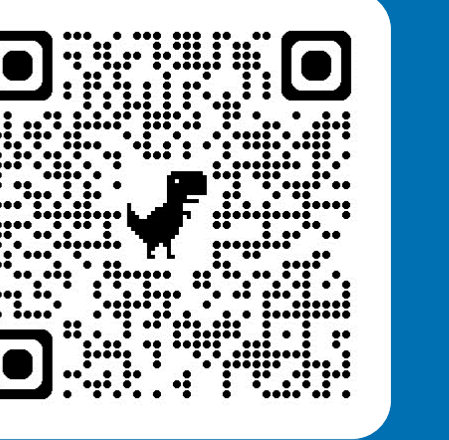




Simplified toy models can make physics harder to grasp

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Idealized models are a natural part of physics research and education. They can serve as **pedagogical tools** to illustrate complex concepts and calculations. *Insight from students use of such models can provide considerations for teachers.*

WE NEED TO BE AWARE OF STUDENT CHALLENGES IN UPPER-DIVISION COURSES

Upper-division is less researched and involves more **abstract** and **complex** content. Increasing demand on **mathematical proficiency** and **metacognitive skills**. **Concepts may evolve:** everyday life → intro levels → advanced levels.

STUDENTS MAY STRUGGLE TO RECOGNIZE THE UNDERLYING STRUCTURE OF IDEALIZED MODELS

Should we take it in a 'stat mech' approach? Because they are talking about lattices, epsilons?

Navigating all the challenges is difficult → students tend to rely on **surface features** in combination with resorting to **'plug and chug'** or similar problem-solving approaches. Appropriate **framing** and **transfer** (e.g. [2,3]) is challenging! See also research on isomorphic problems, e.g. [3].

METHODOLOGY

Our work aims to expand the body of physics education research within **upper-division courses**.

In the topic of **statistical mechanics**, we have studied the challenges faced by nine small **problem-solving groups** of third-year undergraduate physics students [1]. Adopting a **grounded approach**, we video recorded and qualitatively analyzed nine student groups engaging in collaborative problem solving. From the iterative thematic coding process, **ten categories of challenges emerged**. Seven mainly related to **concepts** (A1-A7) and three to **problem-solving strategies** (B1-B3).

A1
Struggling to define and disentangle macrostates & microstates and attributing statistical weight inappropriately

A2
Treating macroscopic quantities like entropy and temperature as microscopic properties of a system's components

A3
Confusing distinguishable and indistinguishable and not recognizing the cause nor the consequences of that distinction

A4
Associating an equilibrium state with increased order

A5
Struggling to recognize the consequences and causes of a system having discrete energy states when the states are bounded or the total energy is kept fixed

A6
Struggling to conceptualize temperature through the statistical definition and misinterpreting the meaning and effects of a heat bath

A7
Reasoning inconsistently about the Boltzmann distribution & the partition function, and their applicability

EMPIRICAL FINDINGS Categories of challenges

B2
Having difficulties managing conflicts between quantitative results and qualitative reasoning

B1
Inappropriately applying typical mathematical relations from statistical mechanics and thermodynamics

B3
Defining new concepts that led to more confusion due to their inconsistency with established relations

CONCLUSIONS

Our findings indicate that students struggle to recognize the **underlying structure** of commonly used toy models. Students faced various **pitfalls** as they tended to rely on **surface features** of the tasks, in combination with loosely connected ideas about key concepts. However, in some cases a similar idealized model was productively used to **reframe** a task, **activate other ideas** and **overcome a conflict**.

We suggest that teachers consider **how** they utilize simplified toy models, spend time **unpacking** its **hidden assumptions and subtleties**, and help students connect to **other contexts**. Also, allow students to **practice identifying the underlying structure** of tasks involving idealized systems.

WE SHOULD CONSIDER BOTH THE ADVANTAGES AND THE PITFALLS OF USING SIMPLIFIED MODELS IN TEACHING

ADVANTAGES: Reduce **cognitive load**, allow **simpler calculations**, **illustrate** new/complex concepts. **Leverage productive analogies** → **transfer** from everyday life experience or from **within physics!**

PITFALLS: Many **implicit assumptions and approximations**, difficult to discern! Can be overly **stripped of context** and connection to real world examples → **framing** difficult. **Transfer** to other contexts is **not guaranteed!** Role of **intuition** may be significant!

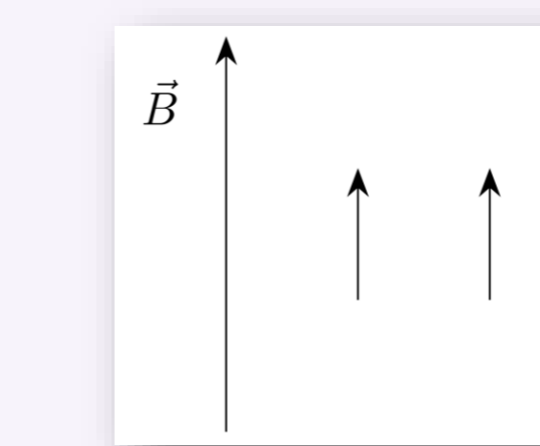
LEVERAGE ANALOGY EXAMPLE FROM OUR DATA

[Talking about the high-temperature limit of the average energy:] maybe they can only be in these three states, but then maybe **all of them will end up in the higher energy state**.

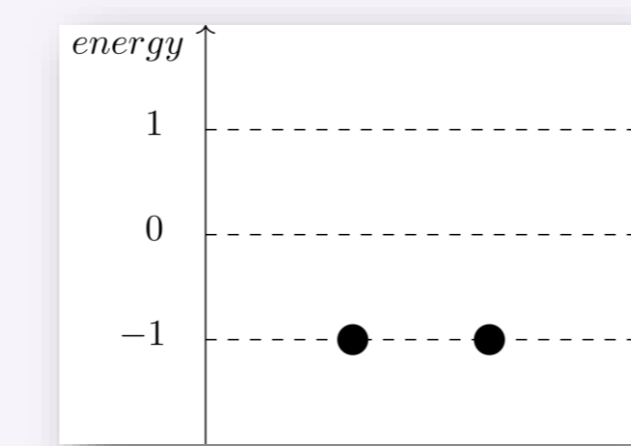


Dylan

[Later on, talking about the two-state paramagnet:] high temperature, then we talked, that the spins don't care about the external magnetic field [flips pointed fingers up and down] and then it becomes like 50-50.

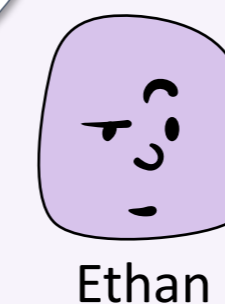


Two-state paramagnet



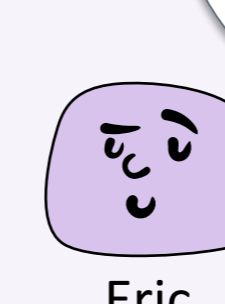
The "three-state system"

1 ... But are you sure that this [the three-state system] is subject to the same rules as the dipole [referring to two-state paramagnet]?



Ethan

2 No but it, I mean. So to speak, it is like they are just two lattices, there are no E-fields, no B-fields, nothing like that. Then it is that if we have a higher temperature, yes then we should get a higher energy [...]



Eric

PITFALL EXAMPLE FROM OUR DATA

References

- [1] E. Koerfer and B. Gregorcic, *Phys. Rev. Phys. Educ. Res.* **2024**, 20, 010105.
- [2] D. Hammer, A. Elby, R. E. Scherr and E.F. Redish, *Transfer of Learning from a Modern Multidisciplinary Perspective* **2005**, 89–119.
- [3] C. Singh, *Phys. Rev. Phys. ST. Educ. Res.* **2008**, 4, 010105.

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