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Applying Decoding the Disciplines in a Construction Engineering Mechanics Course: A description of the Decoding Interview

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Introduction

> *I don't know how many times I've finished what I thought was a great treatment of a topic in structural mechanics, only to find that when I'm grading assignments, the majority of the students just did not 'get it'. I try to use best practices that include an active learning environment, opportunities for students to practice and receive feedback, high expectations and multiple modes of content delivery, are all things that are supported by over 70 years of educational research*[1]*. But the best teaching practices are in vain if the students are not able to make the cognitive moves that I expect them to make.*

It is safe to say that most engineering educators are experts in their own discipline, and yet, concepts that seem to be simple present huge challenges to novice learners because students do not possess the necessary knowledge base[2]. Recognizing the novice perspective is a potentially powerful first step in helping students overcome obstacles to learning. One promising approach coming out of the Scholarship of Teaching and Learning (SoTL) movement is called Decoding the Disciplines (Decoding)[2]. The Decoding process is a comprehensive form of action research[3] that guides the educator to uncover, or 'decode', expert ways of thinking that are not obvious to novice students.

The purpose of this paper is to examine a single step (the decoding interview) in the Decoding process that is at the heart of Decoding process to illustrate how some tacit moves in one engineering mechanics course were uncovered. This study is part of a larger research project, based in the interpretive research paradigm that is common in education research. This project uses case study[4] methodology and autoethnographic methods. Autoethnography is a type of self-study that transcends narration and engages in cultural interpretation[5]. As such, this study is presented in a descriptive narrative format using first person voice. The author acknowledges that, while these methods are not common in engineering and science research[6], they are consistent with the call to bring together disciplinary thinking with research-based practices in education which has been identified as a priority by the American Society for Engineering Education (ASEE) [7]. The resulting description is intended to provide an example for future studies applying the Decoding process in order for researchers to better plan and understand the process. This study is significant because, while results of Decoding the Disciplines have been documented back to 2004[2], the literature is devoid of detailed descriptions of the decoding interview itself.

This paper begins with background on SoTL and Decoding the Disciplines. Next, the context of the specific application of the Decoding process is described to set the stage for the decoding interview that is at the center of this study. Excerpts of the interview are then presented to provide an example of the way an obstacle to learning, or ‘bottleneck’ is decoded. This paper concludes with some closing remarks

Background

Scholarship of Teaching and Learning is a movement that “involves creation and dissemination of original work that makes a useful contribution to knowledge and practice of other teachers” [8]. SoTL has contemporary foundations in Ernest Boyer’s work *Scholarship Reconsidered: Priorities of the Professoriate* [9]; however, scholarly teaching can be traced back to Robert Maynard Hutchins’ suggestion in 1928 that “faculty in all departments should carry on experiments in undergraduate teaching and learning”(p. 2)[10]. “Scholarship of Teaching and *Learning*“ is a term coined by Hutchings and Shulman[11] to emphasize “not only teacher practice but the character and depth of student learning that results (or does not) from that practice”(p. 13). Scholarship of teaching goes beyond what may be considered excellent teaching: It “requires a kind of ‘going meta,’ in which faculty frame and systematically investigate questions related to student learning” (p. 13).

Decoding the Disciplines

In engineering and sciences, SoTL has been recognized by the National Academy of Sciences and is referred to as Discipline Based Educational Research (DBER)[12]. DBER calls for education researchers to embrace disciplinary ways of thinking. As a research-based method, Decoding the Disciplines is well-poised to answer this call; however, no examples have yet been published demonstrating how this process is applied in engineering.

The Decoding the Disciplines (Decoding process) model is based on a seven-step framework “within which teachers can develop strategies for introducing students to the culture of thinking in a specific discipline and, in the process, level the playing field for those students who do not come to college ‘preeduated’ [sic]” (p. 3)[2]. The model was initiated at Indiana University after a realization that the mental operations required of undergraduates differ enormously from discipline to discipline. The Decoding process is based on the premise that these ways of thinking are rarely presented to students explicitly, that students generally lack an opportunity to practice and receive feedback on particular skills in isolation from others, and that there is rarely a systematic assessment of the extent to which students have mastered each of the ways of thinking that are essential to particular disciplines [2].

At least seventeen studies using the Decoding process in various disciplines have been published, including the fields of humanities[13], arts[14,15], and natural sciences[16–20], with the preponderance from the discipline of history[20–24]. In the area of faculty development in engineering education, Froyd[25–27] and associates identify Decoding the Disciplines as one of three useful patterns that have emerged in the research on successful development activities as a model for contextual thinking and communication. Faculty development Decoding sessions have been led at over two dozen universities and in many conference workshop settings (Middendorf, personal communication, March 6, 2012).

The model uses a process of seven sequential steps that are aimed at addressing obstacles to learning in a discipline. Middendorf and Pace illustrate each step by a question that educators can ask themselves as they work on particular challenges to student learning in their own disciplines:

1) What is a bottleneck to learning in this class?
2) How does an expert do these things?
3) How can these tasks be explicitly modeled?
4) How will students practice these skills and get feedback?
5) What will motivate the students?
6) How well are students mastering these learning tasks?
7) How can the resulting knowledge about learning be shared [2(p3)]

Decoding process is a cyclic process that takes the findings shared in step 7 to inform future inquiries into the challenges of learning back at step 1. This paper focuses on question two: 'how does an expert do these things?' In order to address this question, it is necessary to understand what a bottleneck is.

Bottlenecks to learning.

Bottlenecks are "points in a course where the learning of a significant number of students is interrupted"(p. 4)[2]. Some bottlenecks are related to 'threshold concepts,' or conceptual building blocks, in that the bottleneck inhibits access to the threshold concept [28–32]. Mastering threshold concepts progresses the understanding of a particular subject matter and is likely to shift a person's perception of the subject matter in a way that exposes previously hidden relationships in an irreversible way [28]. Other bottlenecks are related to misconceptions about fundamental concepts [7,33,34]. These misconceptions are often sensible, even if they are incorrect, and therefore pose challenges to learning science and engineering. A meta-study sponsored by the National Academy of Science[12] concludes that the most useful research on misconceptions focuses on understandings that involve concepts central to the discipline. The meta-study also concludes that students seem to have difficulty understanding phenomena that are not directly observable and that a variety of teaching strategies are necessary to help students refine or replace incorrect ideas and beliefs.

Bottlenecks are therefore discipline-specific. Experience informs the educator as to where students are getting stuck, and thus identifying a bottleneck may be as easy as reviewing the final examinations from a previous semester for common errors. However, if considerable time is going to be devoted to applying the Decoding process in full, it is important to identify a bottleneck that is worth the effort and will provide access to the most important threshold concepts or clear up major misconceptions. The bottleneck should be "something that is essential for [student] success but which semester after semester, large number of students fail to grasp"(p.

1)[35]. As with learning outcomes [36], the bottleneck should be well-defined and worded such that student success can be measured. What is difficult about these bottlenecks is that they are not obvious to the educator and are therefore overlooked[2]. This is consistent with the research on the difference between how experts and novices approach a discipline.

Expertise has been extensively studied, especially in the domain of problem solving, where it has been established that experts approach content and problem solving in a fundamentally different manner than novices [37]. Teasing out the explicit steps that are tacit to an expert is the objective of the second step in the Decoding process. The decoding model suggests using an interviewing technique whereby one or two "fellow" academics with only a surface familiarity of the educator's discipline probe expert thinking about the bottleneck. In the interview, the educator is pushed to explain "in precise detail just what an expert would do if faced with one of the tasks that students had difficulty completing successfully" [2(p6)]. Middendorf and Pace report that fellows often experience an 'aha' moment during the interviews that give them a preview of how deeply they will examine their students' thinking. These "aha" moments provide the key to unlocking the obstacle to learning.

The goal of the interview is to elicit the intellectual moves that are made when dealing with the topic of the bottleneck, and not to describe the content of the teaching. The one basic question that the interviewer should be asking, the essence of the Decoding, is 'How do you do that?" The interviewer is encouraged to do this by making the following mental moves:

- Ask the interviewee: "How would YOU do that kind of thinking?"
- Think to yourself, "What kind of thinking is this?" Then summarize the thinking back to the interviewee at an abstract level
- Probe at the place where they cannot explain
- Gently interrupt if interviewee talks about how they would teach it, or if they launch into their lecture
- Reassure the interviewee
- Embrace your ignorance; be fearless [38(p2)]

For instance, in the discipline of history education, Pace[39] realized by way of the Decoding process that his "students had to make explicit the assumptions and values implicit within specific cultural artifacts" in order to "analyze a text or image in preparation for placing it in its historical context" (p. 77). The expert move that he was assuming the students would naturally make is recognizing these assumptions and values. Without this key step, something that Pace did automatically, students would not be able to place artifacts in a historical context. In the field of creative writing, Ardizzone[13] found that the process of choosing descriptive images and words was something that students were not doing. Innes[19] discovered that students in molecular biology courses did not understand how biological processes actually worked because they were not organizing information in terms of an animated process. He realized that, as an expert, he visualized the process as a dynamic cartoon[2].

These examples from the literature, however, are not accompanied by descriptions of how these aha moments were realized during the Decoding interview. The next section provides an illustration of a Decoding interview for a bottleneck in a structural design course that is part of a construction management program. While only one step of the Decoding process, the interview, is presented, it is key to the success of the subsequent steps of development and implementation of an instructional model. The explicit description that follows is intended to serve as an example for others who wish to 'decode' their own discipline.

Using the decoding interview in a construction engineering course

Introduction to Structural Design, CM220, is a required sophomore-level course offered as part of an American Council for Construction Education (ACCE) accredited Bachelor of Construction Management (CM) degree program at Northern Arizona University (NAU). This math-intensive course is an "introduction to the basics of statics, mechanics of materials, and structural design philosophies"[40]. While CM students will not become professional engineers, an important part of their education is an introduction to engineering concepts [41]. Knowledge of engineering mechanics concepts can help construction professionals better understand a building structure and its associated parts, assist them in planning and sequencing construction, help them recognize unstable or unsafe conditions, and provide them with the language to communicate with other professionals. In certain circumstances, such as residential structure design, concrete formwork design and the design of temporary structures, the construction professional is actually responsible for the integrity of the structure. In the case of this construction engineering mechanics course, one bottleneck is that students have difficulty relating the abstract stress-strain curves to actual material behavior. Stated explicitly, the bottleneck is that:

> Students can calculate stress and strain given the proper parameters, but have difficulty understanding how they relate to each other and the importance of their relationship to structural behavior and to CM.

Using this bottleneck definition as a starting point, I facilitated a decoding interview of myself. The next section describes the process by which I selected interviewers and provides excerpts from the ensuing interview.

Interviewers

Based on my previous experience with Decoding interviews, I found that selecting interviewers is something that should be done carefully. Middendorf suggests that the interviewers be fellow educators who are 'expert learners', yet from disciplines different than the interviewee, making them 'content novices' (personal communication, May 2012). I have personally found that at least one interviewer should be from a discipline that shares some similar background with the interviewee so that the interview is not dominated by the process of gaining understanding of the bottleneck itself. A key characteristic of a good interviewer is the ability to keep the interview on track, however, the interviewee should also take an active role in keeping focus on expert moves.

I selected two interviewers from the faculty at NAU with whom I had personally worked during a Decoding the Disciplines workshop who met the above criteria. I chose Dr. B. because, as a geologist, she is familiar with the concepts underlying the bottleneck, yet in her discipline these concepts are treated on a global scale. I chose Dr. K. because I was impressed with her ability to keep a Decoding interview focused. Her discipline of comparative cultural studies puts her at a good distance from engineering mechanics, yet I was confident that she would quickly understand the basic concepts underlying the bottleneck because of her personal background.

Decoding interview

At the beginning of the interview, both interviewers read the bottleneck statement to themselves, after which I spent a few minutes describing the CM program and the CM220 class in particular. I then spent about ten minutes explaining the concepts of stress and strain, giving a sort of mini-lecture on the topics, complete with mathematical examples and diagrams. I was pleasantly surprised that only ten minutes were spent on background concepts, something that I attribute to my choice of interviewers. Right away, we identified some sub-bottlenecks: [JT represents the Author, or interviewee]

Dr. B: "So you are saying that the students do understand…. They can do the math?

JT: "They can do the math, it is fairly simple. Same with stress. Force divided by area. The concepts of stress and strain are… I think are both, sub-bottlenecks here. I have to make sure that I get them over those."

This was not surprising. When I developed the bottleneck, I was aware that addressing stress and strain independently of material behavior would have to be an integral part of the instructional model, but here I confirm that this is the case.

After explaining the concepts of stress and strain, and their relationship to material behavior, I started drawing and describing stress-strain curves for different materials (see Figures 1 and 2). Fifteen minutes into the interview, the first decoding takes place:

Dr. K: "What are these diagrams supposed to do for them? When this relationship is in this diagram? [pointing to the graph that I had just drawn, see Figure 1] What are they not understanding about them?"

JT: "So, for instance, um, looking at the diagram, being able to determine how a material will react or behave. So if I have the blue line [①] here, we can say it doesn't go out very far, therefore that type of material is brittle"

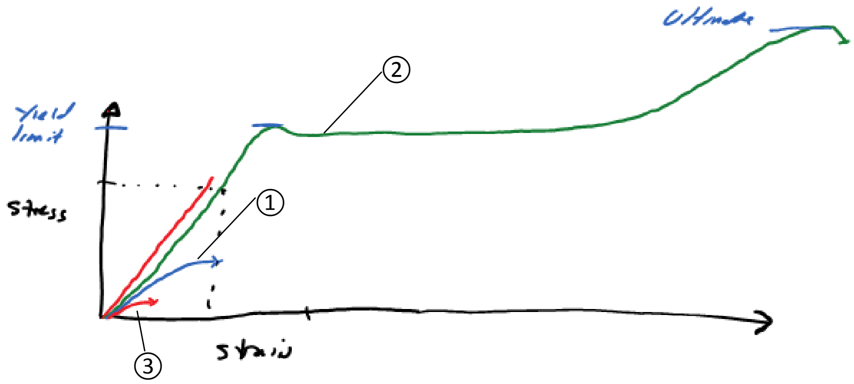

Figure 1: Example stress strain curves drawn during Decoding Interview

At this point in the interview, I am identifying the expert move that I make is to associate the shape of these curves with material behaviors. Brittle materials will break without much warning (blue line ① in Figure 1), while ductile materials (green line ② in Figure 1) will deform extensively before they break, providing warning. Ductility is an important material property that provides a margin of safety in structural design. The relative stiffness of the material can also be determined by the shape of the stress-strain curves. I follow up by providing multiple examples that are easy to relate to: the behavior of a twig from live tree (soft and ductile) as compared to a wooden pencil (stiff and brittle). This elicits another pivotal question:

Dr. K: "Is that something that you do automatically? Coming up with a quick example of different types of materials…?"

JT: "I do, I do... I think I do... For instance with this wood here, you know, the wood, the green wood, is softer, [pointing to green line ② in Figure 2], therefore the curve is going to be flatter, right? It goes further with the stress than the strain -- wait, I've changed -- I'm showing symbols [drawing Greek symbols sigma for stress and epsilon for strain in Figure 2] this is stress [pointing to σ on the graph] and this is strain [pointing to ε]."

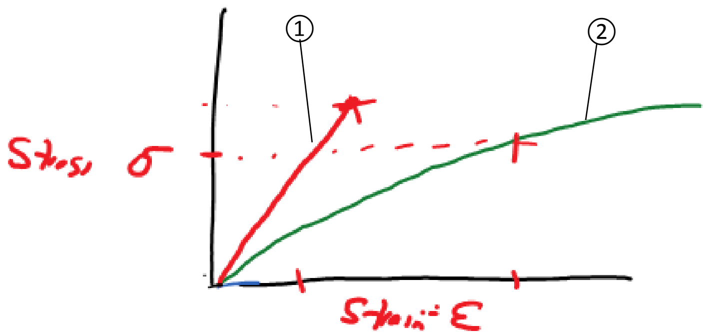

Figure 2: Stress strain relationship showing difference between soft, non-linear and stiff, linear materials drawn during decoding interview

And I go on to show how the flatter curve indicates softer material and the steeper curve is stiffer material. I also realize that I did something that I do in class: interchange nomenclature (*e.g.* f and σ for stress), something that engineers would recognize as being the same. Following up on this, we start to realize how I make sense of these stress-strain graphs and confirm that I am assuming that students are even competent in interpreting a line graph like that shown in Figure 2.

Dr. K: "Do you construct little examples in your head when you … look at a graph,… that connection is made when you have a visual of the material?"

JT: "I have a visual of the graph. I'm thinking that the students have a trouble with graphing."

Dr. B: "Yeah, and that is something that we experience in our intro [to geology] classes -- just reading a graph...is something that we are used to. We [educators] don't even think about it. We say things like 'the x axis' and students -- blank look -- which one is that one?

Dr. K: "…you have been talking visuals for the last 10, 20, 15 minutes. Everything that you have explained to us is in terms of an example that was an actual material,… but then it is transferred into a very abstract x and y axis…"

JT: "… and that is a problem"

Dr. K: "… and that is the transfer that they are not making."

JT: "I think, I think so. I think that they can't -- If I see these four curves here [indicating drawing shown in Figure 1] in can immediately say, well this one is a low-strength, brittle material [blue ①], this is a very low-strength brittle material [bottom red ③], this is a very ductile material [green ②], and so I look at those graphs…

Dr. K: "… and you look at the graph and you immediately relate that to what these two are…"

It is instantly clear to me that if students cannot abstract information on a 2-dimensional chart, they will never be able to get where I want them to go. I assume that they understand that points plotted in the first quadrant imply increases in scalar value. Furthermore, I am assuming that they understand the basic concepts of stress and strain, the very information that I am expecting them to be plotting or interpreting off of these graphs. It is interesting to note that it has been suggested that most errors students make in solving physics problems that involve graphs are due to an inability to interpret the graphs and not to inadequate experience with concepts [42]. Dr. K. wonders if I'm making too much of a leap here:

Dr. K: "But can they get that far? When you look at a graph like this, you didn't even put an arrow (points to the 'y' axis on Figure 1) like this goes up, like it is an increase. That individual thought -- you said that they are not making the connection, so maybe they are stuck still imagining … stress, imagining strain in time. What you said, the x and the y, putting them together. Can you somehow build another step in between?"

I realize that we have identified three sub-bottlenecks that need to be addressed before I can even introduce stress-strain relationships: Students need to have a solid understanding of the concepts of stress and strain and they need to have an ability to use and interpret data graphs. Further, I seem to jump from stress and strain to the connection between the graph and material behavior. Dr. Middendorf predicts this sort of realization: "we have found that everyone who takes this work seriously starts with a bottleneck and then finds that within that bottleneck lie many more bottlenecks…. Think of the layers of the onion metaphor" (personal communication, August 6, 2012). One expert move that I seem to make, therefore, is the use and interpretation of data graphs, something that may be a bottleneck for my students. The conversation continues, exploring how we, as scientists and engineers, use graphs and we muse about where students get hung up. We agree that it is important to provide explicit steps to move from concrete examples of material behavior, through the abstraction of that behavior on a graph, to the subsequent interpretation of material behavior from that graph.

Discussion of the implicit expert moves that I make when I work through the bottleneck are the crux of the entire Decoding process. Explicitly stating something so simple as "I know how to interpret graphs" forces me to evaluate whether this is something that I can reasonably expect my students to do.

Prior to the Decoding interview, I realized on my own that I associate shapes of stress-strain curves with material behavior. The interview process, however, allowed us to explore this expert move in more detail, something that would prove to be useful in developing the instructional model later on. The interview process goes further than just identifying expert moves: It provides a venue to explore them as well.

The abstraction step in creating data graphs invariably involves making some simplifying assumptions:

JT: "…because I am showing something really complicated, and I say, "ok to really use this, we're going to simplify it with two lines". Now that does open up other issues, like, ‘how do you justify that simplification?’ ‘How did you come up with that?’”

…

Dr. B: “’Why is that valid?’ ‘Why can you do that?’… ‘Why are you using those two lines to represent something that doesn't look like that?’ I wonder if it is a -- we can say that it is a simplification. It is easy for us to think about, but does that all of a sudden make a student go ‘wait --- how did you do that? why did you do that’?

…

Dr. K: “For you it is simplifying, but for them it could …”

Dr. K, Dr. B & JT, (in unison):“…make it more complicated.”

JT: “I like that.”

Dr. B: “We don't understand, how that looks like that.”

Dr. K: ”…because you are introducing one of those steps you make unconsciously, because you have made it a hundred times. It actually simplifies for you, whereas for them it does the opposite…”

Dr. B: “…it makes it worse.”

JT: “It makes it worse.”

Dr. B: “It makes it worse, like, ‘I don't understand.’ So if you start with just straight lines -- and for you, you are going to have to decide if you will call them 'steel-like' or 'Substance A', you know, and just talk about substance A…”

JT: “And maybe I'm talking about those properties that those different curves represent…”

…

Dr. K: “For you it's a simplification, for them it is a complication.”

JT: “I think that’s a huge issue”

Dr. K: “That’s a tiny, tiny bottleneck in this particular example, but conceptually…”

JT: “It is part of – It is kind of the essence of engineering. It really is”

This is indeed an ‘aha’ moment. The decoding interview did uncover something that I had not previously considered: A paradox that simplification is actually a complicated process. Simplification is at the heart of the engineering process, something that is done through the use of models by capturing the important aspects of the general phenomena under consideration while disregarding trivial information. Deciding what is essential and what is trivial is truly an expert choice, one that is not simple at all. It is beyond the scope of this construction engineering mechanics class to expect students to create simplified models from scratch, but acknowledging the expert nature of this process can help students make sense of why we simplify and how it is done.

The Decoding interview also produced ideas for modeling expert behavior and student practice. For instance, discussing the concept of strain:

Dr. B: "So, that is what they have the problem with, is understanding that, that it is the same strain. That a longer object, even though it is deforming more…"

JT: "Has the same strain…. so if it is short, it deforms just a little bit, and if it is really long, it deforms more, but they have the same strain..."

Dr. K: "Under the same stress"

…

Dr. B: "You could do that with a rubber band. a small rubber band...and a big one. They are both going to stretch, but the bigger it is, the more it is going to stretch."

Taking it further into material properties:

JT: "Here is an example. A dry branch would look like this [red curve ① in Figure 2]

Dr. K: "Have them chop wood - if it is dry enough you can chop it well…"

JT: "… because it is brittle…"

Dr. K: "… if it is too moist you can't… it gets stuck."

JT: "And the other thing is that a green branch is easy to bend, but it doesn't break, so the green branch is going to look like this [indicating green line ② in Figure 2]. It is going to go way out like this…."

Dr. B: "If you could talk about, if you can show them examples, if you can draw this, and bring in an example of that one and that one [pointing back to the graph]… but maybe not even draw it, but first show them behavior, and talk about it, so … I have a little bit of stress, what is the strain?"

The last fifteen minutes of the interview were spent talking about ways that I could further approach these bottlenecks and unpack the expert moves that I make. Armed with these, I was prepared to enter the next stage of the decoding process. Over the course of the next month, I developed ways to model this expert behavior, interactively present the content to the students, and give the students opportunities to practice and get feedback. Details of these steps, however are beyond the scope of the present study.

Summary

In this particular case, the 60-minute decoding interview resulted in a clearer picture of the bottleneck, including the identification of sub-bottlenecks that may also present as obstacles to student learning:

- The primary bottleneck has two parts: "students have trouble relating stress to strain" and "the importance of this relationship",

- The concepts of ‘stress’ and ‘strain’ themselves are sub-bottlenecks that need to be addressed, and
- Students may be getting stuck just being able to read a graph.

The interview also decoded the following moves that I make when teaching this topic:

- I know how to read/use graphs,
- I automatically use simplification, a natural process in engineering, to aid in problem solving, and
- The expert move that I make is to associate a shape on a graph to a physical behavior

In addition, several good ideas about how to treat the bottleneck in the classroom surfaced.

Discussion

The preceding excerpts from a Decoding interview demonstrate how an educator can uncover the implicit disciplinary moves that an expert (educator) makes when confronting a topic that challenges a novice (student). One relatively universal finding from the research in the field of expertise is that expertise in a domain is not contingent upon some sort of innate ability or talent, but rather that people with ordinary levels of intellect, talent and skill can achieve expert status [37,43,44]. Chi et al. [37] found that experts organize knowledge around fundamental principles that “derive from tacit knowledge not apparent in the problem statement” (p. 70) while novices organize on surficial features. Tapping into expert behavior to help students learn is a powerful tool, but only if the expert moves are identified. One cannot expect novice students to automatically organize information and approach concepts the same way that experts do. It is therefore important to explicitly guide the students in disciplinary ways of thinking.

Conclusion

This paper describes a single instance of a decoding interview applied to a single bottleneck, or obstacle to learning, as part of the Decoding the Disciplines process. The purpose of this study was to provide this illustration not as a definitive model, but rather as an example in order to assist others in a similar context. It is not the specifics of what we uncovered during the decoding interview that are important here, but rather the process by which they were uncovered.

Disciplinary behavior differs among the various fields, and therefore expert moves in engineering will look much different than those in history or art. The strength of the Decoding process is that it helps the educator tap into specific disciplinary expertise.

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