity constraints are routine.

Palestinian schools—particularly in East Jerusalem and the West Bank—offer a salient context for examining an adapted HyFlex model oriented to chronic infrastructure and access constraints. Even prior to major system-wide disruptions, educators contended with electricity outages, travel restrictions, device scarcity, and intermittent internet connectivity (Iriqat et al., 2025). Periods of disruption—notably during the pandemic period—amplified these long-standing inequities: many students in marginalized areas were unable to join live online sessions because of limited broadband or devices, and the rapid pivot to remote instruction exposed substantial gaps in teacher preparedness. In Palestine, emergency remote teaching was hindered by constrained connectivity, device sharing within households, and variable digital literacy, with clear implications for students' right to quality education (Khlaif et al., 2021). These persistent conditions point to the value of instructional designs that flexibly accommodate low-connectivity learners—essentially, a HyFlex approach calibrated for contexts where fully featured live-video classes are not always feasible (Affouneh et al., 2020).

In this paper, "HyFlex-Lite" is proposed and investigated as an adaptation of HyFlex for low-bandwidth, low-infrastructure contexts. The HyFlex-Lite concept is defined as the design of each lesson for delivery in three parallel modes:

- In-Class (Traditional): Students physically present in the classroom.

- Synchronous Remote (Low-bandwidth): Students join class remotely in real time, but using minimal data – for example, via a brief audio call or a lightweight video stream when possible (often just a phone call on speaker).
- Asynchronous Remote (Low-bandwidth): Students access materials and activities after the class, using low-data channels such as WhatsApp messages, SMS, offline PDFs, or printouts, and submit assignments once connected.

Crucially, HyFlex-Lite demands equivalency across these modes: the learning objectives, core content, student tasks, and assessments should be aligned so that no group is advantaged or disadvantaged. This aligns with the equivalency theory of distance education (Simonson, 1999), which argues that while learning experiences need not be identical, they should lead to equivalent outcomes for all students. In practice, achieving equivalency in HyFlex-Lite might mean, for example, that a science lesson includes a hands-on lab for in-class students, a live teacher demonstration (or interactive simulation) for synchronous remote students, and a home experiment with simple materials for asynchronous students – each mode different in delivery but targeting the same competencies. The "Lite" aspect reflects necessary simplifications given infrastructure constraints: e.g. using voice over video, text over multimedia, and more asynchronous work than a typical HyFlex class in a well-resourced setting. Unlike a traditional HyFlex implementation that leverages high-bandwidth tools and maximum student choice, HyFlex-Lite prioritizes low-data solutions and structured flexibility to accommodate severe connectivity limitations.

Implementing HyFlex-Lite poses significant challenges for teachers. They must orchestrate multiple modalities simultaneously, essentially planning and executing three versions of a lesson in parallel, often without additional time or support. This creates a high orchestration load – the cognitive and managerial burden on teachers to coordinate activities, tools, and students across learning spaces (Alvarez et al., 2025). Research on synchronous hybrid teaching indicates that teachers can experience considerable coordination, administrative, interaction, and engagement challenges when managing in-person and remote learners concurrently (Constantinou, 2023). A qualitative study in Europe found that synchronous hybrid teaching (SHT) is a "demanding mode" — one that involves coordination, administrative, interaction, and engagement challenges, and cautioned that hybrid classes often struggle to provide comparable learning experiences for in-person and remote students consistently (Constantinou, 2023). Similar or greater challenges are expected in low-resource Palestinian classrooms, where unreliable connectivity and limited access to advanced educational technologies are common. In such contexts, the viability of HyFlex-Lite is likely to depend on the creativity and adaptability of teachers, along with targeted support.

Literature review

HyFlex in Higher Education: The Hybrid-Flexible (HyFlex) model has seen growing adoption in universities as institutions sought to serve in-person and remote students concurrently and to preserve continuity during routine and acute disruptions. In a HyFlex course, students typically choose their mode of participation on a session-by- session basis

(e.g., attend physically one day, join synchronously online the next, or engage asynchronously later). Evidence points to increased satisfaction with flexibility and support for learning continuity; for instance, university students reported convenience alongside concerns about engagement and workload (Kohnke & Moorhouse, 2021).

Synthesis of implementations over the past decade suggests that, when instructors design for active learning and provide adequate support in each modality, learning outcomes in HyFlex can be comparable to those in traditional or fully online courses. At the same time, recurring challenges include technological reliability, greater instructor workload, and equity issues—such as remote students perceiving diminished inclusion (Bower et al., 2015; Binnewies & Wang, 2019). Recommended strategies include structured discussion forums and collaborative tools to ensure asynchronous learners have an equivalent voice (Binnewies & Wang, 2019). Overall, successful HyFlex teaching requires purposeful orchestration to bridge classroom and online spaces, along with sustained instructor preparation and support—areas where notable gaps have been documented, with many faculty learning by trial and error and calling for targeted professional development in hybrid course design (Armstrong, 2022).

Closely related constructs in the literature help situate HyFlex-Lite conceptually. In particular, blended synchronous learning (BSL) refers to instructional arrangements in which remote learners participate in face-to-face classes simultaneously through synchronous communication technologies (Bower et al., 2015). This construct overlaps with HyFlex in its concern for concurrent participation and inclusion across locations, yet HyFlex extends the model by explicitly preserving learner choice across in-person, synchronous online, and asynchronous pathways, while also emphasizing equivalence of learning outcomes across modalities (Beatty, 2019). Related labels such as synchronous hybrid learning, concurrent teaching, and hybrid learning have also been used to describe similar instructional arrangements, especially in contexts where teachers serve onsite and remote learners at the same time (Raes et al., 2020). Moreover, Wang and Huang's (2024) systematic review of blended synchronous learning highlights persistent challenges related to engagement, interaction, and the inclusion of remote learners, underscoring the relevance of these adjacent constructs for understanding the pedagogical demands of HyFlex-Lite in low-connectivity environments.

Hybrid Models in K–12 Education: Compared with tertiary education, research on HyFlex or hybrid-flexible models in primary and secondary schools remains limited. Nonetheless, periods of disruption and routine constraints have pushed many K–12 systems toward hybrid arrangements (often termed "hybrid learning" or "concurrent teaching") in which teachers simultaneously serve learners in the classroom and at home. While such implementations are not always "true" HyFlex—students may not have full freedom to choose their mode—they share core pedagogical and technological challenges with HyFlex and thus offer relevant lessons for design and support.

Although fully flexible HyFlex implementations remain uncommon in K–12 settings, adjacent school-based and blended synchronous models offer a useful comparative foundation. In these environments, teachers similarly coordinate instruction for co-present and remote learners in real time, even when student choice over attendance mode is

constrained. Evidence from K–12 and blended synchronous research suggests that the central pedagogical issue is not merely the label attached to the model, but whether participation, interaction, feedback, and task access are intentionally designed to remain as equivalent as possible across locations (Filiz et al., 2024; Keiper et al., 2021; Wang et al., 2018; Bower et al., 2015). This point is especially important for the present study: HyFlex-Lite is not positioned as a full replication of higher education HyFlex, but rather as a context-sensitive adaptation of its core principles—flexibility, equivalence, and inclusion—within school systems facing routine infrastructure constraints.

K–12 hybrid learning in under-resourced settings frequently encounters structural and institutional barriers that directly affect instructional quality and equity. Evidence from developing-region contexts shows that many schools lacked the capacity for fully online instruction, resulting in "diluted" hybrid arrangements that relied on phone calls, messaging applications, or take-home packets as partial substitutes for real-time teaching (Pokhrel & Chhetri, 2021; Adedoyin & Soykan, 2020). At the same time, teachers often reported feeling underprepared for the pedagogical and technical demands of hybrid delivery, which in many cases led to more teacher-centred instruction and reduced interactivity during remote participation (Trust & Whalen, 2020). These patterns suggest that successful hybrid implementation depends not only on technology access, but also on deliberate instructional design, targeted professional development, and sustained institutional support (Bower et al., 2015). In contexts such as Palestinian schools, where infrastructure and access constraints are persistent rather than temporary, a streamlined and resource-conscious adaptation such as HyFlex-Lite may represent the most realistic and sustainable pathway for maintaining continuity and promoting inclusion.

Digital Equity and Low-Resource Learning: Equity across attendance modes is a foundational principle of HyFlex-Lite. In this study, equity does not imply identical learning conditions, but rather comparably meaningful opportunities to access instruction, participate in learning activities, and achieve intended outcomes across in-person and remote modes. In low-resource systems, this goal is constrained by the digital divide, including disparities in internet reliability, device availability, and home-based learning support, which often reflect wider socioeconomic and geographic inequalities (UNESCO, 2020). During system-wide disruptions, such disparities became more visible, as well-resourced learners were more likely to sustain online participation while students in marginalized settings often relied on lower-bandwidth or offline alternatives such as printed packets, radio, or asynchronous mobile communication (Czerniewicz et al., 2020). For this reason, digital equity in HyFlex-Lite should be understood not only as a question of access, but also as a matter of instructional design: the extent to which learning tasks, communication channels, and feedback processes remain feasible and educationally meaningful under constrained conditions.

A framework by Mathrani et al. (2022) on online learning in five developing countries highlighted multi-layered inequalities: rural vs urban connectivity gaps, gender disparities in device access, and cultural barriers in communicating online, all of which affected students' ability to participate during school closures. They found that online learning during lockdown often exacerbated pre-existing educational inequities, as well-resourced

learners forged ahead while others were left with minimal instruction. This aligns with what has been characterized as a system-wide "wake-up call" about entrenched inequities—sharpened (Czerniewicz et al., 2020). Similarly, a literature review by Bozkurt and Sharma (2020) concluded that emergency remote teaching in low-income regions frequently defaulted to asynchronous and low-tech channels, which, while better than nothing, were less engaging and less effective for many learners. These findings underscore why equivalence in HyFlex-Lite cannot simply mean putting a webcam in the classroom. Instead, it demands intentional instructional design to support those with limited connectivity. Some recommended practices include using mobile-friendly content, chunking lessons into smaller, self-contained activities that can be done offline, and leveraging ubiquitous apps like WhatsApp or SMS for interaction (Bozkurt & Sharma, 2020; Bouhnik & Deshen, 2014).

In many low-resource settings, WhatsApp has emerged as a pragmatic teaching channel because of its low data demands, broad accessibility, and familiarity to teachers, students, and families. Studies from Arab and other resource-constrained contexts show that teachers used WhatsApp groups, voice notes, short video clips, and text-based prompts to sustain communication, distribute learning materials, and provide follow-up support during periods of disruption (Lassoued et al., 2020; Bouhnik & Deshen, 2014). Although such practices do not fully replicate the richness of face-to-face instruction, they can help preserve continuity and reduce exclusion when more robust platforms are inaccessible. At the same time, the literature suggests that equity in hybrid and low-connectivity learning should not be judged solely by the availability of a communication channel, but by whether learners across modes can meaningfully access explanations, complete tasks, receive feedback, and demonstrate learning outcomes under feasible conditions (Beatty, 2019; Wang & Huang, 2024).

Teacher Orchestration and Support: Implementing HyFlex-Lite places significant demands on teachers' pedagogical skills, technological proficiency, and time. In classroom research, the term "orchestration" refers to how teachers manage the flow of activities, resources, and interactions in a complex learning environment (Dillenbourg, 2013). In a multi-modal setting, orchestration includes not only typical classroom management but correspondingly coordinating across physical and virtual spaces – for example, repeating a student's question aloud so remote learners hear it, or ensuring an assignment is available both online and in printed form. This can result in what researchers call orchestration load, the burden on a teacher's cognitive and affective resources when directing multiple concurrent activities. A recent study by Constantinou (2023) found that primary and secondary teachers in Europe experienced four types of challenges in synchronous hybrid teaching: (1) coordination challenges – difficulty in handling the logistics of two audiences at once; (2) administrative challenges – dealing with technical issues and extra planning; (3) interaction challenges – fostering discussion between in-person and remote students; and (4) engagement challenges – keeping all students actively involved. Filiz et al. (2024) credited a structured training program in HyFlex lesson planning as a key factor in their teachers' success. Trust and Whalen (2020) also recommend that teacher preparation programs and in-service training include modules on online and hybrid pedagogy, given

that such modes are now part of mainstream education. On the institutional side, support might include providing at least basic technology (e.g. a classroom laptop and projector, internet data packages for teachers or students who need them), technical support staff or hotlines, and adjusted expectations (administrators recognizing that teaching in HyFlex-Lite is essentially triple workload and thus giving teachers adequate planning time or assistance). Without such support, there is a risk of teacher burnout and the collapse of initiative after initial trials. This study specifically inquiries about teachers' perceived support needs for sustaining HyFlex-Lite (RQ4), aiming to inform school leadership and policymakers on how to back teachers in these efforts.

Teacher orchestration load is another critical issue in HyFlex-Lite. Managing simultaneous in-class and remote activities imposes a heavy cognitive burden on instructors (Dillenbourg, 2013). Synchronous hybrid teaching has been described as a "demanding mode" requiring logistical coordination, technical troubleshooting, and extra effort to engage two sets of students at once (Constantinou, 2023). To handle these challenges, teachers need training and support: a structured HyFlex pedagogy program was a key success factor in one K–12 pilot (Filiz et al., 2024), and experts recommend that teacher education include hybrid teaching skills (Trust & Whalen, 2020). Institutional backing is also vital—providing basic technology tools, technical assistance, and realistic workload adjustments—to prevent burnout and sustain innovation. This study accordingly inquiries into teachers' support needs for HyFlex-Lite (RQ4) to guide school leaders and policymakers.

Taken together, the literature indicates that HyFlex and adjacent models—particularly blended synchronous and other concurrent hybrid approaches—offer a useful conceptual basis for understanding multi-modal teaching, yet important gaps remain. Most published evidence has emerged from higher education or comparatively better-resourced settings, while limited research has examined how core principles such as flexibility, modality equivalence, and inclusion can be adapted for K–12 schools operating under persistent low-connectivity and infrastructure constraints. In addition, the literature has not sufficiently explained how teachers in such contexts manage classroom orchestration across in-person, synchronous low-bandwidth, and asynchronous low-bandwidth participation, nor what forms of institutional support are most necessary to sustain equitable practice. The present study addresses this gap by investigating HyFlex-Lite in Palestinian schools as a context-sensitive adaptation of hybrid-flexible teaching for under-resourced educational environments.

Methodology

The study adopted a sequential explanatory mixed-methods design, consisting of a quantitative phase followed by a qualitative phase (Creswell & Plano Clark, 2018; Braun & Clarke, 2006). In the quantitative phase, teachers' perceptions were measured and hypothesized relationships were tested in a broad sample, while the subsequent qualitative phase provided deeper insight and context for those results. Ethical approval was obtained from the Al-Quds Open University Institutional Review Board, and informed consent was given by all participating teachers.

Quantitative phase

Design and Participants: A cross-sectional survey of K–12 teachers in East Jerusalem—marked by heterogeneous connectivity and socio-economic conditions—was conducted. Using cluster sampling across 40 primary, middle, and secondary schools, 310 teachers responded (≈68% response rate). The sample was balanced by grade level (32% teaching grades 1–4; 33% grades 5–10; 35% grades 11–12) and gender (53% female; 47% male), with ages 23–60 (M ≈ 38 years) and teaching experience of 1–38 years (M = 18.5, SD ≈ 10.2). About 60% taught in public/government schools and 40% in private or UNRWA schools. Reported school connectivity was poor or inconsistent for 44% of respondents, moderate for 36%, and good for 20%, underscoring the low-infrastructure context.

Survey Instrument: A structured Arabic questionnaire was developed using validated translation/back-translation, comprising six scales measured on a 5-point Likert agreement format (1 = strongly disagree to 5 = strongly agree). The scales draw on prior literature on HyFlex, classroom orchestration, and digital equity and are adapted to the K–12 context.

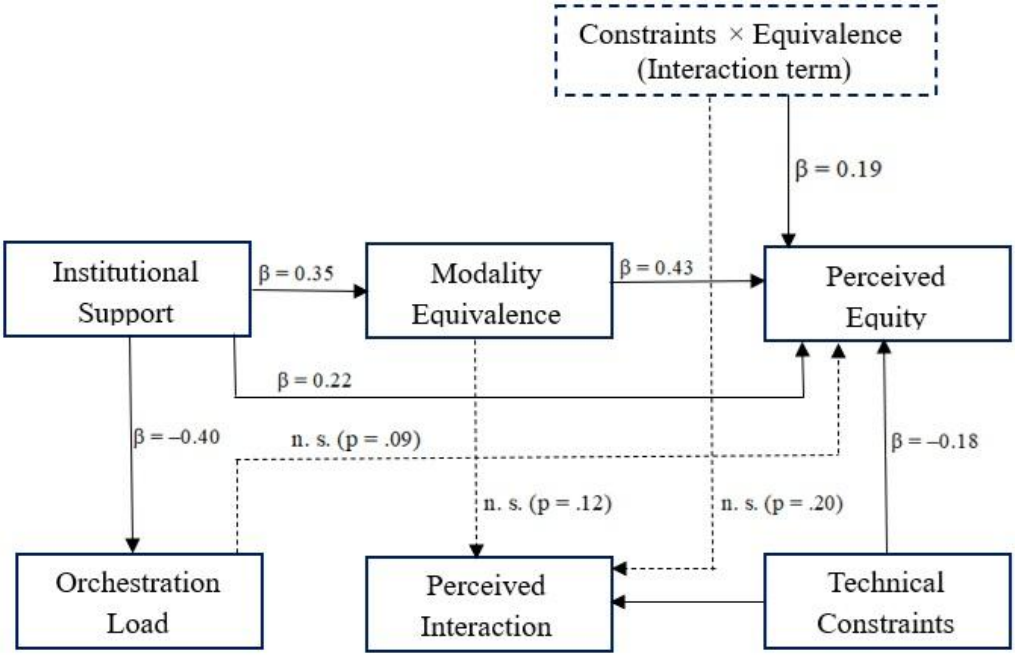
The instrument comprises six five-item scales that together capture design quality, instructional dynamics, and contextual supports in HyFlex-Lite. Modality Equivalence measures the extent to which teachers design equivalent objectives, activities, and assessments across in-person, synchronous remote, and asynchronous modes; an example item is "I ensure that students in all attendance modes achieve the same learning objectives by the end of the lesson," and the construct is grounded in equivalency theory and HyFlex design guidance (Simonson, 1999). Orchestration Load gauges the perceived burden and complexity of coordinating simultaneous in-person and remote activities, for example, "Coordinating simultaneous in-person and remote activities in my class is overwhelming," with items informed by prior measures of orchestration in hybrid settings (Alvarez et al., 2025). Perceived Interaction captures how interactive and participatory the class feels for both local and remote students, for instance, "Students frequently interact and ask questions, regardless of whether they are physically present or online." Perceived Equity reflects the teacher's sense of fairness and equal opportunity across modes, illustrated by, "I feel that students joining remotely are learning as much as those in class," focusing on perceived outcomes and fairness. Technical Constraints assesses infrastructure limits such as connectivity, device access, and technical support—e.g., "Lack of reliable internet for some students often disrupts my lesson plans"—with higher scores indicating greater constraints. Institutional Support measures school- and system-level backing for HyFlex-Lite, including administrative support, training, and resources; a representative item is, "My school provides sufficient technical support or resources for me to teach in multiple modes."

The survey instrument consisted of six short Likert-scale subscales (five items each) covering key aspects of the HyFlex-Lite environment: Modality Equivalence, Orchestration Load, Perceived Interaction, Perceived Equity, Technical Constraints, and Institutional Support. These scales were adapted from prior literature (e.g., equivalency theory for Modality Equivalence (Simonson, 1999), and existing hybrid-teaching measures for Orchestration Load and interaction) to fit the K–12 context. All six scales demonstrated acceptable internal reliability (Cronbach's α ranging from .78 to .90).

Figure 1 presents the structural equation model (SEM) for the HyFlexLite environment. The model showed acceptable global fit (CFI ≈ 0.948; RMSEA ≈ 0.058). Institutional Support increased Modality Equivalence (β = .35) and Perceived Equity (β = .22), while reducing Orchestration Load (β = −.40). Technical Constraints depressed both Perceived Interaction (β = −.30) and Perceived Equity (β = −.18). Modality Equivalence strongly enhanced Perceived Equity (β = .43), whereas its direct link to Perceived Interaction was not significant (β = .10, n. s.). Orchestration Load hindered Perceived Interaction (β = −.25). A significant moderation (β = .19*) indicated that the positive impact of Modality Equivalence on Perceived Equity was stronger when Technical Constraints were low. Bootstrapped indirect effects showed that Support improved Equity via Equivalence (≈ .15) and improved Interaction by lowering Orchestration Load (≈ .10).

Figure 1

Structural equation model (SEM) for the HyFlex-Lite environment.



Note. The model demonstrated acceptable fit (CFI ≈ 0.948; RMSEA ≈ 0.058). Solid arrows indicate statistically significant paths ($p < .05$); dashed arrows indicate nonsignificant paths. Path labels are standardized coefficients (β).

Exploratory and confirmatory factor analyses (EFA and CFA) supported a six-factor measurement model (e.g., total variance ≈ 68%, CFA fit indices: $\chi^2/df \approx 1.98$, CFI ≈ 0.95, TLI ≈ 0.94, RMSEA ≈ 0.056; see Appendix for details). All items loaded significantly on their intended factors, supporting construct validity. We then specified a structural equation model (SEM) to test hypothesized relationships among these constructs. Items were phrased as statements with Likert response options, and several single-item contextual indicators were included (e.g., "average internet speed available in class" on a 3-point scale,

and an estimated "percentage of students with home internet access"). The survey was delivered online via Google Forms and, for low-connectivity schools, in paper format; teachers responded anonymously, with assurances that findings would inform support for teachers rather than evaluate individual performance to encourage candid participation.

To operationalize "modality equivalence" at the lesson level under low-connectivity conditions, a concise rubric with six criteria was employed. Each criterion is rated on a 5-point Likert scale (1 = not equivalent at all, 5 = fully functional equivalence). Alignment is specified across objectives, materials, activities, interaction, assessment, and low-bandwidth access for three parallel modes: in-class, synchronous low-bandwidth remote, and asynchronous low-bandwidth.

Table 1

Example rubric for modality equivalence in a HyFlex-Lite lesson

Dimension / Criterion	In-class (face-to-face)	Synchronous low-bandwidth (remote)	Asynchronous low-bandwidth	Equivalence score (1–5)
Learning objectives	Clear behavioral objectives are stated to students at the start of the lesson.	The same objectives are announced via a brief text/voice note (60–90 seconds).	The same objectives are included in a lightweight PDF/worksheet.	☐
Content & materials	Textbook/board or a concise in-class demo is provided.	A lightweight PDF plus a short audio primer highlighting key points is provided.	A printed or offline-accessible PDF with identical core content is provided.	☐
Learning activities	A guided problem-solving task or light group activity is conducted.	An equivalent task is assigned (e.g., a simple homework step or posting a photo/comment during the session).	A functionally equivalent take-home task with clear steps and comparable time-on-task is assigned.	☐
Interaction & feedback	Short oral Q&A and quick-response signals (e.g., hand-raise/cards) are facilitated.	A text-chat backchannel, a quick reaction (👍/?), and one comprehension-check question are used.	Two reflective prompts are submitted as text/voice, and brief feedback is returned.	☐
Assessment (formative/summative)	A 5-item quiz or product submission is completed in class.	The same items are completed via a lightweight online form or file upload.	The same items are completed on paper with a clear photo submission.	☐
Access & time-on-task	Completion within ~35–40 minutes in class is expected.	Completion within ~30–35 minutes allowing for minor drops is expected.	Completion within 48–72 hours with offline alternatives is expected.	☐

The overall equivalence score for a lesson is computed as the mean of the six ratings. Interpretation: 1–2 = weak equivalence; 3 = partial equivalence; 4–5 = high/full equivalence. A score of 5 on a criterion is assigned when objectives and assessment tasks are functionally identical across modes and when time-on-task and access are comparable. Worked example: "Density" lesson: full equivalence was achieved on objectives, content, and assessment (5); high equivalence was recorded for activity and interaction due to voice-note plus chat alternatives (4); full equivalence was achieved on access/time (5). Mean = 4.8.

Quantitative phase

After initial cleaning, cases with >20% missing items were removed, yielding a final N = 310. Item distributions showed no serious non-normality (all Likert items skewness < |1.0|). To address RQ1–RQ2, scales were validated and interrelations examined via a two-step latent-variable approach:

Exploratory Factor Analysis (EFA): On a random half-sample, EFA (principal axis factoring, oblique rotation) indicated sampling adequacy (KMO = 0.89, "meritorious") and suitability (Bartlett's $\chi^2(435) = 3124$, $p < .001$). A six-factor solution (eigenvalues > 1; scree) matched the theorized scales and explained 68% of variance. Items loaded strongly on intended factors (≥ 0.65) with minimal cross-loadings (< 0.30). For instance, Modality Equivalence items loaded .72–.81 on a single factor. One Support item showing ~0.40 cross-loadings was removed, improving clarity. Reliability was acceptable to high ($\alpha = .78$ for Perceived Equity to .90 for Technical Constraints).

Confirmatory Factor Analysis (CFA): On the held-out half, a correlated six-factor model fit well: $\chi^2/df = 1.98$, CFI = 0.951, TLI = 0.943, RMSEA = 0.056 (90% CI: 0.050–0.062), SRMR = 0.049—all within recommended cutoffs. All items loaded significantly on their targets ($p < .001$; standardized .68–.87). Convergent validity was supported (AVE > .50; composite reliability ≥ .80). Discriminant validity met the Fornell–Larcker criterion (e.g., Modality Equivalence r with Perceived Equity = .50; $\sqrt{AVE} \approx .77 > .50$).

Structural modeling (SEM): With the measurement model established, halves were merged (multi-group CFA indicated no differences). The structural model treated Modality Equivalence and Technical Constraints as exogenous predictors; Perceived Interaction and Perceived Equity as endogenous outcomes; and Orchestration Load and Institutional Support as covariates. Given no strong a priori role for Orchestration Load, alternative specifications tested it as an outcome of constraints/support and as a moderator. Models were estimated via maximum likelihood (N = 310, model complexity suitable for covariance-based SEM). As a robustness check—given mild non-normality and interest in complex relations—PLS-SEM (SmartPLS v4) was also run, yielding very similar results; ML estimates are reported, with any differences noted.

Guided by the research questions, the study posits four hypotheses: H1—greater modality equivalence predicts higher perceived student interaction and equity; H2—greater technical constraints predict lower interaction and equity; H3—institutional support positively influences both modality equivalence (by enabling stronger multi-modal design)

and perceived equity (by providing inclusion resources); and H4—technical constraints moderate the modality-equivalence–equity link, such that stronger constraints weaken the benefits of careful HyFlex design.

For moderation, an interaction term (Modality Equivalence × Technical Constraints) was created after mean-centering the components to reduce multicollinearity. Orchestration Load was also examined as a mediator (e.g., support → reduced load → improved interaction) and as a moderator (high load attenuates the effects of modality equivalence). Indirect effects and interaction significance were assessed via bootstrapping (5,000 resamples).

The SEM achieved acceptable fit (CFI ≈ 0.95, RMSEA ≈ 0.06) and allowed us to examine how Modality Equivalence and Technical Constraints affect teachers' perceived Interaction and Equity, accounting for Orchestration Load and Institutional Support. In line with our research questions, we hypothesized that higher modality equivalence (and strong institutional support) would be associated with greater perceived student interaction and equity, whereas greater technical constraints would depress perceived interaction and equity. We also explored a possible moderation: that technical constraints might diminish the positive effect of equivalence on perceived equity.

Following the quantitative analysis, a qualitative phase was implemented to explain and enrich the survey findings (an explanatory follow-up in line with the mixed-methods design). Semi-structured interviews, non-participant observations, and document analysis were conducted with a purposive subsample of teachers drawn from the survey respondents.

Sampling and Participants: From among survey respondents who volunteered for follow-up, we purposively selected 20 teachers to ensure diversity in grade level, subject area, and survey responses. The subsample included lower-primary (grades 1–4), upper-primary (5–9), and secondary (10–12) teachers across subjects (Arabic, English, math, science, history). It also captured variation in HyFlex-Lite implementation: both "success" cases with high modality equivalence/low constraints and more challenged cases with low equivalence/high constraints were included. The sample comprised 12 female and 8 male teachers (pseudonyms T1–T20 for confidentiality).

Interviews: Semi-structured interviews (approximately 45–60 minutes each, conducted via phone or VoIP for convenience) were conducted in Arabic. The interview protocol was aligned with the research questions, covering four main areas: (a) teachers' lesson planning and orchestration strategies across in-class, synchronous remote, and asynchronous modes (RQ1); (b) the impact of infrastructure constraints (connectivity, device access) on teaching quality and student participation (RQ2); (c) strategies used to reduce learning gaps and support students with poor connectivity (RQ3); and (d) professional development experiences and support needs for hybrid teaching (RQ4). During the interviews, participants were also presented with a draft "Modality-Equivalence Rubric" (covering criteria such as objective alignment, activity and assessment equivalence, low-data accessibility, and clarity of instructions) and asked for feedback on its usefulness; their input was used to refine the rubric. All interview audio was recorded with permission and

transcribed. Key excerpts were translated into English for reporting while preserving meaning and tone.

Observations: We conducted brief classroom observations for 8 of the interviewed teachers (each observed in two sessions: one in-person lesson and the corresponding remote or asynchronous lesson, when feasible). For example, if a teacher taught a lesson to an in-person cohort on one day and repeated it via a low-bandwidth method (WhatsApp call or distributed materials) for remote students on another day, both instances were observed. Observations (lasting ~30–40 minutes each) were non-participant: the researchers took field notes on teacher actions, student engagement, technology use, and any equity issues noted, while minimizing interference. In one case, an observer was asked to momentarily assist by monitoring a WhatsApp group when the teacher was occupied.

Document Analysis: We collected relevant instructional documents from participating teachers to supplement observations. These included lesson plans that outlined parallel activities for in-class and remote students, sample assignments or worksheets for asynchronous learners, instructions sent via messaging apps, and anonymized student work submissions. The research team also piloted the Modality-Equivalence Rubric by applying it to a subset of lesson plans (five lessons) to gauge its effectiveness in identifying gaps between modes.

Data Analysis: A thematic analysis approach (Braun & Clarke, 2006) was applied to interview and observation data using MAXQDA.

Familiarization: Arabic transcripts and field notes were reread multiple times, with memos summarizing each teacher's account and key observations.

Coding: An initial scheme was developed deductively from research questions and inductively from emerging themes; two researchers independently coded four transcripts, reconciled definitions, then coded all data. Frequent codes included "Adapting Materials," "Real-Time vs Delayed Tradeoff," "Student Engagement Strategies," "Infrastructure Failures," "Workload and Stress," "Positive Outcomes," and "Professional Isolation."

Theming: Codes were clustered into themes aligned with RQ1–RQ4: planning/preparation, in-class vs remote techniques, and technology use (RQ1); connectivity/device challenges, constraint-driven adjustments, and effects on quality (RQ2); communication/follow-up, differentiation/flexibility, and social-emotional support (RQ3); and training, administrative/policy support, and infrastructure support (RQ4).

Integration: Qualitative findings were triangulated with quantitative results; strong equivalence–equity links were illuminated by teacher strategies to maintain equivalence, while the non-effect of equivalence on interaction was explained by accounts of remote student silence despite well-planned activities.

Trustworthiness: Member checks were conducted by sharing a thematic summary with three participating teachers, who confirmed resonance and offered minor clarifications; an audit trail was maintained, and investigator triangulation was achieved via comparison of interpretations by two researchers.

Reporting: Results are presented theme by theme with illustrative quotations (translated into English), cross-referenced to quantitative patterns; pseudonyms (T1, T2, …) identify teacher voices, with quotes minimally edited for clarity and context.

Interview and observation data were analyzed using thematic analysis (Braun & Clarke, 2006). The researchers first familiarized themselves with the data by repeatedly reading transcripts and field notes, noting initial observations. Next, a coding scheme was developed combining deductive categories (based on the research questions) with inductive codes emerging from the data. Two researchers independently coded a subset of transcripts to refine the code definitions, then coded all qualitative data. Codes were subsequently grouped into higher-order themes corresponding to the research questions (e.g., themes around lesson planning and multi-modal techniques for RQ1; infrastructure-related challenges for RQ2; gap-bridging practices for RQ3; support needs for R4). The qualitative findings were then compared and integrated with the quantitative results to help explain the survey patterns (for instance, qualitative accounts of remote student disengagement shed light on why equivalence alone did not boost interaction). To enhance trustworthiness, member checks were performed by sharing a summary of the findings with three teachers, who confirmed that the interpretations resonated with their experiences (with minor clarifications incorporated). An audit trail of data, codes, and analytic decisions was maintained, and two researchers engaged in peer debriefing to ensure consistency in theme development.

Results

Quantitative results

Descriptive Overview: Teachers reported moderate success with multi-modal equivalence alongside notable burdens. Modality Equivalence averaged M = 3.58 (SD = 0.80) on a 1–5 scale: 64% agreed that objectives were the same across modes and 59% that assignments were comparable, yet only 35% agreed assessments were equal. Orchestration Load was M = 3.60 (SD = 0.84): 58% found hybrid teaching stressful, >60% said it felt like preparing multiple classes, and 42% *strongly* agreed it was overwhelming. Perceived Interaction averaged M = 3.35 (SD = 0.82): roughly 70% felt in-class students were interactive, but only 40% felt remote students were sufficiently interactive. Perceived Equity was M = 3.38 (SD = 0.78): ~50% agreed opportunities were equal, 25% were neutral, and 25% disagreed. Technical Constraints were mid-to-high at M = 3.45 (SD = 0.85): 55% cited frequent internet interruptions and 50% reported many students lacking devices or data. Institutional Support was lowest at M = 3.14 (SD = 0.90): only ~30% felt sufficiently trained and 40% perceived active leadership support, with many noting they were "largely on our own." These tensions suggest targeted tools may help—interactive platforms like Flipgrid have been associated with stronger engagement and perceived equity in HyFlex settings (Keiper et al., 2021).

Factors Affecting Interaction and Equity: The SEM analysis indicated that higher modality equivalence was strongly associated with higher perceived equity (standardized $\beta \approx 0.43$, $p < .001$) but did not significantly increase perceived interaction ($\beta \approx 0.10$, n.s.), implying that engagement depends on additional factors beyond simply designing equivalent content. Technical constraints significantly depressed both perceived interaction ($\beta \approx -0.30$, $p < .001$) and perceived equity ($\beta \approx -0.18$, $p = .005$). Institutional

support improved perceived equity directly ($\beta \approx 0.22$, $p = .002$) and indirectly by enabling stronger equivalence (support → equivalence $\beta \approx 0.35$, $p < .001$, with a significant mediation effect on equity), and it also reduced teachers' orchestration load ($\beta \approx -0.40$, $p < .001$). In turn, lower orchestration load was associated with slightly better interaction ($\beta \approx -0.25$, $p = .001$, for the effect of load on interaction; note negative sign indicates high load reduces interaction). Orchestration load had a mild negative correlation with equity ($r \approx -.15$) but no significant direct path to equity in the model ($p = .09$).

Moderation of Infrastructure: Notably, the analysis revealed that the equity benefits of careful equivalence planning were *contingent* on infrastructure quality. A significant interaction (Equivalence × Constraints, $\beta \approx 0.19$, $p = .014$) showed that when technical constraints were low (decent connectivity), higher equivalence led to markedly higher perceived equity, whereas under high-constraint conditions the positive effect of equivalence on equity was weaker (though still positive). In other words, as one teacher (T7) explained, "No matter how well I prepare parallel activities, if half my students can't download the files or join the call, it falls apart." This moderation helps explain why some teachers who designed very equivalent lessons still saw limited gains in equity when connectivity issues were severe. (We did not find a significant moderation of equivalence on interaction by constraints, $p = .20$.)

Relationships Among Other Factors: The survey also showed that modality equivalence was moderately correlated with institutional support ($r \approx 0.47$), suggesting that teachers who felt supported were better able to design equivalently. Orchestration load correlated negatively with support ($r \approx -0.50$) and positively with constraints ($r \approx 0.25$), indicating that teachers in low-support or high-constraint contexts felt more burdened. Perceived interaction and perceived equity were only modestly correlated ($r \approx 0.17$), underscoring that a class can feel "fair" yet still not very interactive (and vice versa)—highlighting a need to address interaction separately from content equivalence.

Summary: In the quantitative results, teachers' efforts toward modality equivalence clearly related to higher perceived equity, yet heavy infrastructure limitations remained a primary drag on both interaction and equity. Equivalence-oriented practices help narrow access gaps only insofar as technology permits, leaving the challenge of boosting real-time interaction unresolved by equivalence alone. Meanwhile, institutional support emerged as pivotal: where present, it eased teacher burden and strengthened multi-modal implementation, thereby indirectly improving outcomes. These quantitative patterns motivate the in-depth qualitative analysis that follows, which illustrates *how* teachers orchestrated HyFlex-Lite, how infrastructure issues manifested in practice, which strategies aimed to level opportunities, and what supports teachers say are needed going forward.

Qualitative results

RQ1: Teachers' Orchestration Strategies Across Modalities

(a) Pre-planning and adapting materials: Teachers systematically aligned content across modes while tailoring delivery to constraints. T3's Grade 4 Arabic lesson, for instance, paired an in-class slideshow with printed story packets and a 3-minute WhatsApp audio

summary for at-home students, plus a short reflective worksheet to parallel the in-class discussion. T8 (secondary science) prepared "take-home lab kits" and encouraged student-recorded videos so that learners at home could synchronize their experiences with those in class. Planning was time-intensive: T5 (math) described creating an in-class slide presentation *and* a simplified handout, along with a Moodle version of the lesson with additional explanations for those online. Some teachers, like T14, occasionally reverted to photocopied textbook pages when time was short, acknowledging trade-offs in maintaining equivalence.

(b) Orchestrating synchronous interaction: Teachers acted as bridges between in-class and remote learners, often using basic audio connections. T1 (middle-school English) would repeat or paraphrase in-class students' contributions so remote students could hear, explicitly call on remote students by name to invite their participation, and keep track of who had spoken to "equalize" the discussion. Given limited video, she also sent photos of the whiteboard via WhatsApp so remote students could follow along. Attempts to use full-fledged video platforms (e.g., Zoom trials by T9, a history teacher) slightly improved social presence when they worked, but frequent call dropouts often derailed the interaction, undermining those efforts. Common low-tech tactics included cold-calling remote students periodically to ensure they had a voice, maintaining a text-chat channel that the teacher would read aloud to the class, assigning "remote buddy" helpers in the physical classroom (in-class peers who would look out for questions or chat messages from remote classmates), and even experimenting with parallel discussions (e.g., one group in class and another via WhatsApp) that the teacher would shuttle between. These strategies did boost inclusion of remote learners but at the cost of increased cognitive load for the teacher.

(c) Managing asynchronous learners: Teachers relied on structured follow-up and scaffolded materials to include students who could not join live. For example, T13 (math) scheduled brief weekly phone check-ins with her fully asynchronous students to provide both academic help and socio-emotional encouragement. T4 (Grade 3) sent daily WhatsApp broadcast messages each morning with a short voice note outlining the day's lesson and photos of the board work, to keep families of offline students aligned with in-class progress. T15 created self-explanatory printed packets for each week (readings with guiding questions, step-by-step examples for math) so that even if a student was offline for days, they had something coherent to work on. Despite these efforts, assessment of asynchronous learners remained difficult: teachers observed that students working offline often scored lower on quizzes. In response, some like T13 offered oral check-ins by phone to quiz those students verbally, T8 granted extra time or alternative assignments for those consistently offline, and a few teachers quietly adjusted grading, giving the benefit of the doubt when poor performance might be due to access barriers. These ad-hoc solutions highlight the need for clearer guidance on ensuring fair assessment across modes.

(d) Rubric feedback: In discussing the draft Modality-Equivalence Rubric, teachers overwhelmingly endorsed the idea of a structured tool for planning and reflection. The rubric's proposed dimensions—objective alignment, activity equivalence, assessment equivalence, low-data accessibility, and clarity of instructions (later revised to include "interaction equity")—resonated with their experiences. Teachers like T8, who scored one

of her own lessons using the rubric, found it helpful: her "density" science lesson scored well on objectives and content alignment but only moderate on interaction opportunities for asynchronous students, revealing a gap she had sensed but not explicitly evaluated. Overall, teachers felt the rubric could serve as a practical checklist or PD tool, remarking that if something like this had been introduced earlier, it "could have saved a lot of trial and error" (T14). They suggested minor tweaks (such as explicitly prompting for an interaction strategy for each mode) which were incorporated into the final version.

RQ2: Impact of Infrastructure Constraints on Teaching Quality and Equity

The qualitative evidence reinforced the quantitative finding that infrastructure limitations depress both interaction and equity, with teachers' experiences clustering into three themes: (a) connectivity challenges, (b) device and platform limitations, and (c) workarounds with trade-offs.

(a) Connectivity challenges: Nearly all teachers recounted lessons derailed by unstable internet. East Jerusalem's patchy coverage and slower speeds in some neighborhoods meant that remote students often dropped out of live audio sessions unexpectedly. T12 (computer science) described a programming demo she attempted via screenshare for remote students: "It froze halfway through for them — I had to abandon the live demo and email the code afterward," a much less interactive approach. Winter weather exacerbated outages; during storms, some teachers admitted they had little choice but to focus on the students who made it to the physical classroom, while those at home were told to "catch up when you can" with a worksheet — illustrating how in high-constraint moments, teachers reverted to survival mode, which helps explain why high constraints blunted the equity benefits of even well-designed equivalence. Bandwidth limits also forced pedagogical compromises: full-class video meetings were often impossible, so teachers like T11 rotated which remote students could join a given live session (e.g., inviting half of the remote students on one day and half the next) — an expedient that meant any one student had real-time interaction only once or twice a week.

(b) Device and platform limitations: Many students, especially younger ones, did not have their own devices. Participation often depended on a parent's smartphone and availability. T4 noted, "Whether my 8-year-olds could attend came down to if mom or dad was home and willing to let them use the phone." Shared devices introduced long delays in feedback loops: T16 recalled receiving homework photo submissions from some families only near midnight when a working parent returned home with the phone, meaning she could only respond the next day or later. The lack of a robust learning management system (LMS) or platform was another issue; as T14 put it, "Without any view/submit tracking, I was teaching kind of blind. I often had no idea which remote kids were following along or who had done the offline work until much later," adding to stress and uneven engagement.

(c) Workarounds and trade-offs: To conserve data and improve stability, teachers shortened live sessions, turned off video, or used audio-only conference calls. They would sometimes send photos of completed board work or summaries after a patchy live class, ensuring remote students got the content even if real-time discussion was lost. These choices maintained basic continuity but sacrificed richer interaction and immediate

feedback. Some community initiatives helped at the margins (e.g., a local NGO set up a Wi-Fi hotspot that a few students could use, according to T3), but systemic solutions were absent. Teachers also spoke of morale: "It's demoralizing when a lesson you prepared collapses because the connection died," said T7. She continued, "I do everything I can, but when a student doesn't have internet for a week, I know they are at a disadvantage… Those nuances, those spontaneous questions—they miss it. It feels unfair." Such experiences clarify why teachers in high-constraint environments reported lower perceived interaction and equity despite their substantial efforts: infrastructure issues routinely forced simplifications (shorter sessions, one-way communication, delayed feedback) that kept learning going in some form but undercut real-time engagement and parity.

RQ3: Practices to Reduce Access Gaps among Students

Teachers identified several practices they found effective (to a point) in closing participation and learning gaps for students with poor connectivity. The most common strategies clustered into: (a) flexibility in pacing and deadlines, (b) additional support and remediation, and (c) building community and motivation. Teachers were candid that each approach had limits, but many felt these efforts prevented worse inequities.

(a) Flexibility in pacing and deadlines: Nearly all teachers emphasized being flexible with requirements for students facing connectivity issues. They routinely extended deadlines and accepted alternative forms of work submission to avoid penalizing students for late or offline work. For instance, T11 mentioned she would accept a clear photo of handwritten homework even a week late, stressing "learning over deadlines." Some created individualized pacing plans for chronically asynchronous learners: T3 described crafting mini learning plans for two of her students who were rarely online, focusing them on core outcomes and excusing less critical tasks. T13 allowed mastery-based progression—letting remote learners skip repetitive exercises once they demonstrated understanding, so they could catch up faster. This flexibility, teachers felt, reduced unnecessary failure due to access problems, though they balanced leniency with maintaining clear minimum expectations to prevent procrastination from all students.

(b) Additional support and remediation: One-on-one or small-group support outside regular class time was common. Teachers provided extra help via whatever channels were available—weekly phone tutorials, WhatsApp Q&A chats, even occasional home visits or "drop-off tutoring" for worksheet delivery and pick-up. T5, for example, held an open Zoom hour every Monday after school for any remote students (or their parents) who had questions, which a handful regularly attended. Several teachers instituted "buddy" systems pairing an in-class student with a remote peer to encourage peer explanation and relay class information (T2 found this reduced her own load a bit and kept remote kids more connected socially). Many teachers also dedicated the start of each week to review and catch-up. T9 described how every Monday she'd review last week's key points and address gaps, "trading some curriculum coverage for making sure no one was completely lost." These remediation efforts undoubtedly consumed additional teacher time, but teachers believed they helped many lagging students improve enough to rejoin class activities.

(c) Building community and motivation: Teachers recognized that students who felt isolated or unmotivated at home were at high risk of disengaging. To counter this, they

celebrated remote students' work publicly when possible (e.g., T6 would project a particularly good homework submission from a remote student on the class screen, giving that student a sense of presence and recognition). A few integrated game-like activities that mixed in-person and remote players—for example, T6 formed "Kahoot teams" comprising both in-class and at-home students, so they had to collaborate via chat to answer quiz questions, adding fun and peer interaction. Regular personal outreach was also important: T15 said, "If a kid wasn't showing up, I'd call the parents, not to scold but to ask if everything was okay and how we could help." Teachers mentioned leveraging parents and community when possible: one parent of a remote student in T3's class organized a small neighborhood learning pod with a shared Wi-Fi hotspot, which helped several children stay on track during a particularly tough period. These community-based solutions were rare and depended on local initiative, but they illustrate how social support networks were tapped to bolster student engagement.

Limits and outcomes: Despite their efforts, teachers admitted there remained a subset of students (perhaps 20–30%) for whom these measures fell short—those who rarely engaged or had chronically no connectivity. "We could not save everyone," T7 reflected, noting some students virtually disappeared from learning for weeks at a time. Still, most teachers estimated that around 70–80% of their low-connectivity students eventually caught up to an acceptable level due to the accommodations and support. T8 shared a success story as proof of concept: one of her students was entirely asynchronous (no live access at all) for a semester, but by using the take-home lab kits T8 prepared, attending weekly phone tutoring, and working diligently, that student actually exceeded the class average on the final exam. Cases like this, though not the norm, were cited as evidence that pragmatic low-data strategies can meaningfully narrow outcome gaps when applied consistently and coupled with student perseverance.

RQ4: Professional Development and Institutional Support Needs

When asked about what would help sustain HyFlex-Lite and improve its effectiveness, teachers converged on three broad areas of needed support: (a) training and pedagogical guidance, (b) infrastructure and resources, and (c) policy and administrative measures.

(a) Training and guidance: Nearly all interviewees reported that they had been thrust into hybrid teaching with no formal preparation. They learned through trial-and-error, swapping tips with colleagues, and occasionally finding online resources on their own. Every teacher expressed a desire for targeted professional development (PD) on hybrid teaching tailored to low-bandwidth contexts. They wanted very practical training on using available tools (e.g., effective pedagogical uses of WhatsApp, basic LMS features that work offline), strategies for engaging remote learners, managing time and workload across the three modes, and designing asynchronous materials that can stand alone. T5 said, "I would have loved even a short workshop on best practices for hybrid teaching—what works, what doesn't." No one recalled any ministry- or district-led hybrid teaching workshops through Fall 2024; at best, a few had generic IT trainings. T13 mentioned attending an "online tools" webinar but noted it was geared toward university settings and didn't tackle elementary-level challenges. Teachers suggested that the Ministry of Education or local education offices develop clear guidelines or handbooks for hybrid

instruction in low-tech environments, and organize in-service training sessions. Some also advocated for school-based professional learning communities so teachers could regularly share experiences and co-develop solutions. A couple of teachers had even started a grassroots "tips document" among themselves. Additionally, teachers wanted guidance on assessment practices and policies for hybrid settings—how to fairly assess remote vs. in-person students, how to handle academic integrity for online work, etc. T9 proposed the Ministry could curate a pool of vetted low-bandwidth assignments or projects that schools could draw on, ensuring some standardization and fairness.

(b) Infrastructure and resources: Unsurprisingly, the top requests were for improved connectivity and hardware. Teachers argued that without reliable school internet and student device access, no amount of training would fully succeed. Many called for a push toward at least one device per student (even if just a basic tablet or an arrangement of lending devices to those in need) and partnerships with telecom companies to provide affordable data bundles or zero-rated educational content for students. T4 bluntly stated, "We can train all we want, but if a kid has no device or data, they're cut off." In terms of classroom setup, teachers wanted basic hybrid equipment: at minimum, a decent microphone and speaker in each classroom, and ideally a simple camera or document camera so they wouldn't have to hold their phone for remote students to hear or see. None expected fancy smart boards or multiple cameras—"just a step up from a phone on speaker," as T15 put it. Another idea was a unified platform (or clear official choice of platform) that was mobile-friendly and low-bandwidth, possibly with offline capabilities. Currently, teachers were piecemeal using WhatsApp, email, printed sheets, Google Forms, etc., which could confuse students and parents. A consistent, simple system (or at least guidelines on effectively using one or two free tools) would reduce complexity.

(c) Policy and administrative support: Teachers emphasized the need for supportive policies from both school administrators and the education authorities. A recurring theme was workload adjustment: teaching in HyFlex-Lite was "like teaching extra classes for free," so they suggested measures like reduced teaching loads or additional prep periods for those handling hybrid classes. Some proposed having smaller class sizes or co-teaching arrangements (e.g., an assistant or a rotating second teacher to help manage remote learners) whenever hybrid instruction is regularly implemented. Clear policies on attendance accounting, grading, and curriculum pacing in hybrid mode were also requested—teachers felt they were left to improvise these and feared being penalized later for deviations. Administrative attitude and support were noted: T13 said, "Don't wait for another crisis. Let's invest now in making our schools hybrid-capable in a sustainable way," urging multi-year planning. Teachers called for their principals and supervisors to receive training too, so that leadership understands the challenges and realistic expectations of HyFlex teaching. Simple acts like principals checking in on teacher well-being, acknowledging the extra effort, and facilitating collaborative problem-solving were mentioned as making a big difference. One concrete support many mentioned was having an ICT coordinator or technician available – T15's school had a part-time ICT coordinator who was a "lifesaver" whenever something broke or a quick workaround was needed, and teachers wished such a role could be established in all schools.

Compiling their input, teachers' "wish list" for institutionalizing HyFlex-Lite included: structured hybrid-pedagogy training and ongoing PD, robust internet connectivity and progress toward one-device-per-student (or at least per family), basic classroom tech kits (microphone, speaker, simple camera), a unified low-data digital platform or toolkit, built-in planning time or staffing support (so hybrid teachers aren't overextended), and clear policy frameworks for hybrid instruction. They stressed that implementing these in combination would transform HyFlex-Lite from an emergency improvisation into a stable, equitable model of flexible learning in low-connectivity environments.

Discussion

The implementation of a "HyFlex-Lite" model in Palestinian K–12 schools facing significant connectivity limitations was examined in this study. The findings integrate survey results with interview- and observation-based accounts, highlighting: (i) concrete orchestration routines that kept multi-modal lessons aligned across in-person, synchronous remote, and asynchronous contexts; (ii) bandwidth and device constraints that dampened spontaneous interaction; and (iii) equity gains when equivalence was explicitly designed, though tempered by infrastructure problems.

Equivalence vs. Interaction — a tension: Teachers' efforts to align content, tasks, and assessments across modes were associated with stronger perceptions of fairness in student outcomes, consistent with HyFlex principles and equivalency theory. Quantitatively, higher modality equivalence correlated with a sense that "no one is left behind," underscoring the centrality of instructional design for equity. Yet our results also make clear that high content equivalence did not automatically yield high interaction: remote participation often lagged because of poor audio quality, student reticence, and divided teacher attention. This echoes findings from other hybrid settings that flexibility can coexist with diminished online interaction quality (Kohnke & Moorhouse, 2021). The implication for K–12 is that we must distinguish content equivalence from process (interaction) equivalence. Younger learners, in particular, need deliberate facilitation to engage remotely (e.g., structured turn-taking, polls or chats, targeted "cold-calling" of remote students) and modest technology upgrades (a better microphone, a second device or camera for the teacher) to realize the full benefits of synchronous hybrid learning (Raes et al., 2020). In other words, designing equivalent *material* is necessary but not sufficient—teachers also have to proactively orchestrate interactions to approximate an equivalent experience.

Infrastructure — the fundamental enabler: Consistent with wider evidence, connectivity and device access emerged as decisive factors for HyFlex-Lite success. Our moderation analysis showed that infrastructure quality conditions the equity gains of careful pedagogical design (Pokhrel & Chhetri, 2021; Khlaif et al., 2021). Even the most well-planned hybrid lesson can falter if students cannot get online or access materials. Policy priorities therefore must include improving broadband infrastructure and affordability (e.g., public–private partnerships to expand internet access, subsidies for low-income families), having contingency plans for outages (such as providing cellular data back-ups or pre-loading content on local devices), and issuing guidelines for safe, purposeful use of ubiquitous low-data platforms like WhatsApp. Without these foundations, teachers end up

scaling back interactivity or re-teaching content later to those who missed out, losing precious time and blunting the pedagogical impact of HyFlex-Lite. In essence, infrastructure is the bedrock upon which equitable hybrid learning is built; without it, even the best teacher efforts yield only partial results.

Teacher workload and support: Our mixed-methods evidence indicates HyFlex-Lite currently imposes substantial extra work on teachers. They are effectively managing two or three classrooms at once—juggling in-person facilitation, tech troubleshooting for remote students, creating self-paced materials, and providing individualized follow-up. This mirrors reports from other contexts of under-preparedness and overload when teachers tackle concurrent teaching (Trust & Whalen, 2020). Even by Fall 2024 (well after initial pandemic disruptions), the absence of structural supports meant burdens remained high in these schools. One promising avenue to alleviate this is building communities of practice among teachers. We saw organic peer support emerge (teachers sharing tips informally), and formal facilitation of such communities or mentoring could help spread effective practices and reduce isolation. Additionally, clear administrative guidance on hybrid teaching expectations (for assessment, attendance, academic integrity, etc.) would help teachers by aligning their day-to-day decisions with a supportive policy framework, rather than leaving them guessing or relying on personal discretion. In short, teacher orchestration load needs to be recognized and mitigated through both collegial support networks and top-down policy measures.

Student outcomes and equity: Most teachers reported that the majority of their students made acceptable progress under HyFlex-Lite, but a notable minority lagged significantly—an unequal pattern consistent with the heterogeneous effects seen across many pandemic-era studies (Maldonado & De Witte, 2022). The qualitative data showed that teachers tried to compensate via tutoring, flexible pacing, and other supports, and indeed many previously disengaged students improved over time. Offering learners some choices in how to engage (within the constraints) likely contributed to perceived equity, aligning with evidence that modality preferences and individual learner characteristics matter (Mahande et al., 2024). However, relying on heroic teacher efforts and informal fixes is not a sustainable solution. Institutionalizing remedial programs (extra tutoring, "bootcamps" for those falling behind, etc.) and monitoring student progress across modes systematically would make these equity gains more consistent and less dependent on individual teacher initiative. Importantly, our study did not include direct student perspectives, which is a limitation—one we return to below. Future research and interventions should center student experiences to better understand how hybrid modality differences affect their motivation and learning outcomes.

Rubric and practical framework: The Modality-Equivalence Rubric introduced in this study offers a concrete planning and evaluation tool. It prompts teachers (and observers) to verify alignment across modes—for example, checking that asynchronous learners have a way to ask questions or be assessed fairly, not just that they receive the content. Used in observations or coaching, the rubric can sensitize administrators to the complexities of hybrid teaching and help target professional development to specific needs (e.g., if many teachers score low on "interaction equity," training can focus there). This resonates with

RPTEL's emphasis on design and evaluation of technology-enhanced learning: we provide a design framework that others can adapt and test. The positive reception of the rubric by teachers suggests that practitioners are eager for such tools to systematically reflect on and improve their hybrid lesson designs, rather than proceeding by trial and error alone.

Comparison with other contexts: It is instructive to compare our findings with experiences in better-resourced settings. In well-resourced hybrid classrooms, multiple cameras, tracking microphones, and integrated LMS platforms can create more seamless experiences—yet even there, engagement and workload challenges persist (Miller et al., 2021; Kohnke & Moorhouse, 2021). Across contexts, some common themes recur: the necessity of instructor training (Armstrong, 2022), institutional support as a throughline (Barr & Luo, 2025), and vigilance about equity (Binnewies & Wang, 2019). Solutions trialed elsewhere, such as co-teaching models or assigning a dedicated "remote moderator" to assist the lead teacher, could be adapted to K–12 if resources permit (even a part-time teaching assistant or a trained student helper might fulfill this role). Such measures would complement the low-data, resource-conscious strategies that define HyFlex-Lite. It's also worth noting that studies in Asia and Europe have reached similar conclusions about hybrid learning: clear design principles and support systems are what make the difference, more than the specific technologies used (Wang et al., 2018; Raes et al., 2020; Raes, 2022). Our context extends these lessons to a low-connectivity environment, reinforcing their general importance.

Theoretical Implications: Beyond the immediate context, this study contributes to broader theoretical conversations in educational technology. First, our findings extend equivalency theory (Simonson, 1999) into the K–12 hybrid domain by empirically demonstrating that designing for modality equivalence can foster a sense of fairness and inclusion. At the same time, we refine this theory by showing that equivalence must be multidimensional: achieving *content* equivalence is not enough without attention to *interaction* equivalence. This distinction adds nuance to the concept of modality equivalence and highlights an area for theoretical development in hybrid learning models. Second, we provide empirical insight into orchestration load (Dillenbourg, 2013; Alvarez et al., 2025) under constraint-driven conditions. Our data illustrate how teachers' cognitive and managerial load increases in multi-modal teaching, aligning with orchestration theory but also emphasizing the influence of external constraints (infrastructure, support) on that load. This suggests that orchestration load models should account for contextual factors like bandwidth and institutional backing, not just the number of concurrent tasks. Third, we contribute to the discussion of equity in technology-enhanced learning by examining what equity means in a severely constrained environment. Our findings underscore that "equitable outcomes" in hybrid settings depend not only on giving students access to multiple modalities, but on ensuring the *quality* of each modality is sufficient for learning. This advances conceptual understanding by framing equity as a function of both design and infrastructure—proposing that equity-oriented frameworks incorporate the idea of *constraint-critical design*, where the limitations of the environment are considered a central part of pedagogical planning. In sum, by investigating HyFlex-Lite, we bridge practical

design with these theoretical constructs, thereby enriching the discourse on how modality, orchestration, and equity intersect in new hybrid models.

Limitations: These findings should be interpreted with awareness of context. Conducted in East Jerusalem Palestinian schools during Fall 2024–2025 within a largely necessity-driven hybrid setting (marked by intermittent attendance and external constraints), the results may not generalize fully to stable, fully elective HyFlex environments. The quantitative outcomes also reflect teachers' self-reported perceptions of interaction and equity; future studies could complement these with direct indicators of student learning and engagement (e.g., test scores, platform log data). Finally, although the interview sub-sample was purposively diverse, some self-selection is possible—participants may have been especially innovative or particularly frustrated—so "middle-ground" perspectives might be less prominent despite our survey-informed sampling to broaden representation. Moreover, this study was limited to the teachers' perspective and did not include direct data from students. We do not know how students themselves perceived HyFlex-Lite or how it impacted their learning experience. This absence of student voice is an important limitation that future research should address by incorporating student feedback and performance data.

Implications and recommendations

For teachers, the strategies shared here—pre-recorded audio for asynchronous learners, student "buddy" systems linking home and classroom peers, and flexible assessment windows and formats—can serve as a peer-sourced toolkit. The Modality-Equivalence Rubric can be adapted as a planning aid to check alignment, accessibility, and participation opportunities across modes in lesson design.

For school leaders, concrete supports are needed to make HyFlex-Lite sustainable: schedule adjustments that give teachers time for hybrid planning, structures for peer collaboration and mentoring on hybrid pedagogy, and advocacy for essential technology (even relatively small investments, like an inexpensive classroom microphone, can markedly improve hybrid audio quality and signal institutional backing). Assigning or hiring an ICT coordinator (even part-time) could provide vital on-call technical help and relieve some teacher burden. School leaders should also develop clear guidelines (in consultation with teachers) on hybrid classroom routines, attendance, and assessment policies to ensure consistency and fairness.

For policymakers (e.g., the Ministry of Education in Palestine), a comprehensive Hybrid Learning Preparedness Plan is recommended. This should integrate infrastructure targets (e.g., achieving reliable broadband at all schools and progress toward one device per student or per household), incorporate hybrid-pedagogy training into teacher certification and ongoing in-service programs, and establish contingency protocols (like distributing offline learning kits or providing emergency connectivity solutions) to prevent learning loss during future disruptions. Policymakers could also explore partnerships with community organizations and telecom providers to extend internet access (such as community Wi-Fi hubs or subsidized data for educational use) and reduce data costs for students. Importantly, policy should formally recognize hybrid teaching in teacher

workload calculations and provide incentives or support for those who pioneer these models.

For research, this study opens several avenues. Interventions inspired by these findings should be tested—such as providing a group of schools with structured HyFlex-Lite professional development (including rubric training and low-data tech tools) and comparing outcomes with control schools that continue business-as-usual. Future studies should also directly examine student perspectives, which were missing here, to understand learners' sense of inclusion, motivation, and perceived equivalence across modes. Especially for fully asynchronous learners, hearing their voices would illuminate what works and what doesn't from the student standpoint. Finally, continuing to refine and validate tools like the Modality-Equivalence Rubric in different contexts can contribute to a broader framework for evaluating hybrid learning designs.

Conclusion

Evidence from HyFlex-Lite implementations in Jerusalem's schools demonstrates that even amid infrastructure limits and complex local conditions, a carefully calibrated hybrid-flexible approach can sustain learning and reduce exclusion when deliberately scaffolded. This study contributes much-needed K–12 evidence to a literature on hybrid learning that has been dominated by higher education contexts, and it offers a practical framework—a rubric and related strategies—for designing and evaluating lessons with modality equivalence and low-data accessibility in mind. For the audience of *Research and Practice in Technology Enhanced Learning*, these insights are directly actionable for educational practice and program design in similar contexts.

As education systems worldwide prioritize resilience and flexibility (UNESCO, 2021), the lesson is clear: successful hybrid learning depends as much on people and support structures—teacher capacity, student engagement, community involvement—as on digital tools. Equity should remain the organizing principle: every student, whether seated in a classroom, connecting intermittently by phone, or working offline, deserves learning of equivalent value. Done well, HyFlex-Lite is a pragmatic step toward that ideal, turning constraints into a catalyst for thoughtful innovation.

Abbreviations

AVE: Average Variance Extracted, BSL: Blended Synchronous Learning, CFA: Confirmatory Factor Analysis, CFI: Comparative Fit Index, EFA: Exploratory Factor Analysis, HyFlex: Hybrid-Flexible, HyFlex-Lite: Hybrid-Flexible Lite, IRB: Institutional Review Board, K–12: Kindergarten through Grade 12, KMO: Kaiser–Meyer–Olkin, LMS: Learning Management System, ML: Maximum Likelihood, PD: Professional Development, PLS-SEM: Partial Least Squares Structural Equation Modeling, RMSEA: Root Mean Square Error of Approximation, RQ: Research Question, SD: Standard Deviation, SEM: Structural Equation Modeling, SMS: Short Message Service, SRMR: Standardized Root Mean Square Residual, TLI: Tucker–Lewis Index, VoIP: Voice over Internet Protocol.

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Author's contributions
The authors jointly conceived the study, designed the research framework, collected and analyzed the data, interpreted the results, and wrote the entire manuscript. All stages of the research process—from conceptualization to final editing—were completed independently by the authors.

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Together, the authors bring complementary perspectives from educational technology and information technology to the investigation of HyFlex-Lite models, classroom orchestration, and digital equity in low-connectivity Palestinian school settings.

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Availability of data and materials
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Declarations

Competing interests
The authors declare no competing interests or financial ties that could have influenced the study.

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