Making expert cognitive processes visible: planning and preliminary analysis in theoretical physics research

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Background

- Planning is known to be an important problem-solving process
- Experts' research articles don't detail how they planned their approach to problems
- Thus, this expert process is often invisible to students

Our goal: Want to identify strategies experts use to design and plan their research so students can engage in those practices too

Research Questions

1. What role does preliminary planning play in theorists' research?
2. What are some of the preliminary planning activities that theorists do before executing their main research calculations?

Methods

Artificial (e.g., classrooms)

Natural (e.g., research)

Cognitive Task Analysis

- Methods to elicit expert knowledge of problem solving processes
- Allow for analysis and representation
- Data represent natural environments

Interview Protocol

- Asked theoretical physicists to give accounts of a single research project
- Began with description of the project's broad stages
- Then went back through main tasks and described them in more depth

Demographic Facts

- Theorists interviewed: *N=5*
- Gender: "Male" (*N=2*), "Female" (*N=1*) and "Woman" (*N=2*)
- National Origin: U.S. (*N=2*), India (*N=2*), and Peru (*N=1*)
- Subfields: Cosmology (*N=3*), Biophysics (*N=1*) and Particle (*N=1*)

RQ1: Purposes of preliminary design and analysis

Phases of Theorists' Research Processes

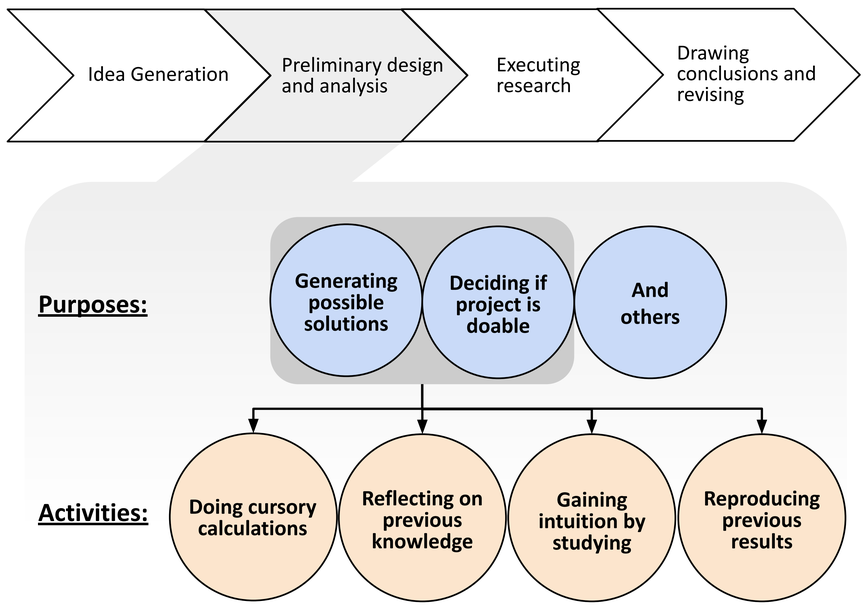

Figure 1: Aspects of theorists' preliminary design and analysis

"I try to minimize the time I waste doing detailed calculations until I can see a path from beginning to end" - Dr. Dunn

Generating possible solutions

- Included coming up with and testing potential solutions to theorists' research questions
- Theorists did not progress until they had a clear plan going forward

Evaluating if project is doable

- Judging whether they believed they could make progress on their question
- Tightly related to generating possible solutions
- Determined whether theorists moved forward with project

"So first is probably like getting the idea, right, which is kind of hard sometimes. And it's really hard to… one has to evaluate if it's doable." - Dr. Bahl

RQ2: Preliminary design and analysis activities

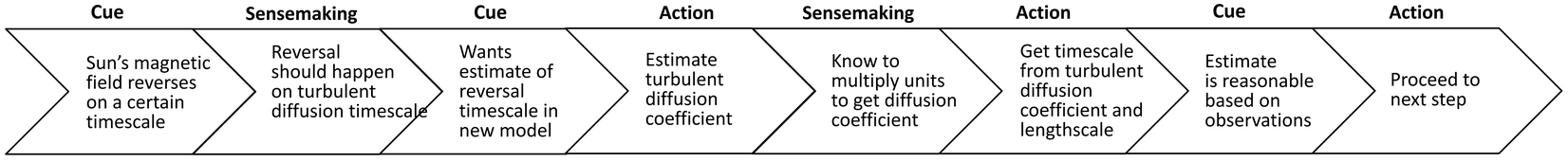

Figure 2: Steps in a cursory calculation described by Dr. Dunn

Doing cursory calculations

- Involved performing math or computation that is not highly detailed
- Helped theorists evaluate doability and gain confidence
- Allowed for narrowing of possible solution paths

"So you have to first assess very basic order of magnitude questions…so common sense calculations, which are non trivial, but save a lot of work." - Dr. Dunn

Gaining intuition by studying

- Theorists studied extensively to learn about new problems
- Included reading articles and talking to other physicists
- Recognized deficiencies in their own knowledge

"So it took me awhile to learn about it. I gave a few talks, I even taught a course as a way to learn the subject." - Dr. Erdogan

Discussion & Conclusions

Theorists convince themselves a project is doable and plan possible solutions before performing major calculations. They do so by performing back-of-the-envelope calculations, gaining intuition by studying, reproducing previous results, and reflecting on previous knowledge.

Ideas to engage students in this expert practice:

1. Integrating "Fermi problems" into curriculum to engage students in back-of-the-envelope/cursory calculations
2. Encourage students to perform cursory calculations using simulations to explore problem parameter space
3. Establishing long-term projects based on open-ended questions