Implications of a framework for student reasoning in an interview

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Abstract: We discuss the implications of a framework to characterize student reasoning in an interview and its underpinnings in cognitive psychology. Our framework, described in a previous paper in these Proceedings, enables a researcher to identify various cognitive elements used by a student during an interview. Our thesis is that this framework can help identify reasoning paths used by the students. We discuss how this framework can be applied to both a coarse and fine grained analysis of reasoning and how it can be used to infer a student's implicit reasoning processes.

Summary of the Framework

From our diverse interview data, we have constructed a framework for student reasoning in an interview. Our framework consists of four elements: (1) *External inputs* {I} (e.g. questions, verbal, graphic and other cues) from the interviewer and interview environment. (2) *Tools* {T} (e.g. memorized facts, formulae, laws and definitions as well as prior experiences) that the student brings to the interview. (3) *Workbench* {W} encompassing mental processes (e.g. induction, accommodation) that incorporate {I} and {T}. (4) The a*nswer* {A} given by the student.

Connections with Cognitive Psychology

It may be evident from the nomenclature of various elements that our framework uses the metaphor of a workshop. The input {I} is analogous to the work order given to a worker (e.g. build a chair). The tools {T} are analogous to the tangible implements (e.g. saw) that the worker uses, as well as her skills in performing the task. The workbench {W} is analogous to the work area (e.g. work table) as well as the fabrication processes. The answer {A} provided by the student is analogous to the finished product (e.g. chair) constructed by the worker.

Our framework also has underpinnings in cognitive psychology. The sensory input and response are analogous to {I} and {A} respectively. The short-term (working) memory, and the mental processes occurring therein are analogous to {W}. The long-term memory and information stored therein are analogous to tools {T}.

Our framework also shares commonalities with a metaphor in cognitive psychology – the computer. Input {I} is analogous to input devices (e.g. keyboard). Answer {A} is analogous to output devices (e.g. monitor). Tools {T} are analogous to stored information (data, software etc.) on the hard drive. Workbench {W} is analogous to active processes in a processor or RAM.

Some Interesting Reasoning Paths

Our framework can unearth some interesting reasoning paths used by students as shown below.

Analogical Reasoning: Analogies can be powerful reasoning tools. [1] An analogy involves two main components -- *source* and *target.* In our framework the target is provided by {I}, however. the source is the tool {T} that the student selects. Analogical reasoning involves three processes in the workbench {W}. First is *recognizing,* i.e. finding {T}. Second is *abstracting* the structural

Example 1

Interviewer:
{I} How does turning the pedals make the rear wheel move? (Real bike provided)
Student:
{A} Because it has a chain
{T} it's kinda like a pulley, almost like an elevator in a way, how this is set up.
{W} It just grabs onto this little round thing (a sprocket), but it works like a pulley thing. As this moves it in turn makes this sprocket move which in turn is connected to this, that rotates this as this is rotating.

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similarities between source and target. Third is *mapping* these principles from source to target.

In Example 1, the student uses a real-world analogy to answer a question about a bike. When asked how the pedals make the rear wheel move {I}, the student uses an analogy of a pulley in an elevator {T} (source). The first process in {W} (recognition) is implicit. The student explicates the other two processes (mapping and abstracting).

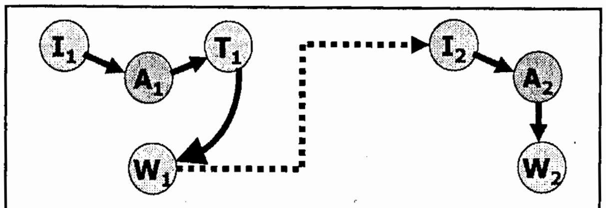


Fig. 1: Conflict resolution reasoning path.

She talks about the mechanism and how it makes the wheel move via the chain {A}.

Conflict Resolution: Cognitive conflict or dissonance [2] can help students learn science. [3] Piaget's [4] cognitive disequilibrium occurs during assimilation and accommodation (both {W}), when a learner's internal knowledge {T} conflicts with her experience in a discrepant event {I}.

In Example 2, when asked to predict how the brightness of two bulbs in parallel will compare to a single bulb {I_1}, the student answers based on a model {T_1} that the battery supplies a fixed amount of energy that is shared by the two bulbs in parallel. She applies {W_1} this model to conclude that the bulbs will be less bright {A_1}. The interviewer completes the circuit so that the bulbs light and asks what happened {I_2}. The student answers that they stayed the same {A_2} reasoning that the energy must be the same going to each bulb {W_2t}. The tool, which is implied, is denoted by 't.' Fig. 1 shows the reasoning path.

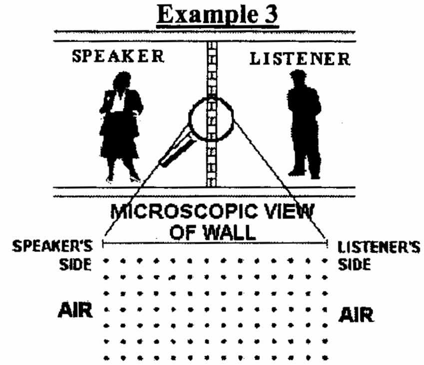
Example 2

Interviewer:
{I_1} How will they (2 bulbs in parallel) compare now (to one battery and one bulb)?
Student:
{A_1} I still think it won't be as bright as a single bulb
{T_1} because you still have two bulbs to light.
{W_1} It will still be less than the first (one battery and one bulb) because you still have energy, you still have to share between two bulbs instead of just one.
Interviewer:
{I_2} So what happened? (Interviewer completed circuit and bulbs light.)
Student:
{A_2} It stayed the same.
{W_2t} Well, you just have that constant energy going to each.

Metacognition, or "thinking about thinking," was first defined by Flavell. [5] Metacognition is often described in terms of two components –*knowledge* and *regulation*. Metacognitive knowledge, a {T} in our framework, refers to self-awareness about one's own learning. Metacognitive regulation [6] involves mental processes i.e. {W} to monitor cognitive outcomes {A}. Therefore, various components of metacognition correspond to the elements of our framework.

In Example 3, a student is asked {I} to explain why sound is softer on the other side of a wall.

Example 3



Interviewer:
{I} What happens when it [the sound] propagates [through the wall], and what happens when [i.e. why does] it gets quieter?
Student:
{W_1} (Pause) Well, if I would say
{T_1} it [i.e. the sound] was material,
{W_2} which I don't think it is … it would go through here (sketches the path shown below), and it would hit some of these until it'd lose some of its strength.
{$T_2(A_0)$} But, since I said it's not material, I'm not sure….
{W_3} So, maybe I'll have to go back and say that maybe there is something material in it, because … I don't know why else
{T_3} it would … be louder on …[one] side and quieter on the other side.
{W_4} [Unless] if it was material … I'm still having a hard time thinking that, like the vibrations are material, but on the other hand
{A} I don't know why they, like how this [sound diminishing] would happen if it wasn't material.

She starts by assuming $\{W_1\}$ that sound is a material entity $\{T_1\}$ based on which she figures $\{W_2\}$ that it would be softer on the other side of the wall. Next she alludes to a response $\{A_0\}$ to a previous question where she had concluded that sound is *not* a material entity [7]; and uses this response as a tool $\{T_2\ (A_0)\}$. Then she reflects $\{W_3\}$ on why this model $\{T_2\}$ does not explain her experience $\{T_3\}$ that sound is quieter on the other side. Finally, she goes back $\{W_4\}$ to her previous assumption that sound is material, which would explain $\{T_3\}$, but she is not comfortable with the idea that sound ("vibration") is material. So the final answer $\{A\}$ is an unresolved dilemma. This reasoning path is metacognitive because she engages in self-regulation $\{W\}$, monitoring her cognitive outcome -- conflict between assumption $\{T_1\}$ and model $\{T_2\}$ -- and tries unsuccessfully to achieve self-consistency.

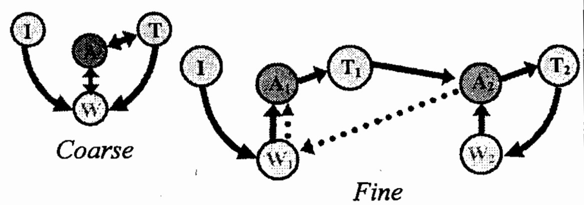
Advantages of Using Our Framework

The framework was constructed from our interview data. Therefore, it can aid in various stages of an interview-based research project. In the research design stage the framework can help focus the overall protocol to better meet the goal of understanding students' reasoning. Second, it can help researchers design individual interview questions $\{I\}$ to better elicit the cognitive tools $\{T\}$ and workbench processes $\{W\}$ that a student uses. In the research implementation stage, i.e. *during* the interview, the framework can help the interviewer ask appropriate follow-up questions $\{I\}$ that would urge students to explicate their reasoning. Finally, in the research analysis stage, the framework can help a researcher glean overall trends in a student's reasoning across several questions or to analyze a transcript at multiple grain sizes.

In Example 4, a student is asked the number of gears that a bike has. The transcript can be analyzed at two grain size levels. We can use a broad brush to see global trends in the data and larger knowledge structures. We can also use a finer brush to see details that emerge from the data such as smaller knowledge structures, trying various tools and the back and forth trying to decide between different answers.

Our framework can be applied in two ways. First, it can be used to understand what students say by categorizing various words and phrases in the transcript as $\{I\}$, $\{T\}$, $\{W\}$ or $\{A\}$. Second, it can be used to *infer* what students think. To do so researchers make informed speculations about what students are *thinking*. Thus, this mode of application is highly susceptible to researcher interpretation and bias. In either case, it is advisable to use standard reliability measures such as inter-rater reliability while using the framework. Example 5 below demonstrates how the framework can be used in the two ways described above.

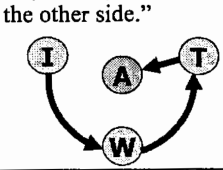
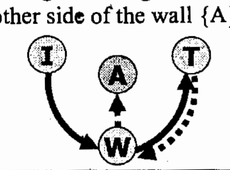
Interviewer:
$\{I\}$ So how many gears do you think this bike has?
Student:
$\{W_1\}$ Well, my first guess
$\{A_1\}$ is a 10 speed
$\{T_1\}$ because this is the size they usually are
$\{A_2\}$ but maybe it's a three speed.
$\{T_2\}$ It's got three little thingies.
$\{W_2\}$ If I was going to use reason
$\{A_2\}$ I guess I'd say three
$\{W_1\}$ if I were going to use a guess
$\{A_1\}$ I'd say a 10 speed.



Example 4: Analysis of transcript at two grain sizes

In Example 5 below, students are asked to explain how sound propagates through the wall. By parsing the student's response one can identify $\{W\}$, $\{T\}$ and $\{A\}$ as they chronologically occur in the transcript. A researcher may also try to infer that the student uses analogical reasoning.

Example 5: Applying the framework to...

What students say	What we *infer* they think
$\{I\}$ Asked how sound gets to the other side of a wall. $\{W\}$ "Well, I would say that to me it is somewhat like $\{T\}$ a maze for the sound $\{A\}$ it just kind of works its way through until it gets to the other side."	Student recognizes $\{W\}$ that the situation is analogous to a maze $\{T\}$ for the sound. She applies the analogy to deduce $\{W\}$ that air works its way through until it gets to the other side of the wall $\{A\}$.
	

Analogical reasoning involves three {W}s recognizing and selecting a target {T}, abstracting the structural similarities between source and target and mapping similarities from source to target. The first of these processes is somewhat evident from the transcript. The other two are inferred based on our theoretical understanding of analogical reasoning. Therefore, the reasoning path goes back to {W} (for abstracting and mapping) before terminating at {A}.

There was no attempt made in the inferential analysis above to separate the abstraction and mapping processes in {W}. This demonstrates that although the framework can be used to bridge data with theory, use of the framework must ultimately be grounded in the data.

Inter-rater Reliability

Our framework may not characterize a student's reasoning definitively. It is plausible that two researchers analyzing the same transcript may arrive at slightly different descriptions of a student's reasoning path. Therefore, our framework is susceptible to a researcher's bias in ways similar to other qualitative methods. We determined the inter-rater reliability of the coding scheme based on our framework as follows: Four researchers involved in this project pooled two transcript segments from each of their data sets. Each segment was coded by two different researchers, who had not originally collected the data. The inter-rater reliability averaged over the four pairs of researchers who coded the transcripts, was 81% ± 6% for the fine analysis and 67% ± 5% for the coarse analysis.

Other Issues

In using our framework to characterize the dynamics of student reasoning in an interview we have so far focused exclusively on student reasoning rather than underlying factors such as a student's epistemology and expectations. These factors are in fact 'higher order' or 'meta' tools in that they influence a student's choice of tools and workbench processes. Wittmann and Scherr [8] have demonstrated that a student's epistemological stance can mediate a student's sense-making processes. Our framework can alert a researcher to these issues and help her identify the possible epistemological mode that the student is operating in.

- A student is asked what gears are on a bicycle.
  Student: Um, I don't really have a **good scientific definition** but it's just they're like different modes ...
- A student is asked to explain why he assumes a charged sphere in an E-field acts like a point charge.
  Student: I wasn't thinking about it in the sense of having - **I should have read the chapters** – um, if it has the same charge, I think you can assume it's a point charge...

In the first segment below, the student says that she needs to be "scientific." Similarly, the student in the second segment indicates that he should have "read the chapter." In both cases it appears that the student is operating in the "knowledge is propagated stuff" epistemic mode.

Our framework alerts the researcher to statements such as those made above, which may reflect a student's epistemological stance.

Acknowledgements

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