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Measuring the Effectiveness of Blended Learning in the Post-Pandemic Era: A Comparative Quantitative Analysis of Flipped Classroom and Hybrid Flexible (HyFlex) Models on Cognitive Achievement and Student Engagement in Indonesian Senior High Schools

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ABSTRACT

The COVID-19 pandemic has accelerated the adoption of blended learning across Indonesian senior high schools (SMA), but systematic evidence comparing different blended models remains limited. This quantitative study conducted a comparative secondary data analysis of flipped classroom–based blended learning and Hybrid Flexible (HyFlex) models with respect to cognitive achievement and student engagement at the upper secondary level. Drawing on a national meta-analysis of blended learning in Indonesia (27 studies, 2016-2020), quasi experimental studies of flipped classroom implementations in SMA, and international HyFlex evaluations, this study synthesizes standardized mean differences, mean score differences, and survey-based engagement indicators. Overall, blended learning demonstrates a large positive effect on Indonesian students' learning outcomes, including in senior high school (SMD ≈ 1.00 vs. Conventional instruction). Within this context, flipped classroom–based blended learning yields substantial gains in critical thinking and other higher order cognitive outcomes, although the effects on writing performance depend strongly on students' self-regulation. HyFlex implementations at the tertiary level generally match face-to-face instruction in cognitive outcomes, but produce mixed patterns in grade distributions and student satisfaction. The discussion interprets these findings for Indonesian SMA in the post pandemic context, arguing that flipped classroom designs have stronger empirical support than HyFlex for improving cognitive achievement and structured engagement under current infrastructural and policy conditions.

Keywords: Pandemic, Flipped Room, Hybrid, Flexible

I. INTRODUCTION

The COVID-19 pandemic fundamentally disrupted schooling in Indonesia. In early 2020, face to face learning was suspended nationwide, and secondary schools transitioned to various forms of distance learning (Pembelajaran Jarak Jauh, PJJ), supported by emergency regulations from the Ministry of Education and Culture (Kemdikbud) and local governments. When limited face-to-face learning (Pembelajaran Tatap Muka Terbatas, PTMT) was gradually reintroduced, schools commonly adopted blended arrangements that combined in-person sessions with synchronous and asynchronous online learning. In parallel, the Merdeka Belajar policy and Merdeka Curriculum began to foreground student centered, flexible, and technology enhanced learning, including project-based, problem-based, and blended learning approaches at the SMA level (Zaharah, 2022).

Indonesian senior high schools have experimented with multiple blended models in this rapidly evolving context. On the one hand flipped classroom–based designs relocate exposure to content (e.g., video lectures,

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digital texts) to pre class online activities and use classroom time for active, collaborative problem-solving and higher-order tasks. On the other hand. Hybrid Flexible (HyFlex) models allow students to choose between face-to-face, synchronous online, and in some variants asynchronous online participation from session to session, under the principle of equivalence of learning outcomes across modalities. Both models can be framed as specific instantiations of blended learning, but they embody different assumptions regarding structure, flexibility, and student responsibility (Mentzer et al., 2024).

Indonesian evidence has accumulated that blended learning can improve learning outcomes across levels, including SMA. A national meta-analysis of 27 experimental and quasi-experimental studies conducted between 2016 and 2020 reported an overall standardized mean difference (SMD) of 1.01 in favor of blended learning over conventional instruction, with a high effect size, specifically at the senior high school level (SMD = 1.00, 95% CI [0.68–1.31]). Subgroup analyses also indicated large effects on knowledge (SMD = 1.02) and thinking skills (SMD = 1.11) and a moderate effect on motivation and self-regulated learning (SMD = 0.66). These findings are consistent with international meta analyses that position blended learning is superior or at least not inferior, to traditional face-to-face instruction across multiple subjects and educational levels (Salma et al., 2023).

However, this aggregate evidence masks important internal variations. "Blended learning" in Indonesia has been operationalized through a range of models: guided inquiry–based blended instruction in physics, collaborative blended learning for English writing, flipped-problem-based learning via Google Classroom, and other locally developed integrations of learning management systems (LMS) and face-to-face activities. Therefore, the meta analytic effect reflects a family of practices rather than a single, well-specified model (Lusa et al., 2021).

Simultaneously complementary global literature on HyFlex instruction has expanded rapidly in the wake of the pandemic. HyFlex courses, originally conceived in higher education, provide students with real time choice of participation mode-face-to-face, synchronous online, or asynchronous online—while aiming to maintain equivalence in learning objectives and assessments. Empirical studies in undergraduate contexts generally show that HyFlex environments do not significantly disadvantage students relative to full face-to-face formats in terms of grades, although the distribution of grades and patterns of participation can shift in complex ways. Student satisfaction tends to be high regarding flexibility; however concerns persist regarding workload, cognitive load, and equity of access to technology (Mulyadi et al., 2024).

For Indonesian SMA, school leaders and teachers contemplating post pandemic blended learning face at least three strategic questions.

Effectiveness: To what extent does blended learning improve cognitive learning outcomes and higher order skills (e.g., critical thinking) relative to pre pandemic conventional teaching?

Model choice within blended learning: Among different blended models, how does a structured flipped classroom approach compare with the more flexible HyFlex model in terms of cognitive achievement and student engagement?

Contextual fit: Which model better aligns with Indonesian upper secondary conditions, such as infrastructure constraints, teacher readiness, Merdeka Belajar curriculum expectations, and persistent digital divide?

While several Indonesian studies have evaluated flipped classroom variants in SMA contexts, especially in science and language learning, there is almost no primary research on full HyFlex implementation at the K-12 level in Indonesia. Nonetheless, the pressure for flexibility during and after the pandemic, driven by health concerns, family obligations, and infrastructural inequalities, has made HyFlex an attractive concept in policy discourse and higher education practice, including in Indonesia and the wider region (Nirwana et al., 2025).

Given this evidence, this study positions itself as a quantitative comparative synthesis of existing empirical work rather than a new field experiment. It leveraged three complementary data streams.

A national meta-analysis of blended learning interventions in Indonesia, with explicit subgroup analyses for senior high school and types of learning outcomes.

Indonesian quasi-experimental studies of flipped classroom–based blended learning in SMA, reporting pre and post-test or treatment–control comparisons on cognitive outcomes and, indirectly, engagement.

International quantitative studies of HyFlex courses are primarily in higher education, but with robust reporting on cognitive performance and student satisfaction.

By consolidating these strands, this study addresses the following research questions (RQs):

RQ1. What is the overall quantitative effect of blended learning on cognitive achievement and engagement-related outcomes for Indonesian senior high school students compared to conventional instruction?

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RQ2. Within blended learning, how effective is the flipped classroom model in improving cognitive achievement (including higher order thinking) and student engagement in SMA contexts?
RQ3. How do HyFlex models perform relative to traditional face-to-face or conventional blended learning in terms of cognitive outcomes and engagement based on available quantitative evidence?
RQ4. Given the existing evidence base and the specific constraints and priorities of Indonesian senior high schools in the post pandemic period, how do the flipped classroom and HyFlex models compare suitability and likely impact cognitive achievement and engagement?
These questions are not merely academic in nature. Under Kurikulum Merdeka, SMA graduates are expected to demonstrate critical thinking, collaboration, communication, creativity, and digital literacy which are more demanding than pre pandemic standards. Blended learning is explicitly cited as a vehicle for achieving such competencies. At the same time, experiences during the pandemic-era PJJ revealed significant gaps in teachers' pedagogical digital competence, uneven student access to devices and connectivity, and variable levels of learner autonomy. Any recommendation regarding a specific blended model must integrate empirical effectiveness with realistic assessments of readiness and equity.
The remainder of this paper is organized as follows. Section 2 reviews the relevant literature on blended learning, the flipped classroom, and HyFlex models, with emphasis on Indonesian SMA contexts and constructs of cognitive achievement and engagement. Section 3 outlines the quantitative synthesis methodology, including study selection, variables, and analytic strategies. Section 4 presents the results in four parts: the overall effects of blended learning, cognitive and engagement outcomes of flipped classroom models, cognitive and engagement outcomes of HyFlex models, and a comparative synthesis. Section 5 discusses the theoretical, practical, and policy implications for Indonesian senior high schools, as well as the limitations and directions for future primary research. Section 6 concludes the study with concise recommendations.

II. METHODS

A. *Research Design*

Given the absence of large scale primary comparisons between flipped classrooms and HyFlex models in Indonesian senior high schools, this study employs a quantitative secondary data synthesis design. The approach is comparative and explanatory: it aggregates and juxtaposes effect sizes, mean differences, and related quantitative indicators from existing empirical studies to assess and contrast the effectiveness of flipped classroom–based blended learning and HyFlex models on cognitive achievement and engagement (Sugiyono, 2019).
The design aligns with the principles of the meta analytic review, but it is more targeted and model-specific than the broad national meta-analysis of blended learning by Lusa et al. (2021). Rather than recomputing pooled effect sizes from scratch, the study extracts reported statistics standardized mean differences, means and standard deviations, p values, and proportions and integrates them into a structured comparative narrative focused on the specific models of interest (Lusa et al., 2021).

B. *Study selection and inclusion criteria*

Study identification proceeded in three conceptual strata:
Blended learning in Indonesia (baseline comparison):
Studies included in the national meta-analysis by Lusa et al. (2021) and related Indonesian empirical work on blended learning in SMA and MA (Islamic senior high schools) were used to characterize the overall effect of blended learning and establish a baseline against which more specific models could be compared (Lusa et al., 2021).
Flipped classroom–based blended learning in SMA.
Indonesian quasi-experimental or experimental studies at senior high school level were sought that:
explicitly implemented a flipped classroom or blended-flipped model;
reported quantitative learning outcomes (test scores or equivalent);
provided sufficient information to interpret effect direction and magnitude.
Key studies meeting these criteria include Radiah's investigation of a blended learning flipped classroom model in SMA biology and Sastri and Anwar's study on flipped classrooms in SMA recount-text writing, supported by additional design and perception studies.
HyFlex or functionally equivalent hybrid-flexible models (for comparative purposes):
As no Indonesian SMA HyFlex studies were identified, HyFlex research from international higher-education contexts was considered, focusing on clear HyFlex or closely related hybrid-flexible designs (students can participate face to face or remotely within the same course) quantitative comparisons with traditional

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face-to-face or online modalities on academic performance (grades, test scores, pass rates), and, where available, engagement or satisfaction (Arikunto, 2017).
Prominent examples include Verrecchia and McGlinchey's comparison of HyFlex and face-to-face statistics courses, Mentzer et al.'s interactive synchronous HyFlex design-thinking course, Guidry's institutional analysis of HyFlex versus face-to-face success rates in business courses, and Rhoads' doctoral work on HyFlex satisfaction and performance.
Only peer reviewed journal articles, conference proceedings, and theses with clearly described quantitative methods and outcomes were included for all strata. Qualitative and purely conceptual works on HyFlex and flipped classrooms were consulted for an interpretive context but were not used as primary data sources (Khairal Abd et al., 2022).

C. *Variables and operational definitions*
Within the selected studies, variables were aligned to two main outcome domains:

Cognitive achievement:
Standardized mean differences (SMD) were calculatd between the experimental and control groups, as in Lusa et al. (2021).
Mean test scores (e.g., critical-thinking essay scores and writing scores) with standard deviations, enabling interpretation of effect directions and approximate magnitudes.
Course grades (final grades and project scores) and pass/success rates in HyFlex vs face-to-face courses.
Engagement related Outcomes.
Motivation and self-regulated learning scales were aggregated in the meta-analysis (SMD for attitudes).
Student perceptions and satisfaction with the flipped classroom and HyFlex modalities were quantified (e.g., percentages of students endorsing flexibility, reporting stress, or preferring specific modalities).
The instructional model (independent variable) was categorized as follows.
Conventional instruction: predominantly face-to-face, teacher-centered classroom teaching with minimal or ad hoc use of digital tools.
Generic blended learning: any structured combination of face-to-face and online elements not explicitly described as flipped or HyFlex (e.g., LMS-supported guided inquiry, collaborative blended learning).
Flipped classroom–based blended learning: blended models where core content is systematically delivered before class via online media and in-class time is used for active application, often with explicit flipped-learning stages (pre-class, in-class, post-class).
HyFlex: courses in which students can choose different participation modalities (face-to-face or remote; synchronous or asynchronous) within the same course under a design that seeks equivalence across modalities.

D. *Data extraction and synthesis procedures*
For the national blended learning meta-analysis, numerical SMD values and confidence intervals by education level and outcome type were extracted directly from the reported forest plots and summary tables. For SMA-level flipped classroom studies, the following data were recorded: sample sizes per group; mean and standard deviation of post test scores (and, where relevant, pre-test scores); t-test results and p values indicating statistical significance of differences; and descriptions of instruments used to measure cognitive and engagement outcomes.
For HyFlex studies, the primary extracted metrics were the means and standard deviations of quizzes, exams, and final grades for HyFlex vs face-to-face groups; success rates (proportion of A–C grades) by modality; survey results on satisfaction and perceptions of flexibility and workload, where numerically reported.
Given the heterogeneity of designs and outcome measures, formal re calculation of pooled effect sizes across all studies was not attempted. Instead, the analysis proceeded in two stages: Within-model synthesis: For each model (generic blended, flipped, HyFlex), central tendencies and reported effect sizes were summarized to characterize the typical magnitude and direction of impact on cognitive achievement and, where possible, engagement.
Cross-model comparison: The synthesized findings were then compared qualitatively across models, focusing on differences in effect sizes, patterns of benefits and risks (e.g., distributional changes, dependence on student self-regulation), and contextual considerations such as technology requirements and teacher competencies.
This study deliberately avoids inflating precision by pooling the incommensurable statistics. Instead, it aims to construct an evidence informed comparative profile that can guide decision making in Indonesian SMA.

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E. *Validity, limitations, and ethical considerations*

Using published secondary data avoids ethical concerns regarding the direct involvement of human participants; all cited studies obtained ethics approval under their respective institutional frameworks. Nevertheless, this synthesis has several validity and generalizability constraints.

Contextual mismatch for HyFlex: HyFlex evidence is derived almost entirely from higher education contexts in different countries. Extrapolation to the Indonesian SMA must therefore, be cautious and contingent on local conditions.

Model overlap: Some Indonesian "blended" studies may in fact incorporate flipped elements without labeling them as such, and some HyFlex implementations also use flipped pre class materials. This overlap may blur the category boundaries.

Measurement diversity: Different instruments and grading practices across studies introduce measurement non-equivalence, limiting formal cross study pooling.

Publication bias: Although Lusa et al. (2021) reported symmetrical funnel plots for blended learning studies,specific to flipped classrooms and HyFlex. there may still be bias toward publishing positive or novel results.

The analysis acknowledges these limitations and interprets the findings as indicative rather than definitive, especially in relation to recommendations for Indonesian senior high schools.

III. RESULTS AND DISCUSSION

A. *Research Design*

The national meta analysis provides a robust quantitative benchmark for the impact of blended learning in Indonesia. For senior high schools, the pooled SMD of 1.00 (95% CI [0.68–1.31]) indicates that, on average, students in blended learning conditions performed one standard deviation higher on learning outcomes than students in conventional classes. This effect magnitude is considered large by Cohen's conventions, and suggests pedagogically meaningful gains in test performance and other cognitive measures.

Subgroup analyses by type of learning outcome further show:

Knowledge mastery: SMD = 1.02 (95% CI [0.77–1.26]), indicating that blended learning substantially improved students' mastery of declarative and procedural knowledge.

Thinking ability: SMD = 1.11 (95% CI [0.76–1.47]), suggesting even stronger effects on higher order cognitive skills such as critical thinking, problem solving, and reasoning.

Attitudes (motivation and self-regulated learning): SMD = 0.66 (95% CI [0.02–1.30]), reflecting moderate but significant positive impacts on motivational and self-regulatory dimensions.

These patterns were consistent with the individual SMA studies included in the meta analysis. For example, a quasi-experimental study at SMA Negeri 1 Pangkalan Susu reported average physics test scores of 73.52 in a blended class vs 63.05 in a conventional class, alongside high observed student activity (average 71.85, "good" category). Similar gains have been documented in SMA mathematics and geography, with blended instruction supported by Edmodo and other platforms.

The key implication is that blended learning, in aggregate, is a high yield strategy for cognitive achievement in SMA, particularly when designed to engage students in active processing of content and higher order tasks. This establishes a positive baseline against which specific blended models, including the flipped classroom and HyFlex, can be compared.

B. *Cognitive outcomes of flipped classroom–based blended learning in SMA*

The flipped classroom literature at Indonesian senior high schools, although more limited in volume than generic blended studies, offers direct comparative data on cognitive outcomes.

The blended learning model with a flipped classroom component in SMA biology in Malinau during the transition to limited face to face learning. Sixty students from two grade-XII science classes were randomly assigned to the experimental (flipped blended) and control (conventional) groups (n = 30 per class). The flipped model followed three phases: pre class online engagement with learning materials, in class active application and discussion, and post class project based tasks, aligning with higher levels of Bloom's taxonomy.

Critical thinking was assessed using an 11-item essay test validated for content and reliability ($\alpha = 0.713$). The results are summarized as follows.

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Table 1. Critical thinking scores under flipped blended vs conventional SMA biology instruction

Group	n	Pre-test mean	Post-test mean	Key findings
Flipped blended (experimental)	30	64.57	77.00	Significant pre–post gain (p = 0.000)
Conventional (control)	30	63.50	67.97	No significant pre–post gain (p = 0.160)
Between-group comparison	_	_	70.917 vs 64.383 (post-test means)	Flipped blended significantly higher (p < 0.05)

The pre test means were similar (64.57 vs 63.50), indicating comparable initial critical-thinking levels. After the intervention, the mean of the flipped blended group increased to 77.00, while that of the conventional group rose modestly to 67.97. The between group difference in post test scores (70.917 vs. 64.383, as reported in the Abstract) was statistically significant. These results indicate a sizable advantage of flipped blended instruction for developing critical thinking in SMA biology, consistent with the large SMD for thinking skills found in the broader blended learning meta analysis.
Qualitative classroom observations in the same study reported that flipped blended classes exhibited more student driven problemmsolving, group discussions, and connections to real life contexts, whereas conventional classes were dominated by teacher exposition and note-taking with limited opportunities for students to articulate and justify reasoning. This qualitative pattern aligns with the quantitative gains and illustrates how flipped classroom design reallocates the cognitive load from passive reception to active inquiry.
The post test writing scores, assessed using an analytic rubric for recounting texts, were:

Table 2. Writing scores under flipped vs conventional SMA recount-text instruction

Group	n	Post-test mean	SD	t_observed vs t_table	Statistical conclusion
Flipped classroom	32	70.63	10.85	t = 1.906 < 2.000	No significant difference
Conventional	30	65.00	12.37	–	–

Although the mean of the flipped group was 5.63 points higher than that of the control group, the difference was not statistically significant at $\alpha = 0.05$. The authors attributed the limited effect primarily to low student motivation and weak engagement with pre class online materials; many students read messages in the WhatsApp group but did not actively study the videos and texts or ask questions. In addition, students were more accustomed to conventional teacher centered writing instruction and some perceived the flipped tasks as burdensome or confusing.
This case illustrates that flipped classroom designs do not automatically translate into significant cognitive gains; their success depends on how effectively students are scaffolded and motivated to take responsibility for out-of-class preparation and on how well teachers orchestrate in-class activities to build on that preparation.
Considering these and related studies, three patterns emerge:
Higher order cognitive gains are robust in the sciences.
In SMA science subjects (biology, physics, mathematics), flipped classroom–based blended learning consistently enhances critical thinking, reasoning, and problem solving relative to conventional instruction, with effects ranging from moderate to large, as exemplified by Radiah (2022) and studies of flipped problem-based mathematics learning in Medan and other regions.
Skill-based outcomes are more sensitiveto motivation.
In language and writing contexts, the cognitive advantage of flipped learning appears contingent on sustained student engagement with pre class content and iterative feedback. When learners lack self regulation or perceive limited support, the potential benefits may not materialize despite structurally sound flipped designs.
The flipped classroom is a high structure, high support model.
Unlike more loosely specified blended arrangements, effective flipped classroom implementation requires detailed planning of pre class, in class, and post class tasks, clear expectations, and ongoing monitoring of student preparation. This structured nature can be advantageous in the SMA context, where students'

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independent learning skills are still developing, but it also increases the demands on teacher time and instructional design capacity.

C. *Engagement outcomes under flipped classroom models*

Although relatively few SMA flipped classroom studies quantify engagement with standardized scales, available evidence suggests that flipped blended models can enhance classroom participation, perceived relevance, and collaborative learning, while placing significant responsibility on students for out-of-class work.

In Radiah's biology study, classroom observations during flipped blended sessions documented more student initiated questions, peer explanations, and group problem solving compared with conventional classes, where many students remained passive listeners. The author argues that the flipped model aligns well with the scientific-inquiry character of biology and encourages students to connect abstract concepts to local environmental issues, thereby fostering deeper engagement.

Perception surveys in Indonesian EFL contexts indicate that students often appreciate the increased interaction and feedback opportunities in flipped classes, reporting that the model helps them practice language skills more actively during class. However, students also expressed concerns about uneven video quality, heavy workloads, and insufficient guidance on how to use pre-class materials effectively, pointing to the need for careful design and teacher professional development.

From a broader perspective, the meta analytic finding that blended learning generates a moderate positive effect on attitudes, including motivation and self regulated learning (SMD = 0.66), suggests that well-implemented flipped blended designs in the SMA can contribute meaningfully to engagement-related competencies emphasized in Kurikulum Merdeka, provided that support structures for autonomy and time management are in place.

D. *Cognitive outcomes of HyFlex models*

As HyFlex research is dominated by tertiary contexts, the cognitive outcomes reported must be interpreted as indicative of the model's potential rather than being directly generalizable to SMA. Nonetheless, the consistency of the findings across multiple courses and institutions provides a useful reference.

Across the key HyFlex studies examined, the central finding is the cognitive equivalence between HyFlex and face-to-face modalities:

In Verrecchia and McGlinchey's 300-level statistics course, out of ten quizzes and one final exam, only two quiz scores and the final exam showed significant differences between the HyFlex and face-to-face groups; overall course grades and most assessment components did not differ significantly. The HyFlex class outperformed the face-to-face class on the final exam (mean 19.15 vs 15.32 out of 25) and one quiz, whereas the face-to-face class outperformed the HyFlex class on another quiz.

In Mentzer et al.'s design-thinking course, the overall semester grades and major project scores were statistically similar between the 2019 face-to-face cohort and the 2020 interactive synchronous HyFlex cohort, although students in the HyFlex group could switch daily between in person and remote participation. The primary difference was in grade distribution: the HyFlex cohort had a higher proportion of A and F grades, suggesting that the model may particularly benefit self-regulated, resourceful students while exposing less self-regulated students to a higher risk of failure.

Guidry's institutional study found no significant effect of delivery mode (HyFlex vs. face to face) on success rates (A–C grades) across 166 business course sections, with average success rates of 85.54% (HyFlex) and 88.24% (face to face). Instead, the quantitative intensity of the course and its level (freshman versus senior versus graduate) predicted performance.

These results reinforce a core conclusion from earlier HyFlex literature syntheses: properly designed HyFlex courses do not, in general, reduce student academic performance relative to traditional formats, and may, in some cases, support equivalent or slightly improved outcomes.

Evidence on engagement and satisfaction under HyFlex is more nuanced:

Qualitative and mixed methods studies report that students value HyFlex autonomy and flexibility particularly when balancing work, family, and studying or dealing with health and transportation constraints. Surveys in adult and professional programs often show that a large majority of students appreciate the ability to switch between modalities; for example, one report cited in Lieberman (2018) found that 95% of students liked flexibility and 98% liked the ability to change attendance modes as needed.

However, Guidry (2022) documented that, in a business faculty experiencing emergency HyFlex deployment during the pandemic, 59% of surveyed students perceived their HyFlex experience as worse than traditional

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face-to-face instruction, citing difficulties in understanding material, higher distraction levels, and reduced interaction with faculty. Over 75% reported academic stress, and many highlighted technological and economic barriers (limited access to functional computers, unreliable Internet, and costs of remote-proctoring tools).

Rhoads (2020) and other studies summarized in Beatty (2019) emphasize that HyFlex can increase satisfaction when students choose the modality proactively and when courses are deliberately designed and supported. However, rapid, unplanned transitions to HyFlex under crisis conditions can result in confusion and reduced perceived quality.

In short, HyFlex appears to offer strong benefits for flexibility and access, particularly for diverse working or commuting student populations, but engagement outcomes are highly sensitive to instructional design quality, institutional support, and students' technological circumstances.

E. *Comparative synthesis: flipped classroom vs HyFlex for SMA-relevant outcomes*

Bringing together the evidence on flipped classrooms and HyFlex, several comparative observations can be made regarding cognitive achievement and engagement, focusing on their relevance to Indonesian senior high schools in the post pandemic context.

Magnitude and robustness of cognitive gains:

Flipped classroom–based blended learning at SMA, especially in science subjects, demonstrates clear and often large improvements in cognitive outcomes compared with conventional instruction, exemplified by Radiah's critical thinking gains and corroborated by related STEM focused studies. These gains align with the high SMD values for the effect of blended learning on thinking skills in the national meta-analysis. In contrast, HyFlex model generally yield cognitive performance equivalent, but not substantially superior, to traditional face-to-face teaching in higher education contexts.

HyFlex implementations may reshape grade distributions, increasing both high and low outcomes, as observed in Mentzer et al.'s design-thinking course, whereas flipped classroom studies in SMA typically report more uniformly positive shifts in class averages with limited attention to distributional extremes. For SMA systems in which equity and minima (e.g., minimum competency standards) are policy priorities, a model that raises the average performance without disproportionately increasing failure may be preferable.

Structured versus flexible autonomy.

Flipped classrooms offer structured autonomy: students are required to engage with specific pre class materials by given deadlines, and in class activities are tightly designed to build on that preparation. This arrangement may suit SMA students who benefit from guidance but can be gradually introduced to self-regulated learning. HyFlex, by granting autonomous choice of participation modality session by session, presupposes higher levels of self-regulation, time management, and digital literacy, which are unevenly developed among Indonesian adolescents, particularly in contexts with digital divide.

Technology and equity constraints.

Both the flipped classroom and HyFlex require access to devices and connectivity. HyFlex amplifies these requirements because synchronous remote participation and, in some variants, remote proctoring must be reliably supported. In many Indonesian regions, SMA students continue to face unstable Internet connections, limited device ownership, and shared family responsibilities that constrain synchronous attendance. Under such conditions, a carefully designed flipped blended model that emphasizes asynchronous pre-class engagement and predictable limited in person sessions may be more resilient and equitable than a full HyFlex deployment.

Teacher capacity and institutional support.

The high quality implementation of both models demands significant professional teacher development. However, HyFlex additionally requires proficiency in the simultaneous management of onsite and online students, use of conferencing technology, and maintenance of equivalence across modalities, which many Indonesian SMA teachers are unlikely to have at present, given the documented challenges in adopting even basic digital tools during the pandemic. Flipped classroom design, while also demanding, aligns more closely with existing blended practices (e.g., distributing materials via WhatsApp or Google Classroom and using class time for exercises) and may therefore represent a more realistic evolutionary step.

Overall, the evidence suggests that for the near- to medium-term in Indonesian senior high schools, flipped classroom–based blended learning offers a stronger and more context-appropriate pathway for raising cognitive achievement and structured engagement than HyFlex, which remains promising but more technically and organizationally demanding.

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F. *Discussion*

The comparative synthesis presented here indicates that blended learning is an effective macro strategy for improving cognitive outcomes and higher order skills in Indonesian senior high schools and that within this broad category, flipped classroom–based models currently have a more robust and contextually appropriate evidence base than HyFlex for the post pandemic period. This section discusses the implications of these findings through four lenses: (1) alignment with Indonesian policy and curriculum reforms, (2) pedagogical mechanisms underlying effectiveness (3) organizational and infrastructural feasibility, and (4) research and evaluation priorities.

Merdeka Belajar and the Merdeka Curriculum emphasize student centered, competency based learning, with a strong focus on critical thinking, collaboration, communication, creativity, and character education. Blended learning, project-based learning, and problem-based learning have been highlighted as core strategies for realizing these aims in SMA.

Flipped classroom–based blended learning closely aligns with these policy directions. By design, flipped models shift classroom time away from teacher centered lecturing toward student centered activities such as discussions, problem solving, experiments, and collaborative projects. This reallocation directly supports the development of higher order competencies, as evidenced by gains in critical thinking and conceptual understanding in SMA science subjects and positive student perceptions of collaborative engagement. Furthermore, the requirement that students engage with pre class content cultivates self-regulated learning, digital literacy, and responsibility for one's own learning—competencies explicitly valued in Merdeka Belajar (Misbah & Saleh, 2025).

In principle, HyFlex models also resonate with Merdeka Belajar's vision of flexibility and personalization, granting students the autonomy to choose modalities that fit their circumstances and learning preferences. For older learners, particularly university students juggling work and family responsibilities. HyFlex can expand access to and support lifelong learning without sacrificing cognitive outcomes. However, for SMA students, who are still developing foundational autonomy and whose access to technology is often constrained, the open-choice element of HyFlex may be premature and could exacerbate inequities unless carefully scaffolded and supported (RAMADHANİ et al., 2019).

From a policy standpoint, therefore, flipped classroom models can be viewed as an operationalization of Merdeka Belajar's pedagogical aspirations within existing SMA structures, while HyFlex represents a more radical structural shift whose benefits may be more fully realized in later education stages or in specific well-resourced pilot contexts.

The superior cognitive performance of the flipped blended models in SMA science subjects can be interpreted through several mutually reinforcing mechanisms.

Advanced organizer effect:

Pre class materials in flipped designs serve as advance organizers, allowing students to build initial mental models before engaging in more complex in class tasks. Sequencing can reduce intrinsic cognitive load and free cognitive resources during classroom activities for higher order processing. The observed critical thinking gains in Radiah's biology study align with this explanation, as students came to class already acquainted with core concepts and could devote time to analyzing and synthesizing, rather than merely encoding, information (Nasongkhla & Sujiva, 2022).

Increased opportunities for feedback and formative assessments.

When content delivery is moved outside the class, teachers gain more time to circulate, question, and provide immediate feedback during class activities. This formative support is particularly important in STEM contexts, where misconceptions are common and can be corrected in real time. Flipped designs also allow for pre, class quizzes that provide early signals of misunderstanding enabling targeted remediation.

Activation of social constructivist processes.

Flipped classroom sessions typically incorporate collaborative problem solving, peer explanation, and group projects, harnessing peer-to-peer learning mechanisms that are known to deepen understanding and engagement. In Indonesian SMA classrooms, where cultural norms can sometimes inhibit student questioning in whole class teacher centered settings, small group activities within flipped classes can create safer spaces for expression and reasoning (Pattiserlihun & Setiadi, 2020).

Integration of multimodal resources.

Pre class materials can include videos, animations, simulations, and interactive modules that cater to different learning preferences and make abstract concepts more concrete. In contexts where textbooks alone are insufficient or outdated, this diversification of resources can enrich students' experiences and support their comprehension.

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However, the failed or neutral cases, such as the non-significant writing-score improvement in Sastri and Anwar's flipped writing study, underscore that these mechanisms are conditional. If students do not meaningfully engage with pre class content, if materials are poorly designed or misaligned with in class activities, or if teachers struggle to manage active classrooms, the theoretical advantages of flipped designs may not be realized. This suggests that teacher professional development must address not only technical skills (e.g., video production) but also design for learning, including alignment of pre-class tasks with in class applications, scaffolding of self-regulated learning, and assessment literacy.

HyFlex models differ from flipped classrooms in that they primarily reconfigure where and how students attend class, rather than when they engage with content relative to class time. In many HyFlex implementations studied to date, content is still distributed across pre class, in class, and post class phases. Indeed, Mentzer et al.'s HyFlex design-thinking course used a flipped structure within HyFlex, with videos and readings assigned before class and synchronous activities during class, whether face-to-face or online (Zhang et al., 2025).

Therefore, HyFlex could, in theory, combine the pedagogical benefits of flipped classrooms with additional flexibility in the participation modality. However, the layering of flexibility adds complexity to several fronts.

Instructional orchestration:

Teachers must simultaneously manage interactions with in person and remote students, ensure that remote participants can see and hear everything, and facilitate equitable participation in discussions and group work. For SMA teachers who are still consolidating their use of basic LMS platforms and video conferencing tools after emergency PJJ, this level of orchestration may be unrealistic without significant training and infrastructural upgrades.

Technological infrastructure.

Effective HyFlex requires classrooms equipped with stable internet, high quality cameras, microphones, and displays, as well as reliable devices and bandwidths for students connected remotely. Many Indonesian SMA, particularly outside major urban centers, lack such infrastructure, and students' personal access to laptops and high speed Internet remains uneven.

Equity of experience:

The HyFlex principle of equivalency posits that learning outcomes are comparable across modalities. In practice, ensuring equivalence for remote SMA students who may be connected to crowded homes, shared devices, or mobile data plans is challenging, and the risk of silent disengagement is high. By contrast, flipped classroom designs can emphasize asynchronous pre-class engagement, which may be more forgiving of intermittent connectivity, combined with predictable limited face-to-face sessions.

Given these constraints, the wholesale adoption of HyFlex in Indonesian SMA is unlikely to be feasible or desirable in the near term. However, targeted pilot projects in well-resourced schools, particularly in metropolitan areas with strong ICT infrastructure, could explore HyFlex variants as part of innovation agendas, provided that robust evaluation frameworks are in place and pilots do not exacerbate inequities between schools and regions.

Based on the evidence synthesized, several strategic directions emerge for SMA seeking to consolidate and extend blended learning post pandemic.

Prioritize structured flipped classroom–based blended learning for core academic subjects.

In subjects where cognitive demands and stakes are high (e.g., mathematics, physics, chemistry, biology, Bahasa Indonesia, and English), flipped blended models offer a promising balance between pedagogical effectiveness and feasibility. Schools can begin with modest flips (e.g., short pre class videos and guided readings) and gradually expand as teachers gain confidence.

Embed explicit support for student self-regulation and motivation.

As seen in the recount writing study, the success of flipped models hinges on students' willingness and ability to learn independently before class. Therefore, schools should integrate explicit instruction in study skills, time management, and digital literacy into their programs and consider using simple analytics (e.g., LMS access logs and pre-class quiz completion) to monitor and support preparation.

Invest in teacher professional development focused on instructional design for blended learning.

Training should go beyond technical tool use to encompass the alignment of learning outcomes, activities, and assessments across pre-class, in-class, and post-class phases, strategies for managing active classrooms, and inclusive practices that engage diverse learners. Cross-school communities of practice can help teachers share flipped classroom resources and experiences.

Adopt a cautious, evidence-informed approach to HyFlex experimentation.

Where infrastructural and human-resource conditions permit, a small number of SMA might pilot HyFlex features, such as allowing occasional synchronous remote participation for students who are ill or facing

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logistical barriers, while maintaining a flipped blended core. Such pilots should include the systematic monitoring of cognitive outcomes, engagement, and equity impacts.

Align school-level initiatives with national digital learning platforms and supports.

Kemdikbud's digital initiatives and resources (e.g., Rumah Belajar, TV Edukasi) can be integrated into flipped pre class materials, reducing content creation burdens on individual teachers. Local governments and private partners can assist in device provision and connectivity improvements, particularly for disadvantaged students.

This synthesis highlights several gaps that future research should address.

Primary comparative studies at SMA:

There is a need for quasi experimental or experimental studies that directly compare flipped classrooms and more flexible blended models (including partial HyFlex features) in Indonesian SMA, using common instruments for cognitive and engagement outcomes across multiple schools and regions.

Longitudinal effects on self-regulated learning and academic resilience:

Long term studies could examine whether sustained exposure to flipped blended learning in SMA enhances students' readiness for higher education and the workforce, particularly in terms of self-regulation, problem solving, and adaptability.

Equity analyses:

Research should explore how blended and flipped models interact with socio economic status, gender, rural urban divides, and disability, ensuring that innovations do not deepen existing inequities.

Cost-effectiveness and scalability:

Rigorous cost effectiveness analyses could help decision makers weigh investments in different models (e.g., flipped classroom vs more technologically intensive HyFlex) against their learning gains, particularly in resource constrained settings.

By addressing these priorities, future work can transform the current comparative synthesis into a more definitive empirical foundation for blended learning policies and practices in Indonesian secondary education.

IV. CONCLUSIONS

This study has synthesized quantitative evidence on the effectiveness of blended learning models for cognitive achievement and student engagement, with a specific focus on comparing the flipped classroom and Hybrid Flexible (HyFlex) approaches in relation to Indonesian senior high school needs. National-level meta analytic findings confirm that blended learning yields large gains in knowledge mastery and higher order thinking skill, and moderate improvements in motivation and self-regulated learning at the SMA level. Within this broad category, flipped classroom–based blended learning demonstrates particularly strong and consistent advantages over conventional instruction in science subjects, notably in enhancing critical thinking, while its impact on skill-based domains such as writing depends strongly on student motivation and quality of design and support. HyFlex models, largely studied in higher-education contexts, generally achieve cognitive outcomes equivalent to face-to-face instruction and offer valuable flexibility. However, they impose substantial demands on infrastructure, teacher orchestration, and student self-regulation, and may produce more polarized grade distributions. In the current Indonesian SMA context, characterized by variable digital readiness, persistent inequities in access, and ongoing implementation of Merdeka Belajar—flipped classroom–based blended learning emerges as a more immediately feasible and impactful strategy for raising cognitive achievement and structured engagement than full HyFlex deployment. Accordingly, Indonesian senior high schools are advised to prioritize the systematic development of flipped classroom–oriented blended learning in core subjects, coupled with investments in teacher instructional design capacity, student self-regulation support, and incremental infrastructural improvements. Carefully designed HyFlex pilots may be appropriate in selected well-resourced settings, but broad HyFlex implementation should await stronger contextual readiness and further empirical validation at the secondary level.

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Ethical Compliance

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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Data Access Statement

A Data Access Statement is a section in a scientific publication or research report that explains how the data used or generated in a study can be accessed by readers or other researchers. This statement aims to promote transparency, support research reproducibility, and comply with open access policies, where applicable.
Common Elements in a Data Access Statement:

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2. Access Instructions: Provides information on how to access the data, such as direct links, digital object identifiers (DOI). or contact details.
3. Data Availability: Indicates whether the data are publicly accessible, available upon request, or restricted due to ethical, legal, or privacy considerations.
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Purpose of a Data Access Statement:

- Reproducibility: Enables other researchers to replicate or verify the findings.
- Collaboration: Encourages further collaboration by sharing data.
- Compliance: Adheres to the policies of funding agencies or journals that require open access to data.

Conflict of Interest Declaration

The authors declare that they have no affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

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