A FRAMEWORK FOR THE DYNAMICS OF STUDENT REASONING IN AN INTERVIEW

We propose a framework to characterize student reasoning during an interview. Our framework is based on data collected by five researchers, each with different goals. The research participants were enrolled in various introductory physics courses at Kansas State University. The framework has the following elements: 'External Inputs' (e.g. questions, verbal, graphic and other cues) from the interviewer and interview environment; 'Tools' (e.g. memorized and familiar formulae, laws and definitions, prior experiences) that the student uses; 'Workbench' encompassing mental processes (e.g. induction, accommodation) that incorporate the aforementioned inputs and tools; 'Answer' given by the student and reasoning paths connecting these elements. We have used a coding scheme to map out the reasoning paths in our framework. We discuss the applications and implications of our framework.

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Introduction

Interviews have long been used in physics education research. However, they are often influenced by the researcher's agenda and the assumption that knowledge remains static while it is probed. This assumption is not always true. Sometimes students create answers as they speak; thus, we need to be cognizant of the factors that may influence a student's responses. This paper addresses the following questions:

- How do students construct their reasoning during an interview?
- What factors mediate students' sense-making processes during an interview?

Relevant Literature

Student knowledge has been described across a spectrum of grain size. Near one end of the spectrum, Driver (1995), Glasersfeld (1989) and others describe knowledge in terms of mental models. Learners test these models in light of new experiences and may then modify or reorganize them. Near the other end of the spectrum, diSessa (1988) believes in knowledge in pieces or "p-prims." Minstrell (1992) has divided concepts into units called "facets." Hammer (2000) describes "resources" as the smallest usable pieces of knowledge. Our framework, which describes knowledge change in an interview is not anchored at any particular grain size, rather we consider all grain sizes equally and simultaneously.

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Our framework describes knowledge change or cognitive dynamics in an interview. Piaget (1975) describes this change in terms of assimilation (adapting our experiences to fit our knowledge) and accommodation (modifying our knowledge to account for our experiences). More recently researchers have talked about conceptual change in terms of conceptual combination (Ward, 1997) or hybridization (Hrepic, 2002). Researchers often use a flexible semi-structured interview format. This flexibility can make the format susceptible to a researcher's bias. Recently, Scherr and Wittmann (2002) demonstrated how a researcher's agenda "filters" out some of what the student is saying in an interview. Our framework enables a researcher to identify some of these "filters."

Evolution of a Framework

Researchers in the KSU physics education research group often shared anecdotal experiences of their interviewees making up or changing responses in an interview. Therefore, we decided to re-examine our previous data from the perspective of the dynamics of student reasoning in an interview. We emphasize that these data were from five researchers working independently on different projects with different goals. The students were from diverse backgrounds (non-science majors, engineering/physics majors) in different introductory physics courses. Through deliberations we identified four common elements that encapsulated the dynamics of reasoning in an interview.

Elements of the Framework

Our framework is shown in Figure 1. The interconnecting arrows represent all possible reasoning paths followed by students as they articulate their response to an interviewer's question.

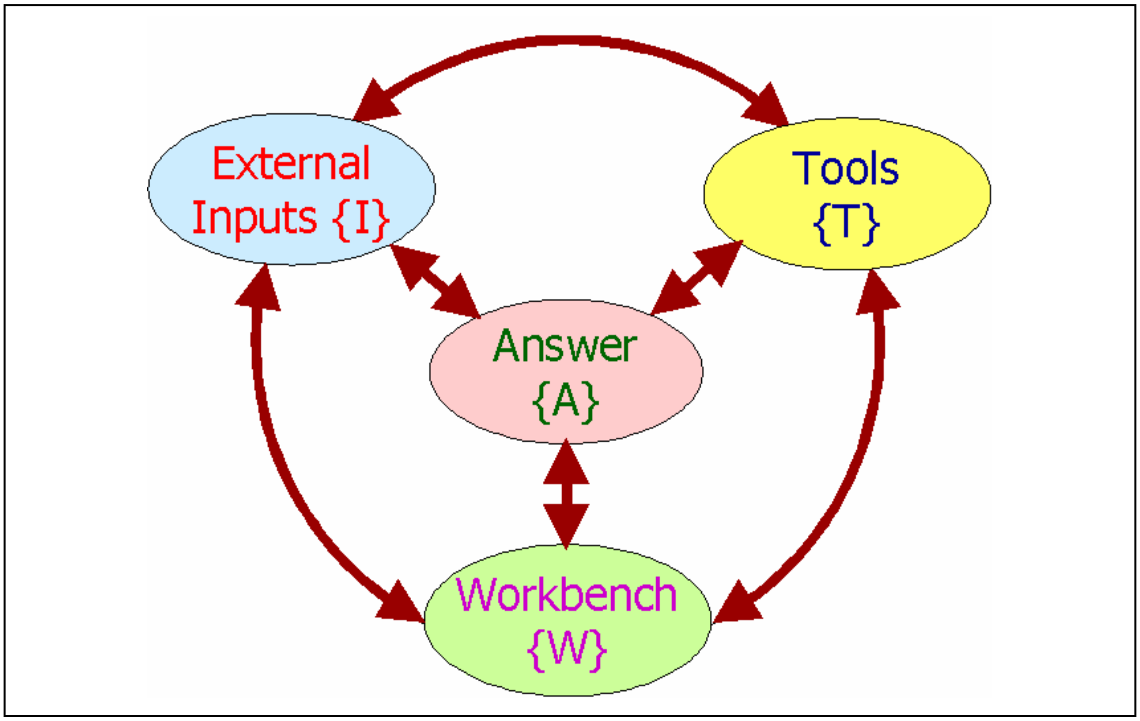


Figure 1: Our framework with four interconnected elements.

External Inputs denoted by {I} is the input provided by the interviewer such as protocol questions, follow-up or clarification questions, hints or cues, both verbal and non-verbal. It also includes other materials e.g. text, pictures, demos, videos, etc. that the student is allowed to use.

Tools denoted by {T} include the knowledge structures that a student uses in her or his reasoning. Tools can be either pre-existing or created. Existing tools include a student's prior experience, memorized information, facts, data, formulae, definitions, rules, procedures, etc. It also includes knowledge structures of different grain sizes, ranging from p-prims or facets to mental models or theories. Additionally, tools include a student's epistemological stance (Wittmann and Scherr, 2002) and expectations about the type of knowledge ("knowledge as fabricated stuff" vs. "knowledge as propagated stuff") that can be used in given situation. Created tools are dynamically constructed knowledge and experiences at an earlier instance in the interview, such as answers to or knowledge acquired through previous questions.

Workbench denoted by {W} includes mental processes used by the student. These processes activate dormant knowledge in {T}, such as executing a known rule or procedure. These processes often reorganize and restructure knowledge (e.g. assimilation, accommodation) or synthesize different pieces of knowledge (e.g. conceptual combination, hybridization). {W} includes transferring and applying prior knowledge and experiences in new situations such as analogical, inductive or deductive reasoning as well as decision making. The latter can occur when a student decides that a given analogy or explanation is applicable to the situation at hand or when the student has to choose an answer from more than one option.

Answers denoted by {A} are the conclusion of a reasoning process, but could be articulated first by the student. Answers could also be an intermediate stopping point. This type of situation occurs during metacognition (Flavell, 1979). Answers can be decisive, i.e. a single conclusion or indecisive, e.g. two or more answers, "don't know" or a request for more information. In the latter case {A} is in fact a question.

Applying the Framework -- Analyzing Students' Reasoning Paths

Our framework can unearth some interesting reasoning paths used by students and their components. An example (Figure 2) from our interview data demonstrates the details of cognitive conflict demonstrated by a student during an interview. Cognitive conflict or dissonance (Festinger, 1957) can help students learn science (Hewson, 1984). Piaget's (Piaget, 1975) cognitive disequilibrium occurs during assimilation and accommodation (both {W}), when a learner's internal knowledge {T} conflicts with her/his external experience in a discrepant event {I}.

Interviewer:
{I_1} How will they (two 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.
Interviewer:
{I_3} Why?
Student:
{W_2t} Well, you just have that constant energy going to each
{A_2} so it stays the same.

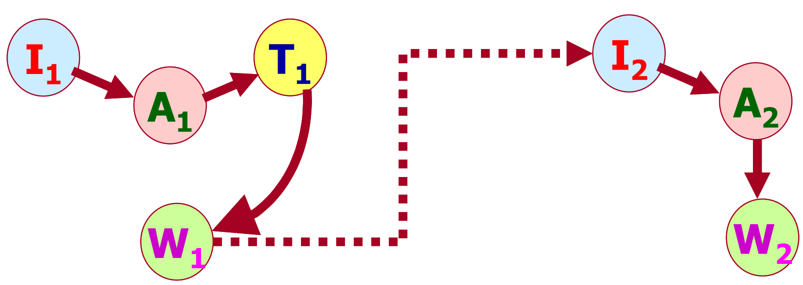


Figure 2: Conflict resolution reasoning path

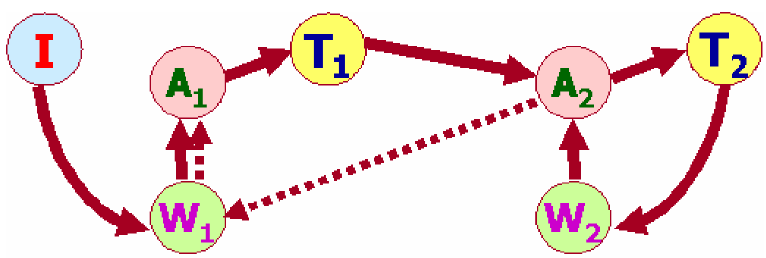
When asked to predict how the brightness of two bulbs in parallel will compare to a single bulb {I_1}, the student answers based on a p-prim (more is less) {T_1}, and elaborates {W_1} their answer - less bright {A_1}. The interviewer completes the circuit so that the bulbs light and asks what happened $\{I_2\}$. 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 implicit, is denoted by 't.'

Advantages of Using the Framework

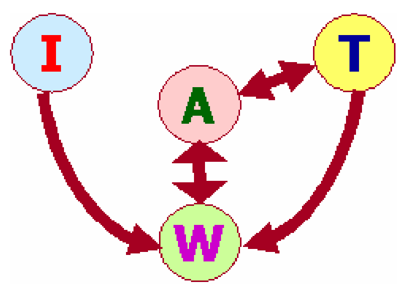
The process of identifying various elements of the framework in an interview transcript forces a researcher to carefully consider what the student is saying, without overlooking words or phrases which may have been filtered out by the research agenda. The framework urges the researcher to look for evidence of each of these four elements. Therefore, using this framework alerts the researcher to the absence of one or more of these elements, especially {T} and {W}, thereby avoiding an exclusive focus on {A}. By interconnecting the elements, the researcher can carefully trace the effect of various inputs and cues. For instance, the {T} that a student uses when presented with a particular input {I} may have been lost if the focus had been only on {W} or {A}.

The framework can help the researcher design questions that elicit cognitive tools {T} and processes {W}. During the interview, the framework can help the interviewer ask follow-up questions {I} that explicate students' reasoning. The framework can also help the researcher glean overall trends in a student's reasoning across several questions or to analyze a transcript at multiple grain sizes. The example below shows a transcript analyzed at two grain sizes (Figure 3). We can use a 'fine brush' to see details that emerge from the data such as small grain size knowledge elements (e.g. resources), selection of various tools and the back and forth deciding between different answers. We can also use a 'broad brush' to see global trends in the data and large grain size knowledge elements (e.g. mental models).

Interviewer:
{I} So how many gears do you think this one has (bike 1)?
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.



Fine Analysis

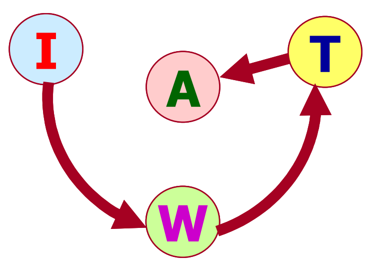
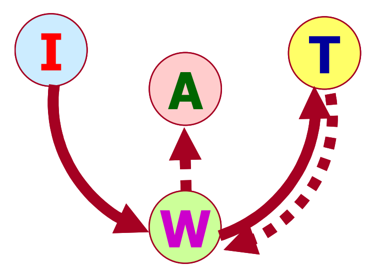


Coarse Analysis

Figure 3: Analyzing the transcript above at two grain sizes –Fine and Coarse

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. This mode of application is more susceptible to researcher interpretation and bias than the first one. In the example below (see Table 1), a student was 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 can also infer that the student uses analogical reasoning (Gentner, 2000) involving three {W} processes: -- recognizing a target {T}, abstracting structural similarities between source and target and mapping similarities from source to target. The first of these processes is somewhat evident in 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}. Note that there was no attempt made in the inferential analysis to separate the abstraction and mapping processes in {W}. This demonstrates that although the framework can bridge data with theory, use of the framework is ultimately grounded in the data.

Table 1: Applying the framework in different ways

What the student says	What we *infer* the student thinks
{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 other side of the wall {A}.
	

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/his 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 (Driscoll, 2000). 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.

Limitations of Framework

The descriptions of various elements in our framework are not exhaustive, e.g. {W} can include processes (e.g. abduction (Josephson, 1994)) that we have not mentioned. It is possible that a student's statement cannot be uniquely categorized as a particular type of tool. For instance, a {T} prior experience (e.g. pushing a grocery cart), could also be a p-prim (motion implies force). Similarly in {W} two processes can be inseparable, e.g. abduction includes decision making. The boundaries between various elements in our framework can often be difficult to distinguish, e.g. the procedure, "If 'X' then 'Y'" is either a {T} or a {W}. Elements can sometimes be implicit, e.g. the answer {A}, "It speeds up because a net force acts on it" implicitly uses {T}, Newton's II law.

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.

Summary and Conclusions

Our research has shown that students indeed do construct their reasoning during the course of an interview. Therefore, students' dynamic sense-making process in an interview and the factors that control these processes are worthy of attention. In carefully re-analyzing interview transcripts from our data we conclude the following:

- Students' reasoning in an interview can be described in terms of an analytical framework that comprises four elements. Three of these elements: Tools, Workbench and Answer together describe the cognitive processes through which the student constructed her/his response to the question.
- The factors that control students' sense-making processes are often controlled by the fourth element, i.e. the external input provided to the student by the interviewer. The external input may provide tools that a student uses in her/his reasoning. More subtly, the external input can also cue the student into a certain epistemic mode and indirectly affect the types of knowledge that he/she utilizes in her reasoning process.

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