Exploring how interventions aligned with dual-process theories support student reasoning

THE UNIVERSITY OF MAINE
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Overview

For over 30 years, research-based materials developed by the physics education research community have helped transform introductory physics instruction. An emerging body of research, however, suggests that poor student performance on certain physics tasks – even after research-based instruction – may stem more from the nature of human reasoning itself than from specific conceptual difficulties [1]. Analysis of student reasoning patterns through the lens of dual-process theories of reasoning (DPToR) [2,3] from cognitive science suggests that students may struggle to engage analytical processing productively when responding to physics questions containing salient distracting features. There is thus a need to identify strategies for leveraging DPToR that can be used by curriculum developers and instructors to strengthen student reasoning in physics. In this poster, we discuss a novel methodology to probe students' reasoning trajectories prior to answer submission *(metacognitive prompts)* [4] and how we have integrated this methodology into the design and testing of a DPToR-aligned intervention aimed at promoting productive and consistent reasoning *(reasoning pathways intervention)* [5].

Background

Dual-process theories of reasoning (DPToR) [2,3]

Process 1: Fast, automatic, non-conscious
Role: Generates provisional mental model (informed by prior knowledge, beliefs, and contextual cues)

Process 2: Slow, deliberate, conscious
Role: Analyzes and evaluates provisional mental model if engaged (also subject to reasoning biases)

Screening-target question pair methodology [6]

Screening Question: Do students demonstrate the requisite *mindware* (knowledge and skills) [7]?

Target Question: Can students apply that same mindware when there are salient distracting features (SDFs)?

Approaches combined for this work

Metacognitive prompts

- Probe students' reasoning prior to initial answer submission
- Previously shown to uncover students' reasoning trajectories [4]

Reasoning pathways intervention

- Online micro-intervention
- Explicit focus on reasoning consistency
- Previously shown to be effective at supporting consistent reasoning [5]

Metacognitive Prompts

Administered after explanation to target question

Overview of complete thought process	Please describe your ***entire thought process*** for this question, from when you first read the question prompt to when you submitted and then explained your final answer.
First idea	What was the ***very first idea*** that came to mind when you first read the physics question? Why do you think this idea came to mind first?
Provisional answer choice	On the basis of your first idea, which of the answers below, if any, most closely follows from that idea?
Reflection on first idea?	Did you ***reflect on and/or evaluate*** your first idea (or preliminary answer)? [Follow-up questions]
Resolution of thought process	How did you ultimately settle on your final answer?

Reasoning Pathways Intervention : Overview

- Screening Q: MC & explanation on same page
- Target Q: MC on own page
- Intervention:
  - Target Q: Explanation on new page
  - Metacognitive Prompts: Target Q reasoning
  - Consistency Check: Screening & Target Qs
  - Apply Reasoning: Screening Q to Target Q *(if Screening correct and Target incorrect)*
  - Content-Specific Prompt: Modified Target Q
- Opportunity to Revisit Target Q

Would you like to change your response (*i.e.*, answer and/or reasoning)?

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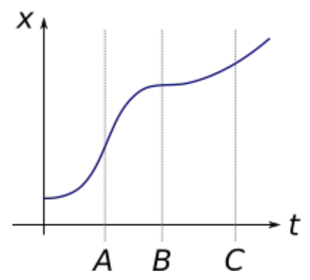
Physics Questions: Introductory Calculus-based Mechanics

Included in weekly online participation-based homework assignments

Kinematics

Screening Question [8]

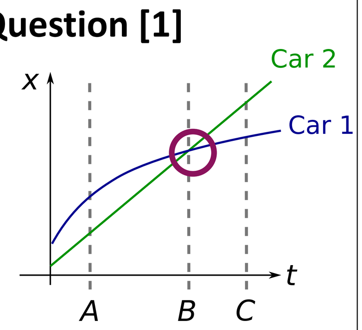
At which of the three labeled times is the speed of the car the greatest?



N = 200 demonstrated mindware

Target Question [1]

At which of the three labeled times are the speeds of the cars the same?

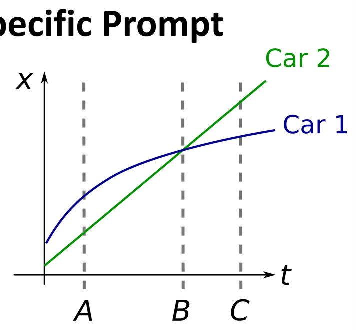


Answer: Time A (same slopes)

Salient distracting feature: Intersection point

Content-Specific Prompt

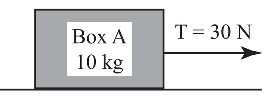
At which of the three labeled times are the *positions* of the cars the same?



Friction

Screening Question [8,9]

Box A is at rest on a rough floor. A horizontal 30 N force is then applied to the box. The box remains at rest.



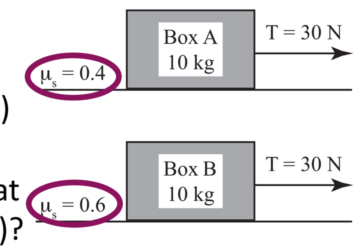
Is the magnitude of the applied force *greater than, less than,* or *equal to* the magnitude of the frictional force?

N = 137 demonstrated mindware

Target Question [8,9]

A horizontal 30 N force is applied to each box, and both boxes remain at rest.

Is the magnitude of the friction force exerted on box A (f_A) *greater than, less than,* or *equal to* that exerted on box B (f_B)?



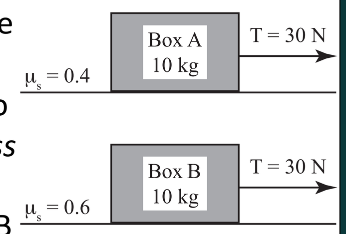
Answer: $f_A = f_B$ ($F_{net} = 0$)

Salient distracting feature: Coefficients of static friction

Content-Specific Prompt

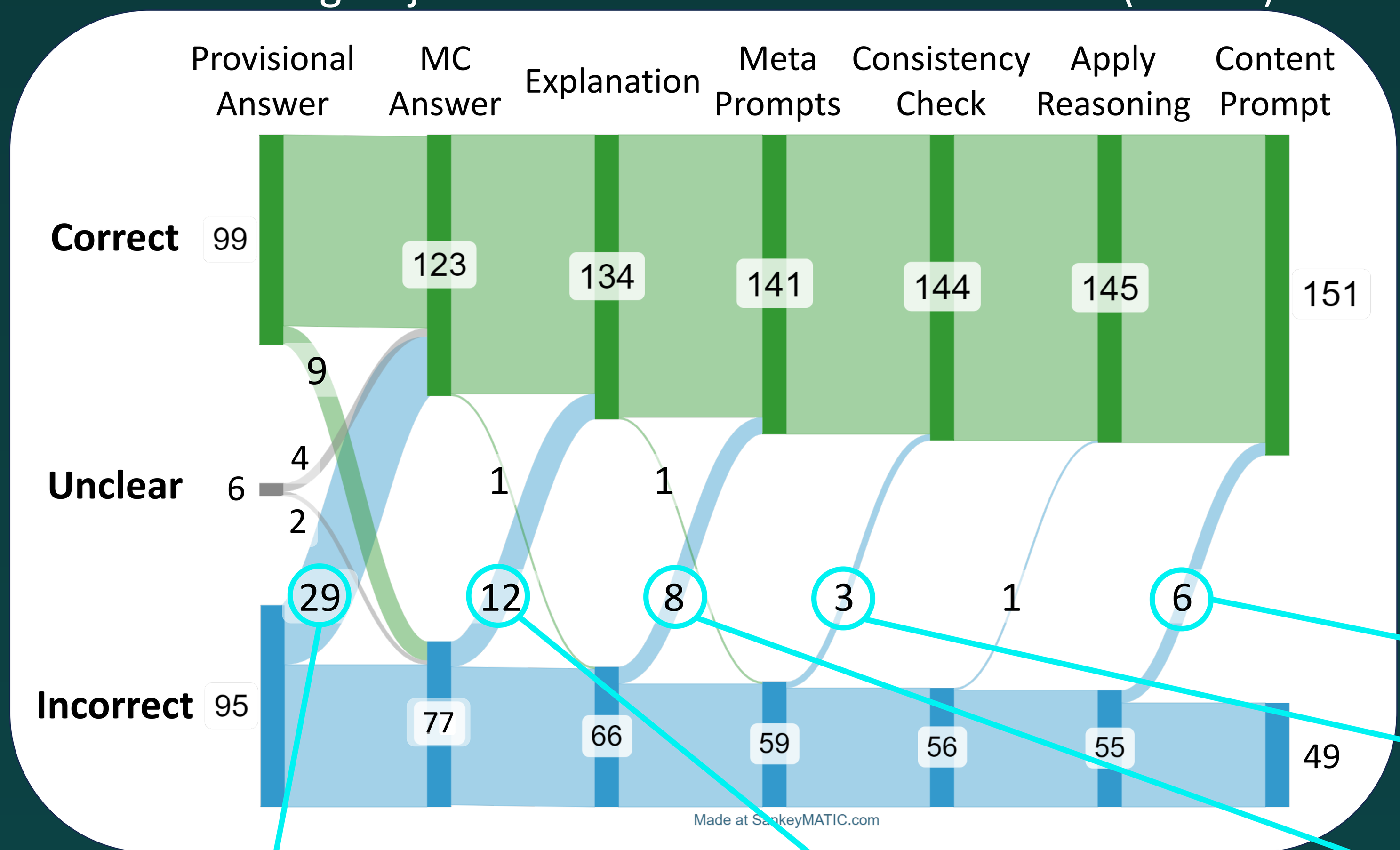
The magnitude of the horizontal force applied to each box is slowly increased until each box begins to move.

Is the magnitude of the applied force required to make box A begin to move *greater than, less than,* or *equal to* that required to make box B begin to move?



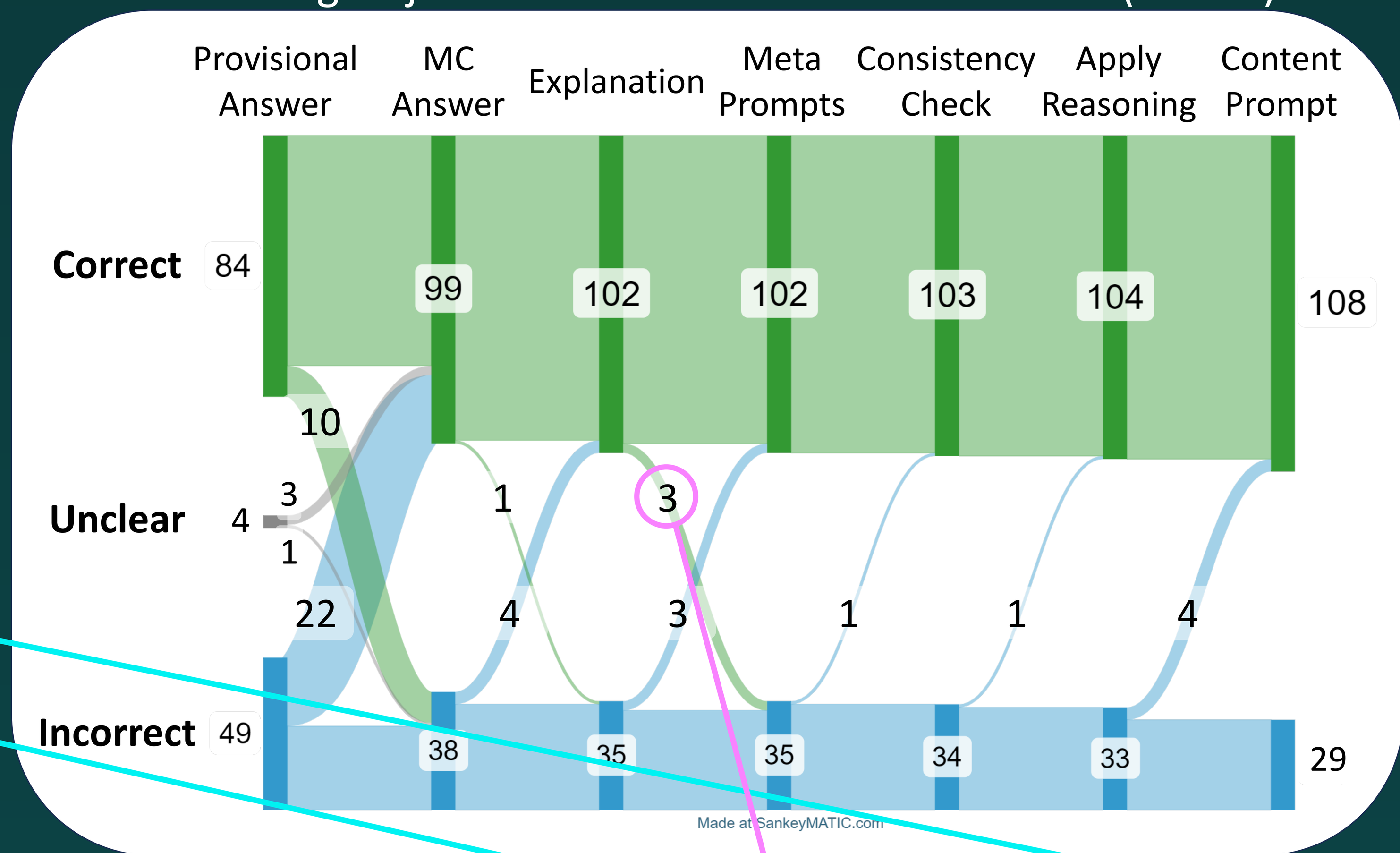
Kinematics Target

Reasoning trajectories of students with mindware (N=200)



Friction Target

Reasoning trajectories of students with mindware (N=137)



Shift after Provisional Answer (N=29, 30% of incorrect provisional)

First Idea
"Point B is where the lines cross, I wonder if it's that. It is a very noticeable part of the graph."

Thought Process
"When I first read the question and looked at the graph I originally thought about point B being where the magnitudes of the velocities are the same. Then I thought about how the slope, or in this case distance over time represents the magnitude of the velocity. Looking for a point where the slopes where parallel I found point a Appeared to have parallel slopes and choose that."

Process 2 analysis and evaluation leads to rejection of provisional model.

Shift at explanation phase (N=12, 16% of incorrect MC answers)

"I picked point B because of the overlap but upon further review, A would be a better choice because the slopes are the same."

Explanation prompts promote process 2 engagement, which may lead to increased scrutiny of the provisional model.

Shift after Meta Prompts (N=8, 12% of incorrect)

"After reevaluating, I noticed that the time where the velocities are the same would be time A, where they are parallel to each other, not an intersection point. I noticed the intersection first and jumped to that conclusion…."

Scaffolded reflection on reasoning may lead to increased scrutiny of the provisional model.

Shift after Consistency Check (N=3)

"In the first question I looked at the differently sloped parts of the line, whereas in the 2nd question I mainly focused on the point of intersect. The slope of the line is the true representation of the velocity…."

Examination of whether or not similar reasoning was used on both questions may help raise a red flag about original response.

Shift after Content Prompt (N=6)

"I realized that the two lines crossing over at that point in time only represents that the cars met each other at that point, not that their speeds were the same."

By asking for the time at which the positions are the same (intersection), red flags may be raised about original response.

Shift to Incorrect after Meta Prompts (N = 3)

"I am a little thrown off by the differing static friction so I'm unsure of my answer…. I believe that the [coefficient of] static friction is an indicator as to which one is exerting more force."

Scaffolded reflection may lead to increased scrutiny of provisional model and switching in either direction.

Were our interventions successful for students with mindware?

Target Question (# with mindware)	Target Question Response	*% of responses*		*Statistics*	
		Pre-Intervention	Post-Intervention	McNemar	Binomial
Kinematics (N=200)	Correct (A)	**62%**	**75%**	*p < .001* *g = 0.44*	*p < .001* *h = 0.30*
Friction (N=137)	Correct ($f_A = f_B$)	**72%**	**79%**	*p = .049* *g = 0.26*	*p = .051* *h = 0.15*

Were student responses primarily shifting in the intended direction? *Yes for both – statistically significant with large effect size.*

Was the distribution of responses impacted by the intervention? *Yes for kinematics only, but small effect size.*

Takeaways and Next Steps

- Of students with mindware, 20-25% of students submitting correct MC answers switched from SDF-aligned incorrect provisional responses.
  - *Our data provide strong evidence of both (a) salient distracting features (SDFs) impacting provisional models generated by process 1, and (b) productive process 2 analysis prior to MC answer submission.*
- Explanation prompts promote process 2 engagement and may lead to increased scrutiny of the provisional model.
  - *Several students switched at the explanation stage.*
- Scaffolded reflection on reasoning appears to be productive for students on the kinematics task but not on the friction task.
  - *Possible difference: Kinematics SDF is entirely perceptual and cannot be rationalized via physics, unlike the friction SDF.*
- Posing the question for which the SDF-aligned answer is correct appears to help students scrutinize their original reasoning.
  - *Juxtaposing both questions may raise a red flag on the original response.*
- After the full intervention, up to 25% of students who demonstrated the requisite mindware did not revise their SDF-aligned response.
  - *Challenging to address SDF-aligned provisional responses with strong feelings of rightness.*
- We are currently examining the relationship between intervention effectiveness and several factors of interest, including mindware, cognitive reflection skills, the specific reasoning trajectories of students as they engage with the physics question prior to the intervention, and the nature of each question's salient distracting feature.

References

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