

Implementing a structured pedagogical framework to integrate Symbolab into critical thinking in calculus

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What problem is addressed?

The proliferation of powerful, accessible Computer Algebra Systems (CAS) like Symbolab available on students' smartphones or electronic devices has created a pedagogical challenge in mathematics education. Instructors still face the dilemma: ban these tools or attempt to integrate them in ways that unfortunately often default to superficial answer-obtaining, which can circumvent the development of critical thinking and conceptual understanding (Bokhove & Drijvers, 2010). This study addresses this implementation gap by examining *not whether* such technology should be used, but *how* it can be integrated effectively to serve deeper learning goals in calculus.

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How is it addressed (theory/methods)?

Theoretically, this study is framed by instrumental genesis (Trouche, 2004) to understand how students appropriate Symbolab as a tool for mathematical reasoning. Furthermore, Facione's (1990) model of critical thinking, with its six core skills (interpretation, analysis, inference, evaluation, explanation, and self-regulation), is employed as an analytical framework to assess how the activities can contribute to deeper reasoning.

Methodologically, a qualitative research design is used. The participants were 76 first-semester undergraduate calculus students from the Faculty of Economics. Data from completed student worksheets were analyzed through thematic analysis aligned with Facione's critical thinking components to identify evidence of metacognitive engagement and sophisticated problem-solving.

What is implemented/replicated?

This study introduces a guided pedagogical worksheet and a defined process for its use, designed to redirect student use of Symbolab as a tool for answer-generation to one of critical analysis.

Implementation process

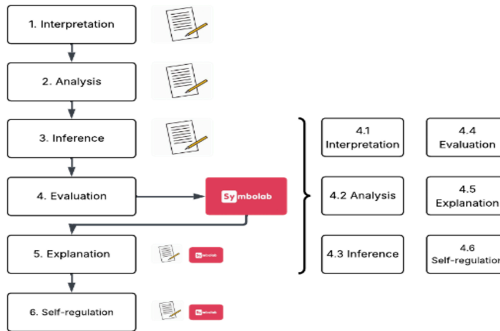
The study is organized into five phases spanning design, classroom implementation, and analysis: (1) the instructor designs the instruments, aligning prompts with Facione's components; (2) students complete Interpretation, Analysis, and Inference independently without digital tools; (3) students engage with Symbolab to analyze steps and evaluate output; (4) students synthesize their solution and reflect on how the tool shaped their understanding; (5) the instructor analyzes completed instruments using thematic analysis.

Structure of the instrument

The worksheet employs a nested design intended to create a "cognitive pause" before and during CAS use (Figure 1). Students first work through the Interpretation and Analysis steps without involving any mathematical procedures yet. Then during the Inference step, they derive the mathematical expression(s) that need to be solved, which takes them to the Evaluation step, where Symbolab is introduced. At this point, the instrument makes use of each of the skills (Interpretation, Analysis, Inference, Evaluation, Explanation, and Self-Regulation) within Symbolab. Once those are completed, the student "returns" to the outer remaining components: Explanation (now within the context of the original problem) and Self-Regulation. In this final step, they reflect on their reasoning process and the tool's role in their understanding.

Figure 1

Nested structure of the instrument



Preliminary findings

Preliminary evidence from the pilot study suggests that the structured framework reshapes the use of Symbolab from a means of answer-generation to a tool for analytical engagement. Three key patterns of cognitive development, aligned with Facione’s critical thinking skills, were identified:

1. **Fostering Analysis and Evaluation:** The structured use of Symbolab prompted students to move beyond simply copying the tool’s results to analyzing the steps and evaluating the output. For example, one student demonstrated this by explaining the procedural steps they observed: “first it is doing the quotient method... to find the derivative of the equation and then it’s just solving the substitution to find the value” (Participant S03). Another student showed evaluation by connecting the mathematical result to the real-world context, justifying the output by reasoning, “Yes, because the rate is negative and when we substitute 6 in Symbolab the result is the same, which means the company is spending less money per new customer, showing better efficiency” (Participant S04).

2. **Enhancing Interpretation and Explanation:** The “Explanation” step, which required a conclusion based on the numerical result of the tool, led to clear interpretations of the derivative’s meaning. Students consistently articulated the significance of the negative sign, with one stating, “The value of the rate of change is -2.903, that means that the customer acquisition cost at that month is decreasing, which means that the strategy is working” (Participant S03). Another student provided a detailed explanation: “The rate of change is -2.9 dollars per month. This means the company’s cost per new customer is decreasing, the marketing strategy is becoming more cost-efficient over time” (Participant S06).

3. **Developing Self-Regulation and Metacognitive Awareness:** The final self-regulation prompts encouraged students to reflect on their own

learning process and the tool's role. One student demonstrated this by assessing, "I would rate it a 9, because it solves very quickly but it doesn't give all the steps... it requires you to have the conceptual understanding" (Participant S01), showing an understanding of the tool's limits. Another student identified the specific moment their understanding solidified, noting it was "after [using Symbolab] because I checked and I get it in that moment, after watched [sic] all steps" (Participant S07), highlighting the importance of the post-use reflection phase mandated by the framework.

Overall, the structured use of Symbolab appears to have increased engagement with the mathematical process. Instead of trying to just obtain the solution through Symbolab, students engaged with all critical thinking components—interpretation, analysis, inference, evaluation, explanation, self-regulation—as distributed prior, during, and after its use.

What is the potential importance and significance?

This study provides educators with a transferable model for intentional CAS integration and contributes evidence to the debate on technology in mathematics, showing that the structured use of CAS, as opposed to replacing reasoning, can contribute to it.

This implementation also opens important avenues for future research. Although this study focused on integrating Symbolab into calculus instruction, further work can explore other CAS tools as well as additional mathematical subjects.

References

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