



Design Thinking and Meta-Analysis for a DECABOT-Assisted Instructional Design in Critical Thinking

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Abstract

Indonesian students face persistent challenges in developing critical thinking skills in mathematics, as reflected in low international assessment performance and national reports linking weak reasoning to classrooms dominated by one-way, conventional teaching. Accordingly, this study sought to identify the underlying learning problems and propose an evidence-based instructional design. Employing a mixed-method, design-oriented approach that combined a qualitative Design Thinking needs analysis with quantitative meta-analytic synthesis, the researchers gathered data from 85 Grade XI students and 6 mathematics teachers across three senior high schools in Central Java through questionnaires, interviews, and classroom observation. Empathize-phase data showed over 85% of students reporting mathematics anxiety, 70% fearing mistakes, and calculus (functions, limits, derivatives, integrals) as the hardest topic; empathy maps for students and teachers converged on a five-part problem profile: critical thinking held back by mathematics anxiety, monotonous teaching media, weak contextual grounding, slow feedback, and unaddressed socio-emotional needs. These findings point toward the Empathic-PBL model, supported by DECABOT (Desmos Classroom Activities and Chatbot AI), as the resulting design solution. To ground this proposal empirically without directly validating DECABOT, a random-effects meta-analysis of 13 analogous-component studies (not direct trials of DECABOT) covering PBL, SEL integration, interactive digital media, and AI chatbot assistance produced a large pooled effect size (Hedges' $g = 0.859$, 95% CI: 0.825–0.892, $I^2 = 11.3\%$, $p < .001$) via a random-effects model. DECABOT thus stands as a theoretically grounded, conceptual instructional design candidate for senior high school calculus, supported by evidence from analogous interventions rather than a tested product, and still awaiting experimental confirmation.

Keywords: Design thinking; critical thinking; meta-analysis; empathic-PBL; innovative learning

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How to Cite: Nugroho, D., Dwijayanti, I., & Nugroho, A. A. (2026). Design Thinking and Meta-Analysis for a DECABOT-Assisted Instructional Design in Critical Thinking. *Formatif : Jurnal Ilmiah Pendidikan MIPA*, 16(2), 411-424. <https://doi.org/10.30998/formatif.v16i2.4273>

INTRODUCTION

Education is fundamental to national development. In secondary mathematics, a primary objective is to develop students' logical, analytical, and systematic reasoning, alongside critical, creative, and collaborative skills. This priority is formalized in Permendikbudristek No. 5 of 2022 on Graduation Competency Standards, which positions numeracy and critical mathematical reasoning as a core objective of mathematics education.

Critical thinking is a fundamental competency students must cultivate to understand and articulate mathematical principles. According to Ardianingtyas et al. (2020), critical thinking plays an important role in student creativity and must be stimulated through planned learning in which students learn to articulate reasons for their conclusions. Teachers should emphasize this so students think logically according to well-established

patterns and rules. Meta-analytic evidence confirms critical thinking is teachable when instruction deliberately targets it (Abrami et al., 2015), and that collaborative, computer-supported environments amplify these gains (Chen et al., 2018).

Indonesia's standing in the 2022 PISA assessment lays this problem bare: out of 81 countries, it placed 69th in mathematics proficiency, with scores dropping 13 points relative to earlier cycles (OECD, 2023). Because PISA items assess reasoning and problem-solving rather than rote computation, this ranking is indicative of students' critical thinking. A report from the Center for Education and Culture Policy Research points to a similar gap in practice: barely 3 in 10 teachers bring critical-thinking instruction into their lessons (Kemendikbudristek, 2021).

Many students also struggle to link mathematical concepts to real-life situations, keeping higher-order skills like critical thinking underdeveloped. Visual, contextual, and interactive materials remain scarce in Indonesian classrooms (Wulandari et al., 2025), pushing students toward memorizing rather than understanding. Wulandari et al. (2025) note that students handle routine procedural questions well but falter once a task calls for reasoning or modelling a real situation. Closing that gap calls for technology able to render abstract concepts visually and dynamically. Meta-analytic syntheses support this direction: dynamic mathematics software yields significant learning gains (Juandi et al., 2021), and technology consistently amplifies K-12 mathematics achievement, including through game-based environments (Ran et al., 2022; Tokac et al., 2019).

Desmos Classroom Activities (DCA), a web-based dynamic mathematics environment, lets teachers design, manage, and assign interactive learning activities in a virtual classroom (Heryanti et al., 2024). Its dynamic visualization can transform abstract concepts into concrete learning experiences that stimulate critical thinking. However, Rosidah & Kurniasih (2025) report that Desmos users often rely heavily on immediate visual results and neglect problems requiring analysis and evaluation. Consequently, integrating a digital assistant that provides instant feedback is recommended.

An AI chatbot is one way to address this gap: pairing Desmos' interactive visualization with an AI chatbot is expected to give a learning environment that is demanding yet adaptive (Claudya et al., 2026), consistent with meta-analytic evidence that AI chatbots have a large positive effect on learning outcomes (Wu & Yu, 2024). Problem-Based Learning (PBL) offers a complementary route, having students build their own understanding through real-world problems. Folding Social-Emotional Learning (SEL) into PBL matters too, since emotional and social skills give students resilience to sustain critical thinking through collaborative problem-solving (Mufidah et al., 2025). Decades of meta-analytic work likewise show school-based SEL programmes deliver reliable gains in socio-emotional competence and academic achievement (Durlak et al., 2011; Zhao & Sang, 2025).

This study set out to understand why critical thinking remains such a persistent obstacle, and on that basis to propose an evidence-based instructional design built around Desmos Classroom Activities and Chatbot AI (DECABOT). It is hoped this study will feed into the broader effort to develop educational technology supporting students' critical thinking. This study was guided by three research questions: (1) What learning problems underlie students' difficulties in developing critical thinking, as revealed through the empathize, define, and ideate stages of Design Thinking? (2) What instructional design solution emerges from these findings? (3) To what extent does meta-analytic evidence from analogous studies support the effectiveness of the proposed DECABOT-assisted design's components in enhancing critical thinking?

METHODS

This study employed a mixed-method, design-oriented methodology combining a qualitative Design Thinking needs analysis with a quantitative meta-analytic synthesis. Design Thinking functions here as an iterative, collaborative process for drawing insights from multiple stakeholders and translating them into solutions centred on the end-user's needs, making learning more engaging than conventional instruction (Regita & Rani, 2023). The complete model comprises five phases, from empathize to test; this study drew only on the first three empathize, define, and ideate to uncover learning problems and arrive at design solutions. The output is therefore a conceptual instructional design, not a product implemented or tested in the classroom.

Respondents were drawn from three senior high schools, SMAN 1 Sidareja, SMAN 1 Dayeuhluhur, and SMAN 2 Ungaran, comprising 85 Grade XI students and 6 mathematics teachers in total, recruited through purposive sampling targeting Grade XI classes and their mathematics teachers at each school. The three schools were purposively selected to represent a range of school contexts in the Sidareja-Dayeuhluhur-Ungaran catchment area: SMAN 1 Dayeuhluhur is rural (*pedesaan*), SMAN 1 Sidareja is semi-urban (*semi-kota*), and SMAN 2 Ungaran urban (*kota*), so the empathize-phase data would reflect varied school environments. Three instruments classroom observations, questionnaires, and interviews were used to gather data, each reviewed by two expert validators (mathematics education lecturers) before use; classroom observations were conducted to map students' needs, after which the validated questionnaires were administered across the three schools.

Three sequential Design Thinking phases guided DECABOT's development. During empathise, questionnaires, interviews, and classroom observations surfaced what students and teachers needed regarding critical thinking. The define stage distilled these into user personas and How Might We (HMW) questions pinning down the problem statement. The ideate phase drew on brainstorming and mind-mapping, informed by meta-analytic evidence, to arrive at candidate design solutions (Brown, 2019). The overall flow of this process is visualized in Figure 1.

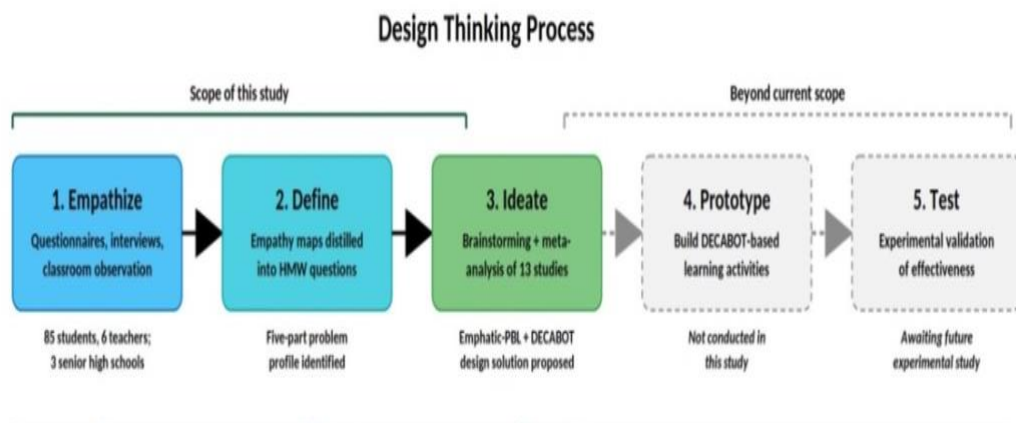


Figure 1. Flowchart of the Design Thinking Process Integrated with Meta-Analytic Evidence

Three complementary strategies built a rounded picture of how DECABOT functions within PBL and its effect on critical thinking. First, in-depth interviews with students and teachers surfaced their experiences and difficulties (Fook & Sidhu, 2015). Second, classroom observations focused on how students and teachers interacted around

AI-based technologies, particularly in supporting PBL and engagement. Third, questionnaire results, interview transcripts, and Design Thinking activity records were compiled to cross-check the interview and observation findings (Lake et al., 2021).

Combining these three strands gave the study a richer, more reliable evidentiary base. Interview and observation data were processed thematically, while questionnaire responses were summarised through descriptive analysis (Rini et al., 2024). To strengthen credibility, a triangulation procedure cross-checked findings drawn from questionnaires, interviews, observations, and supporting documentation; where sources converged, the finding was retained as-is, and where they diverged, the discrepancy was resolved by re-examining raw transcripts and field notes, prioritizing the pattern corroborated by at least two of the three sources, with the resolution recorded in the analysis memo (Marlina et al., 2024). Data validity was further established by checking consistency between questionnaire and interview responses, alongside a separate meta-analytic procedure used to compute the effect size underpinning the proposed design. This meta-analysis was carried out in R ($\alpha = .05$), with model suitability evaluated using heterogeneity diagnostics (Q, tau-squared, I-squared) rather than the p-value alone. Study identification followed a PRISMA-informed procedure; the three eligibility filters reported above were applied during full-text screening, and studies were coded independently by two coders, with disagreements resolved through discussion. Because included studies vary in which DECABOT component they test, effect sizes are also reported by component subgroup (Table 2), so the pooled estimate is read as scoping evidence across analogous interventions rather than proof of DECABOT's own effectiveness. Effect sizes and standard errors were converted onto a common metric from each study's reported statistic (mean-SD, t, F, r, or odds ratio) using standard conversion formulas, since several sources are dissertations or report outcomes other than critical thinking directly. A prediction interval, leave-one-out sensitivity analysis, and a funnel plot/Egger's test for publication bias were not computed, a limitation addressed below.

RESULTS & DISCUSSION

Results

Empathize, the starting point of Design Thinking, exists to surface what end-users actually need, sharpening innovators' awareness of context. Data for this phase were gathered from Grade XI students and mathematics teachers at three schools: SMAN 1 Sidareja, SMAN 1 Dayeuhluhur, and SMAN 2 Ungaran.

Table 1. Students and Teachers Respondents

School	Number of Students	%	Number of Teachers	%
SMAN 1 Sidareja	35	41.2%	3	50%
SMAN 1 Dayeuhluhur	28	32.9%	2	33,3%
SMAN 2 Ungaran	22	25.9%	1	1,67%
Total	85	100%	6	100%

Among the 85 student participants, over 85% reported anxiety about their ability to grasp mathematics content, while 70% admitted to feeling unsure, embarrassed, or afraid of getting problems wrong. Calculus emerged as the hardest area, particularly functions (67.1%), limits (64.7%), derivatives (61.2%), and integrals (58.8%). Teacher accounts matched this picture, with calculus the hardest topic to teach and classroom media still

largely conventional and one-way. These percentages come from a semi-open questionnaire administered during the empathize phase, validated beforehand by two mathematics education lecturers, which also supplied the raw data for the empathy maps below. This pattern is echoed in the interview data: one student recalled, *"I usually get nervous right away because the problem looks different from the examples we were taught... I'd rather wait for someone else to answer first or wait for the teacher to explain the method"* (S-01), while a teacher observed, *"the hardest combination is abstract material with passive students; many memorize formulas, but as soon as they are given a contextual problem they get confused, because they are not used to connecting concepts to real situations"* (G-01).

An empathy map was then built to dig deeper into what students and teachers were dealing with. On the student side, four dimensions stood out: (1) anxiety and difficulty with critical thinking, rooted in seeing mathematics as intimidating and dull; (2) a sense that lessons were repetitive due to rarely varied instructional resources; (3) a wish for more innovative, student-centred, technology-woven, problem-based teaching; and (4) on the teacher side, a recognised need for methods that better build critical thinking. Empathy maps were constructed for both student and teacher user groups; Figure 2 presents the key dimensions of each empathy map. Each quadrant (Says, Thinks, Does, Feels) was populated from a specific source: the questionnaire supplied Says/Feels, observation supplied Does, and interview transcripts supplied Thinks.



Figure 2. Student and Teacher Empathy Map

Building on the empathy maps, the define phase distilled those insights into user personas and How Might We (HMW) questions, pinning down the core problem. The resulting teacher persona has substantial classroom experience, is aware that change is needed, but currently lacks practical tools to act on it.

 user HIGH SCHOOL STUDENTS	NEEDS • Teaching methods that understand students' conditions • Varied and interactive learning resources • Digital media & game/video-based E-Modules • Learner-centered instructional model • Real-world problem-based learning (Contextual) • Technology-based learning (Desmos, Chatbot AI) • Safe and empathetic learning environment	 user MATHEMATICS TEACHERS	NEEDS • Ability to understand and create digital learning media • Proficient knowledge of structured Desmos Classroom Activities • Learners understand concepts deeply and thoroughly • Contextual and real-world mathematics learning • Technology-based learning tools (Desmos, AI) • E-Modules, digital video, and game-based media • Ready-to-use teaching kits integrated with digital-AI
Student Profile Students are disengaged and struggle to understand abstract math concepts. They feel anxious, lack confidence, and are reluctant to ask questions. Over 85% are afraid of making mistakes. They belong to Generation Z and are accustomed to digital technology, yet it has not been leveraged pedagogically in mathematics learning.	INSIGHT • Engaging and meaningful mathematics learning • Supportive learning environment free from pressure • Adequate and diverse learning resources • Teachers using innovative instructional media • Technology-based learning innovation • Interactive concept visualization (Desmos/GeoGebra)	Teacher Profile The average teacher has been teaching for more than 10 years. Teachers are always enthusiastic about learning but still find it difficult to provide interactive learning media. Teachers are less updated on technological developments in education. They have used GeoGebra/Desmos on an ad hoc basis but not yet in a pedagogically structured manner.	INSIGHT • Effective and efficient learning innovation • Proficient knowledge of how to create digital media • Skilled in educational technology tools • Students understand the subject matter well • Fun, engaging, and critical thinking-oriented learning • Innovative learning with critical thinking integration

Figure 3. User Persona: Students and Teachers

Reframed as HMW prompts, the identified problems become starting points for design rather than mere complaints. These are the questions that emerged from that process:

- 1) How can we make mathematics concepts more concrete and contextually meaningful for students who struggle with abstraction?
- 2) How can we reduce mathematics anxiety while simultaneously elevating cognitive demands toward critical thinking?
- 3) How can interactive digital technology be harnessed to support both visualization and personalized scaffolding in calculus learning?
- 4) How can AI-driven feedback replace or supplement the teacher's real-time guidance when students are stuck?
- 5) How can collaborative, emotionally supportive learning structures be built into the PBL model to address socio-emotional barriers?
- 6) How can teachers efficiently design and deploy rich, multi-format learning activities without excessive preparation burden?

These six HMW questions were grouped into four core design challenges to reduce overlap: (1) visualization and contextualization of abstract concepts (Q1, Q3); (2) reducing mathematics anxiety and strengthening socio-emotional support (Q2, Q5); (3) real-time, AI-driven feedback and scaffolding (Q4); and (4) reducing teacher preparation burden (Q6). Each challenge maps onto a design component: challenges 1 and 3 are addressed by Desmos Classroom Activities' visualization and real-time-response features, challenge 2 by the SEL components woven into Empathic-PBL, and challenge 4 by DECABOT's pre-built, reusable activity structure.

Moving into the ideate phase, brainstorming and mind-mapping techniques surfaced a range of possible directions, converging into five interlocking solution clusters. At the centre sits calculus content, specifically function composition and inverse functions

for Grade XI, the area students find hardest and most foundational, taught through an Empathic-PBL framework. SEL elements emotional awareness, social responsibility, and relationship skills are woven into every phase to address the affective side of students' struggles. Two digital tools support this pedagogical core: Desmos Classroom Activities (DCA) supplies real-time visualization and a shared collaboration space, while DECABOT, an AI chatbot built on the GPTBots AI platform, offers instant, tailored feedback and scaffolding. Tying the system together is a commitment to contextual problem design, rooting every task in situations students recognize from their own lives.

From there, the brainstormed ideas were sorted and organized into a mind map, which became the blueprint guiding what features the prospective application would eventually need.



Figure 4. *Brainstorming Results*

Taken together, the empathize, define, and ideate phases point to five clusters of difficulty: (a) weak critical thinking compounded by mathematics anxiety, (b) conventional media that students find dull and disconnected from their needs, (c) calculus instruction that rarely links to real-life contexts, (d) feedback and scaffolding that arrive too slowly or not at all, and (e) collaborative learning settings that overlook students' socio-emotional needs. It is this five-part profile that the design solutions discussed next are built to address.

The Empathic-PBL Design Solution

Addressing the five-part problem profile above calls, first and foremost, for a pedagogical response, and that is what the Empathic-PBL model provides. It weaves the five PBL phases (Arends, 2012) together with SEL competencies (Mufidah et al., 2025) to build a learning environment that is demanding on the cognitive side while still attending to students' emotions. Table 2 lays out how the two are integrated.

Table 2. Integration of Empathic-PBL with SEL Components

No	PBL Phase	SEL Component	Empathic Activity
1	Phase 0: Introduction	Self-awareness	Students express their emotional state using DCA's interactive polling; teacher builds emotional connection
2	Phase 1: Problem Orientation	Social awareness	Contextual problem presented through a real-life scenario (e.g., functions in app design); students practice active listening.
3	Phase 2: Organizing for Learning	Relationship skills	Heterogeneous group formation with peer tutoring; roles assigned to harness diverse digital competencies within the group
4	Phase 3: Guided Investigation	Responsible decision-making & Social awareness	Students use DCA for visual exploration of function composition; DECABOT provides scaffolding when stuck.
5	Phase 4: Developing & Presenting Work	Self-awareness & Relationship skills	Groups present findings; peers provide structured supportive feedback; emphasis on psychological safety and growth mindset
6	Phase 5: Analyzing & Evaluating	Self-awareness	Students articulate reasoning behind their solutions.
7	Phase 6: Closing / Reflection	Self-management	Students use 'emoji reflection cards' to document their emotional and cognitive journey; teacher facilitates metacognitive debrief

What this structure delivers, in practical terms, is feedback that arrives without delay, collaboration woven into every PBL phase, emotional safety through SEL, and relevance grounded in real-life problems. Through it, PBL stops being a purely cognitive exercise and becomes something more rounded: a learning experience tuned to what today's students actually need.

DECABOT: (Desmos Classroom Activities and Chatbot AI)

DECABOT brings together two digital tools whose strengths complement one another, meeting the demand for learning that is interactive, personalized, and responsive in real time. Desmos Classroom Activities (DCA) is a browser-based environment for dynamic mathematics that lets teachers build and run interactive lesson sequences (Heryanti et al., 2024). Three features stand out: graphs and functions can be manipulated live on screen, suiting students who respond to dynamic, multimodal material; and teacher-paced screens with anonymized peer responses let the whole class explore a problem together; and built-in formative tasks give immediate feedback without publicly exposing mistakes. Simanungkalit & Rajagukguk (2022) note that DCA-based tasks push students toward genuine investigation and independent strategy-building, which is precisely what activates critical thinking.

The chatbot side of DECABOT runs on the GPTBots AI platform, and operates as an always-available calculus tutor. Its functions span giving immediate feedback, Socratic-style questioning rather than handing over answers, adjusting scaffolding to each student's responses, and flagging misconceptions (Rahmah & Novita Zahra, 2025). Having a chatbot on hand removes the wait for teacher availability that often stalls independent critical thinking. Claudya et al. (2026) report that once AI was folded into Desmos-based lessons,

how often students interacted per session climbed from roughly 4 to 9 times, and reflection scores rose from about 50% to 80%.

Combined, DCA and the chatbot form what Claudya et al. (2026) describe as a ‘challenging yet adaptive learning ecosystem’. What makes it effective is simply that it meets students where they already are on digital platforms, expecting quick feedback, learning collaboratively, and with their socio-emotional needs taken seriously rather than left as an afterthought.

Rather than validating DECABOT itself, the meta-analysis mapped what the existing empirical literature shows about approaches mirroring DECABOT’s components: PBL, SEL integration, interactive digital media, and AI chatbot assistance for building critical thinking. The synthesis grounds the proposed design empirically; it is not direct proof that DECABOT itself works.

Out of the broader literature, 13 studies made it into the meta-analysis after passing two filters: every selected study needed to follow an experimental or quasi-experimental design that included measurements taken both before and after the intervention, and involve an intervention that maps onto at least one DECABOT component (PBL, digital media, Desmos, or an AI chatbot). The resulting coded dataset appears in Table 3.

Table 3. Article Data with Effect Size (ES) and Standard Error (SE)

Researcher	Treatment	N	ES	SE
(Noweski et al., 2012)	Design Thinking	58	0.800	0.060
(Riti et al., 2013)	PjBL and Design Thinking	38	0.790	0.066
(Wardani, 2020)	Critical Thinking	42	0.762	0.066
(Halawa, 2024)	Problem-Based Learning	32	0.875	0.059
(Muliatmika et al., 2024)	Problem-Based Learning	43	0.861	0.053
(Sutisnawati et al., 2024)	SEL- Differentiated Learning	30	0.933	0.046
(Deswita et al., 2024)	Differentiated PBL	23	0.870	0.070
(Mayoza et al., 2024)	Interactive Digital Media	28	0.857	0.066
(Ramdani, 2024)	Outdoor Learning and AI	20	0.950	0.049
(Hartanti & Purnomo, 2023)	PBL and Critical Thinking	35	0.829	0.063
(Nurwahid & Ashar, 2023)	Innovative Learning Media	40	0.800	0.058
(Rosidah & Kurniasih, 2025)	PBL + Desmos + Lumio	36	0.861	0.059
(Claudya et al., 2026)	AI-Integrated DCA	30	0.867	0.062

The figures below come from running a random-effects model (REML method) through the metafor package in R 4.4.1.

Table 4. Overall Meta-Analytic Estimates

Indicator	Estimate	SE	Z	p	CI Lower	CI Upper
Effect Size (ES)	0.859	0.017	49.75	< .001	0.825	0.892
Tau ² (variance)	0.0008	—	—	—	—	—
I ² (%)	11.3%	—	—	—	—	—

Pooling the 13 studies produced an effect size of 0.859 (95% CI: 0.825–0.892, I² = 11.3%), which is large by Cohen's (1988) benchmark. The result clears the significance threshold comfortably ($p < .001$), meaning the combined effect of PBL, SEL integration, interactive digital media, and AI chatbot assistance on critical thinking is practically substantial. With I² at only 11.3%, the studies line up consistently rather than pulling in different directions. Across the individual studies, effect sizes spanned from 0.762

(Wardani, 2020) up to 0.950 (Ramdani, 2024), with every single one sitting at or near the large-effect mark of 0.80.

Discussion

The findings point to three interrelated themes discussed below. The first concerns the five-cluster problem profile built through the empathize-to-ideate sequence: mathematics learning difficulties are cognitive, affective, and environmental all at once. The interview data illustrate this: on the affective side, one student explained the avoidance behind the anxiety figures, *"when a problem is hard, I feel like giving up before I even try... it feels safer to just stay quiet than be labeled as not smart"* (S-02); on the environmental side, a teacher pointed to constraints beyond the classroom itself, *"the biggest obstacle at my school is limited access to devices and uneven internet connectivity... that creates a gap, where students with access get further ahead than those without"* (G-02). That over 85% of students report mathematics anxiety, alongside weak engagement with abstract material and heavy reliance on conventional media, echoes patterns already documented in the literature on mathematics anxiety and disengagement (Ardianingtyas et al., 2020; Barroso et al., 2021 Wulandari et al., 2025).

The second theme concerns how well the Empathic-PBL plus DECABOT design holds up against what is already known about learning. Folding SEL into PBL speaks directly to the affective barriers anxiety, social comparison, and uncertainty about identity that Mufidah et al. (2025) identify as prerequisites for cognitive engagement in collaborative learning. DECABOT itself meets what students expect from a digital tool today: quick responses, real interactivity, and personal-feeling feedback, tracking with what Claudya et al.'s (2026) data shows: integrating AI into Desmos-based learning lifted both interaction frequency and reflection quality. The design thus addresses more than the cognitive level it also speaks to motivation and emotion, setting it apart from earlier attempts at integrating technology into mathematics teaching (Heryanti et al., 2024 Rosidah & Kurniasih, 2025). Interview data offer concrete illustrations of this affective shift. Describing a Desmos-based lesson, one student noted, *"it was quite fun because I could see the graph change right away without being afraid of getting it wrong in front of the class, since only I could see my own screen; that made me more willing to experiment"* (S-01), a shift a teacher observed from the front of the room as well: *"the ones who are usually quiet became active, asking why the graph flips when a is negative"* (G-01). Similar affective-cognitive synergies have been reported for gamified STEM practices, which strengthen intrinsic motivation and critical thinking dispositions simultaneously (Asigigan & Samur, 2021).

The third theme rests on the meta-analytic results, which give the proposed design solid empirical footing. A large pooled effect size ($ES = 0.859$) with low heterogeneity ($I^2 = 11.3\%$) suggests that combining PBL, SEL integration, interactive digital media, and AI chatbot assistance may support critical-thinking outcomes across a range of settings, not just isolated cases. This estimate converges with earlier syntheses: PBL has repeatedly been shown to improve critical thinking across disciplines and levels (Ulger, 2018; Widyatiningtyas et al., 2015), inquiry-based approaches produce comparable gains (Antonio & Prudente, 2024), and PBL's benefit for critical thinking holds regardless of cognitive style (Arifin et al., 2020; Ibrahim et al., 2020).

A few limitations are worth noting. The Design Thinking process stopped at the ideate stage, so no implementation data exist; the effect-size claims rest on inference from analogous studies rather than direct measurement of DECABOT in action. The meta-analytic sample is also modest ($k = 13$), and because the data come from three schools in

Central Java, findings cannot yet be generalized beyond that setting. Methodologically, no formal assessment of publication bias or study quality was conducted, and because DECABOT itself has not been implemented, no direct validation data exist for the design as a whole. Future work should move toward (1) a quasi-experimental pre-test/post-test trial of DECABOT at SMAN 1 Sidareja, (2) replication across other regions, and (3) an updated meta-analysis as more analogous-component studies become available.

CONCLUSION

By applying Design Thinking through its empathize, define, and ideate phases, this study arrived at a diagnostic picture of mathematics learning problems and an evidence-based instructional design. The resulting five-cluster profile makes clear that the difficulties students face are cognitive, affective, and environmental all at once none of these dimensions can be addressed in isolation. Out of this diagnosis came the Empathic-PBL model supported by DECABOT, built around what today's students need: real-time feedback, genuine digital interactivity, and a learning environment treating emotional safety as integral. Pooling 13 analogous studies through meta-analysis produced a large effect size ($ES = 0.859$, $p < .001$, 95% CI: 0.825–0.892, $I^2 = 11.3\%$). DECABOT can thus be considered an instructional design candidate for senior high school calculus that is theoretically coherent and evidence-supported, though it still requires direct empirical validation through experimental testing. What should follow is a quasi-experimental trial of DECABOT at SMAN 1 Sidareja, along with replication in other school settings, to establish how far these findings can be generalized.

REFERENCES

- Abrami, P. C., Bernard, R. M., Borokhovski, E., Waddington, D. I., Wade, C. A., & Persson, T. (2015). Strategies for teaching students to think critically: A meta-analysis. *Review of Educational Research*, 85(2), 275–314. <https://doi.org/10.3102/0034654314551063>
- Antonio, R. P., & Prudente, M. S. (2024). Effects of inquiry-based approaches on students' higher-order thinking skills in science: A meta-analysis. *International Journal of Education in Mathematics, Science and Technology*, 12(1), 251–281. <https://doi.org/10.46328/ijemst.3216>
- Ardianingtyas, I. R., Sunandar, S., & Dwijayanti, I. (2020). Kemampuan berpikir kritis siswa SMP ditinjau dari kemampuan pemecahan masalah matematika. *Imajiner: Jurnal Matematika dan Pendidikan Matematika*, 2(5), 401–408. <https://doi.org/10.26877/imajiner.v2i5.6661>
- Arends, R. (2012). *Learning to Teach* (9th ed.). McGraw-Hill.
- Arifin, S., Setyosari, P., Sa'dijah, C., & Kuswandi, D. (2020). The effect of problem-based learning by cognitive style on critical thinking skills and students' retention. *Journal of Technology and Science Education*, 10(2), 271–281. <https://doi.org/10.3926/jotse.790>
- Asigigan, S. I., & Samur, Y. (2021). The effect of gamified STEM practices on students' intrinsic motivation, critical thinking disposition levels, and perception of problem-solving skills. *International Journal of Education in Mathematics, Science and Technology*, 9(2), 332–352. <https://doi.org/10.46328/ijemst.1157>
- Barroso, C., Ganley, C. M., McGraw, A. L., Geer, E. A., Hart, S. A., & Daucourt, M. C.

- (2021). A meta-analysis of the relation between math anxiety and math achievement. *Psychological Bulletin*, 147(2), 134–168. <https://doi.org/10.1037/bul0000307>
- Brown, T. (2019). *Change by design: How design thinking transforms organizations and inspires innovation* (Rev. ed.). HarperBusiness.
- Chen, J., Wang, M., Kirschner, P. A., & Tsai, C.-C. (2018). The role of collaboration, computer use, learning environments, and supporting strategies in CSCL: A meta-analysis. *Review of Educational Research*, 88(6), 799–843. <https://doi.org/10.3102/0034654318791584>
- Claudya, C., Fitriani, F., Faisal, F., & Anggreni, F. (2026). AI-integrated Desmos activity for understanding the concept of straight-line equations: An intrinsic case study. *Jurnal Pendidikan Matematika Dan IPA*, 17(1), 385–394. <https://doi.org/10.26418/jpmipa.v17i1.96948>
- Deswita, H., Siregar, N., & Hardi, S. P. (2024). Peningkatan kemampuan berpikir kritis peserta didik pada pembelajaran IPAS kelas V melalui pendekaan pembelajaran berdiferensiasi. *Journal in Teaching and Education Area*, 1(3), 401–416.
- Durlak, J. A., Weissberg, R. P., Dymnicki, A. B., Taylor, R. D., & Schellinger, K. B. (2011). The impact of enhancing students' social and emotional learning: A meta-analysis of school-based universal interventions. *Child Development*, 82(1), 405–432. <https://doi.org/10.1111/j.1467-8624.2010.01564.x>
- Fook, C. Y., & Sidhu, G. K. (2015). Investigating learning challenges faced by students in higher education. *Procedia - Social and Behavioral Sciences*, 186, 604–612. <https://doi.org/10.1016/j.sbspro.2015.04.001>
- Halawa, F. (2024). Peningkatan hasil belajar matematika materi trigonometri melalui penerapan model pembelajaran problem based learning pada siswa kelas X SMA Negeri 1 Gomo tahun pelajaran 2022/2023. *Journal on Education*, 6(2), 13654–13672. <https://jonedu.org/index.php/joe/article/view/5230>
- Hartanti, A., & Purnomo, Y. W. (2023). Peningkatan keterampilan berpikir kritis matematis dan hasil belajar menggunakan model pembelajaran problem based learning. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika*, 12(2), 1728. <https://doi.org/10.24127/ajpm.v12i2.6891>
- Heryanti, H. A., Huda, W. N., Sulastri, S., & Prabawati, M. N. (2024). Pengembangan media pembelajaran interaktif Desmos pada materi persamaan kuadrat. *Jurnal Kongruen*, 3(4), 337–346. <https://jurnal.unsil.ac.id/index.php/kongruen/article/view/13634>
- Ibrahim, Almukarramah, Gunawan, Marwan, & Yahya, D. (2020). Implementation of problem-based learning to improve students' critical thinking skills. *Journal of Physics: Conference Series*, 1460, Article 012058. <https://doi.org/10.1088/1742-6596/1460/1/012058>
- Juandi, D., Kusumah, Y. S., Tamur, M., Perbowo, K. S., & Wijaya, T. T. (2021). A meta-analysis of Geogebra software decade of assisted mathematics learning: What to learn and where to go? *Heliyon*, 7(5), Article e06953. <https://doi.org/10.1016/j.heliyon.2021.e06953>
- Kemendikbudristek. (2021). *Panduan pembelajaran dan asesmen*. Badan Penelitian dan Pengembangan dan Perbukuan
- Lake, D., Flannery, K., & Kearns, M. (2021). A cross-disciplines and cross-sector mixed-methods examination of design thinking practices and outcome. *Innovative Higher Education*, 46(3), 337–356. <https://doi.org/10.1007/s10755-020-09539-1>
- Marlina, E., Purwaningsih, M., Siagian, A. H. A. M., Hakim, S. Al, & Maryati, I. (2024). Ensuring trustworthiness in qualitative research: The role of triangulation techniques. *Qualitative Research Methods for Dissertation Research*, 347–375.

<https://doi.org/10.4018/979-8-3693-3069-2.ch012>

- Mayoza, H., Harahap, T. H., & Manurung, S. A. (2024). Model pembelajaran problem based learning berbantuan media pembelajaran Articulate Storyline 3 untuk meningkatkan hasil belajar matematika siswa. *Kognitif: Jurnal Riset HOTS Pendidikan Matematika*, 4(3). <https://doi.org/10.51574/kognitif.v4i3.1598>
- Muliatmika, I. W. P., Sukendra, I. K., & Suwiasa, I. W. (2024). Upaya peningkatan hasil belajar matematika melalui penerapan model pembelajaran Problem Based Learning (PBL) pada siswa kelas X.E1 SMA Negeri 6 Denpasar tahun pelajaran 2023/2024. *Widyadari*, 25(1), 60–72. <https://doi.org/10.59672/widyadari.v25i1.3654>
- Mufidah, E. N., Cholily, Y. M., Rosyadi, A. A. P., & In'am, A. (2025). Problem-based learning and social emotional analysis of students' written math communication. *Mosharafa: Jurnal Pendidikan Matematika*, 14(1), 151–166. <https://doi.org/10.31980/mosharafa.v14i1.2698>
- Noweski, C., Scheer, A., & Erdmann, J. (2012). Towards a paradigm shift in education practice: Developing twenty-first century skills with design thinking. In *Design thinking research: Measuring performance in context*. Springer. <https://doi.org/10.1007/978-3-642-31991-4>
- Nurwahid, M., & Ashar, S. (2023). Media pembelajaran Panganmewah dan Jargon untuk meningkatkan pemahaman konsep dan motivasi belajar siswa pada materi perbandingan trigonometri. *Plusminus: Jurnal Pendidikan Matematika*, 3(2), 221–234. <https://doi.org/10.31980/plusminus.v3i2.1338>
- OECD. (2023). PISA 2022 results factsheets Indonesia: The language of science education (Vol. 1, pp. 1–9). <https://oecdch.art/a40de1dbaf/C108>
- Rahmah, A., & Zahra, N. (2025). The Implementation of AI-powered chatbots and virtual assistants to assist students in solve math problems in real-time. *MAXIMA: Jurnal Pendidikan Matematika*, 3(1), 9–18.
- Ramdani, A. N. (2024). *Penggunaan Math City Map pada Outdoor Learning Math untuk Pemecahan Masalah Matematika* [Doctoral dissertation, IAIN Parepare].
- Ran, H., Kim, N. J., & Secada, W. G. (2022). A meta-analysis on the effects of technology's functions and roles on students' mathematics achievement in K-12 classrooms. *Journal of Computer Assisted Learning*, 38(1), 258–284. <https://doi.org/10.1111/jcal.12611>
- Regita, A. P., & Rani, S. (2023). Gamifikasi pembelajaran matematika untuk anak SMP menggunakan metode design thinking berbasis Android. *JIKA (Jurnal Informatika)*, 7(1), 117–124. <https://doi.org/10.31000/jika.v7i1.7550>
- Rini, F., Pratiwi, L., Mary, T., & Weay, A. L. (2024). Analysis of student responses toward activities using e-learning in higher education. *Journal of Engineering Researcher and Lecturer*, 2(1), 1–8. <https://doi.org/10.58712/jerel.v2i1.143>
- Riti, Y. U. R., Degeng, I. N. S., & Sulton, S. (2013). Pengembangan model pembelajaran berbasis proyek dengan menerapkan metode design thinking untuk meningkatkan keterampilan berpikir kritis siswa dalam mata pelajaran kimia. *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, 6(10), 1581. <https://doi.org/10.17977/jptpp.v6i10.15056>
- Rosidah, I. L., & Kurniasih, A. W. (2025). Kemampuan berpikir kritis matematis peserta didik pada problem based learning berbantuan Lumio by Smart dan Desmos. *Jurnal Ilmiah Multidisiplin*, 1(4b), 2384–2396. <https://doi.org/10.63822/0ncmj250>
- Simanungkalit, K. M., & Rajagukguk, W. (2022). Application of mathematics learning model creative problem solving that assisted with Desmos to improve students' critical thinking skills of SMKN 14 Medan. *Formosa Journal of Science and Technology*, 1(8), 1185–1200. <https://doi.org/10.55927/fjst.v1i8.2136>

- Sutisnawati, A., Rakhman, G. G. F., & Sumantri, M. S. (2024). Penerapan pembelajaran diferensiasi untuk meningkatkan keterampilan berpikir kritis siswa sekolah dasar. *Pendas: Jurnal Ilmiah Pendidikan Dasar*, 9(2), 7363–7374.
- Tokac, U., Novak, E., & Thompson, C. G. (2019). Effects of game-based learning on students' mathematics achievement: A meta-analysis. *Journal of Computer Assisted Learning*, 35(3), 407–420. <https://doi.org/10.1111/jcal.12347>
- Ulger, K. (2018). The effect of problem-based learning on the creative thinking and critical thinking disposition of students in visual arts education. *Interdisciplinary Journal of Problem-Based Learning*, 12(1). <https://doi.org/10.7771/1541-5015.1649>
- Wardani, F. (2020). An analysis of student's concepts understanding about simple harmonic motion: Study in vocational high school. *Journal of Physics: Conference Series*, 1511(1), Article 012079. <https://doi.org/10.1088/1742-6596/1511/1/012079>
- Widyatiningtyas, R., Kusumah, Y. S., Sumarmo, U., & Sabandar, J. (2015). The impact of problem-based learning approach to senior high school students' mathematics critical thinking ability. *Journal on Mathematics Education*, 6(2), 30–38.
- Wu, R., & Yu, Z. (2024). Do AI chatbots improve students learning outcomes? Evidence from a meta-analysis. *British Journal of Educational Technology*, 55(1), 10–33. <https://doi.org/10.1111/bjet.13334>
- Wulandari, T., Firsta, R. R., Darmawijoyo, D., & Hartono, Y. (2025). Analisis kemampuan pemodelan matematika dan penalaran siswa dalam menyelesaikan soal kontekstual PISA. *Journal of Instructional and Development Researches*, 5(3), 302–312. <https://doi.org/10.53621/jider.v5i3.538>
- Zhao, Y., & Sang, B. (2025). The effect of social–emotional learning programs on elementary and middle school students' academic achievement: A meta-analytic review. *Behavioral Sciences*, 15(11), Article 1527. <https://doi.org/10.3390/bs15111527>