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Using *Decoding the Disciplines* to Elucidate the Mental Processes Involved in Reading Graphical Data

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Summary

A goal of many undergraduate majors is to improve quantitative literacy. This paper addresses one aspect of quantitative literacy, namely the reading of graphical data. Using the *Decoding the Disciplines* approach, we have identified graph reading as a *bottleneck* and engaged three faculty in *decoding* interviews. The interviews revealed these mental moves in graph reading: establishing a context or orienting to the graph (including understanding the axes), looking for a *pattern* in the data and generating a verbal statement about the relationship between variables. We found that graph reading is an iterative rather than a linear process. Moreover, there was a consensus among the interviewees that faculty make assumptions about students' ability to understand graphical data and that many students have not been taught, at least explicitly, how to read a scientific graph as scientists read them.

Keywords: Quantitative Literacy; Graph; Decoding the Disciplines; Bottleneck

Die Anwendung von *Decoding the Disciplines* zur Verdeutlichung der mentalen Prozesse beim Lesen grafisch visualisierter Daten

Zusammenfassung

Ein Ziel vieler Studiengänge ist es, die Kompetenz zu verbessern, quantitative Daten zu verarbeiten und interpretieren. Dieser Beitrag befasst sich mit einem Aspekt dieser Datenkompetenz, nämlich dem Lesen grafischer Darstellungen. Mit Hilfe des Decoding the Disciplines-Ansatzes haben wir das Lesen von Grafiken als Engpass identifiziert und drei Lehrkräfte in Interviews befragt. Die Interviews ergaben folgende mentale Schritte beim Lesen von Diagrammen: Herstellen eines Kontextes oder Orientieren am Diagramm (einschließlich Verstehen der Achsen), Suchen nach einem Muster in den Daten und Erstellen einer verbalen Aussage über die Beziehung zwischen Variablen. Wir haben festgestellt, dass das Lesen von Diagrammen eher ein iterativer als ein linearer Prozess ist. Darüber hinaus waren sich die Befragten einig, dass die Lehrkräfte Annahmen über die Fähigkeit der Studierenden treffen, grafische Daten zu verstehen, und dass vielen Studierenden nicht – zumindest nicht explizit – beigebracht wurde, wie wissenschaftliche Grafiken zu lesen sind bzw. wie Wissenschaftler:innen sie lesen.

Schlüsselwörter: Quantitative Datenkompetenz; Diagramme; Decoding the Disciplines; Lernhürden; Statistik

1 Introduction

A goal of many undergraduate programs, particularly in the social and natural sciences, is to improve students' quantitative literacy skills. One aspect of quantitative literacy that is particularly important to students' success is their ability to read[1] graphical data. In psychological science, there is an ever-increasing emphasis on methods and statistics, even at the very early stages of undergraduate education in the United States. The American Psychological Association (2023) explicitly states that the interpretation and communication of graphical data should be a goal of undergraduate psychology education. Reading graphs, the topic of the current study, is a skill needed by students in many disciplines in addition to psychology. Graph literacy is defined as the "ability to understand graphically presented information and includes general knowledge about making inferences from different graphic formats" (Okan et al., 2016, p. 271). If it is low, it leaves one susceptible to accepting misinformation. Thus, the interpretation of graphical data and quantitative literacy, generally, is important for informed citizens.

Many students struggle with graph literacy (for a review, see Glazer, 2011). We have also observed that many psychology students struggle to communicate clearly about data, which in some cases is a failure to understand data. We have observed this in students' oral presentations of empirical findings presented graphically (Cameron & Duffy, 2015). Specifically, when presenting data orally, students often did not identify what had been manipulated and measured (i. e., describe axis label), nor did they describe important differences between conditions (i. e., describe *trends* in the data), consistent with the findings of Picone et al. (2007). In a lab setting, in which students and faculty read graphs while their eye movements were monitored, students often failed to *describe* graphs and jumped quickly to attempting to state conclusions without carefully examining the data (Pelnar, 2019; Robbins et al., 2019). Moreover, in that study, overall performance on graph reading was lower in students than faculty and the faculty spent more time looking at parts of the graph that provide important information for reading the graph. These findings are in accord with other findings in the literature that have reported that eye movements when viewing graphical data depend upon scientific expertise (e. g., Harsh et al., 2019). Interestingly, students do not always demonstrate awareness of their lack of understanding (Cameron et al., 2016), a general feature of metacognition that has been described in a variety of contexts (e. g., Kruger & Dunning, 1999).

The ultimate goal of our work is to help undergraduate students understand and communicate more clearly about graphical data. We find this to be a struggle that exists in our students, despite the fact that, anecdotally, students indicate that they began encountering graphical data in elementary school and teaching about graphs and tables is part of primary and secondary curricula in the United States (Friel et al., 2001; Zucker et al., 2015). Glazer (2011) argued that graph reading competence should be explicitly taught given its importance and its complexity, but noted that few scholarly articles were available on explicit educational pedagogical practices at that time. Life science faculty endorse the importance of teaching science skills at the college level, including interpreting graphical data (Coil et al., 2010) and some methods have been suggested for teaching these skills at the college-level (e. g., Harsh & Schmidt-Harsh, 2016; Picone et al., 2007) and pre-college (Zucker et al., 2015).

In order to develop a systematic approach to teaching graph reading in post-secondary education, we have taken a *Decoding the Disciplines* approach to, first, identify the steps experts take when reading graphs (the primary focus of the current paper) and second, to develop teaching tools. The *Decoding* approach is distinct from verbal protocol procedures such as think-aloud (Trickett & Trafton, 2007), which does not involve asking participants *what* and *why* particular mental processes are at play.

1 We use the word "read" graphs because it seems to be the most encompassing term for this activity, which includes looking at a graph, interpreting and describing it. Our understanding of the processes changed through these interviews and hence we have needed to modify our word-choice accordingly. For example, we originally used the word "interpretation", which we discovered really seems to refer to a very high-level mental process and the bottleneck we face with our students is much more fundamental than that. Students have difficulty even describing graphical data. We describe the evolution of terminology in the Results section, under "Decoding the Disciplines Step 1: The Bottleneck."

Decoding has begun to be applied in the teaching of psychology, particularly in research methods and scientific thinking (Bihun & Handelsman, 2018; Pinnow, 2016). Decoding has been described as part of the "second wave of SoTL" (Gurung & Schwartz, 2010) as it provides a mechanism for studying learning within a discipline.

The current work revolves around *Decoding* interviews (Step 2 in *Decoding*), which start with articulating a bottleneck. The current bottleneck evolved throughout the course of this work, as described below. Articulating the bottleneck and describing the mental moves used by faculty in the task at hand is central to *Decoding* but is sometimes difficult because the expert unconscious mental processes have become so automated. Many experts find it challenging to articulate their mental processes and some even experience frustration or resistance to the process (Pace, 2017). The problem is akin to the *curse of knowledge* (e. g., Camerer et al., 1989), which can make teaching difficult (Bransford et al., 2000, cited in Pace, 2017).

The goal of this project is to apply *Decoding* to clarify the steps used by faculty who are proficient at interpreting and communicating about graphical data. We describe *decoding* interviews with faculty who have agreed that, generally speaking, reading graphical data is a bottleneck for the undergraduate students they teach. These interviews, which are available on OSF[2], reflected the difficulty in making explicit the implicit steps involved in a task that is routinely performed by faculty in the social and natural sciences. However, the interviews revealed a set of mental operations that faculty go through as they read graphs and also reinforced the fact that being able to read a graph is not the same as consciously knowing how one does it. Armed with the knowledge of *how* one reads a graph should allow faculty to teach these steps to students to improve their ability to read and describe graphical data.

2 Method

2.1 Decoding Interviews

We conducted three interviews in which we asked undergraduate-level teaching faculty to make *explicit* their *implicit* mental processes as they interpret graphical information. The Carthage College Institutional Review Board approved this study and participants gave their informed consent.

In Interview #1, the first author (LC, a psychologist) and a physicist (PR) were interviewed by the second author (KD, a communications professor) and a historian (DP), experienced in *Decoding*. This interview took place at the European Scholarship of Teaching and Learning Conference in Lund, Sweden, after LC and PR attended a pre-conference workshop on *Decoding* and requested that the workshop leader (DP) conduct an interview to decode their mental processes as they read graphs, which they had discovered was a shared *bottleneck* in their students' learning.

The second two interviews were conducted by the authors of this paper. The interviewees were selected because they had participated in the related pilot experiment in which their eye movements were tracked while they read and described a set of graphs (Cameron, 2019; Pelnar, 2019; Robbins et al., 2019). The descriptions of graphs by these two faculty were excellent and thus they were considered to be very proficient graph readers.

In Interview #2, the interviewee was a recently-retired male faculty member from the Chemistry Department at Carthage College. In Interview #3, the interviewee was a mid-career female faculty member from the Environmental Science Program at Carthage College. Interviews lasted about an hour each.

At the start of each interview, the *decoding* paradigm and the goal of the interview were briefly described. The interviewees confirmed that the ability to read graphs is a *bottleneck* for students in their science classes. In these semi-structured interviews, the interviewer was an active participant.

2 https://osf.io/3ntqv/?view_only=f22ca25098c54507919954fa0b699f3d

They asked open-ended questions to encourage the interviewee to articulate their implicit mental processing. When appropriate, they sought clarification and asked follow-up questions. The goal of these interviews was to uncover underlying mental processes involved in disciplinary thinking.

2.2 Data Analysis

Interviews were transcribed by an undergraduate research assistant and checked for accuracy by the authors and another undergraduate researcher. Then, each interview was scrutinized to confirm the bottleneck and to extract the main steps to graphical interpretation that were articulated by the interviewee. These articulated steps were confirmed by trained undergraduate researchers. Finally, we developed a more thorough set of steps in graph reading that could be used to create exercises to teach to students, given that moving beyond the bottleneck will help students understand, consume and communicate more clearly about data.

3 Results

3.1 Decoding the Disciplines Step 1: The Bottleneck

The first part of each *decoding* interview involved the interviewee clearly articulating the *bottleneck* they had identified.

The precise articulation of the bottleneck identified here, with respect to graph literacy, evolved over the course of this project. Given that the evolution of the bottleneck illustrates how our thinking about the problem became more nuanced and clarified our understanding of what needs to be taught, we describe that evolution here in some detail.

We came to the first interview with the idea that our (LC and PR) shared bottleneck was about "data interpretation." One of the interviewers (KD) summarized the bottleneck early on in that interview by saying "You're having a hard time... *teaching* students how to *interpret* the data." While we agreed with this articulation, PR indicated something that we both agreed upon, "I've never taught them!" he said. This theme, interestingly, emerged in all interviews. There was agreement that graph reading is not a skill that we explicitly teach, and, in fact, we often make assumptions about what students know. Yet, we all agreed that graph reading is a critically important skill. Moreover, LC indicated several times in the original interview that the fundamental bottleneck was really in the *description* of data. At the start of the interview, she described the problem this way:

> So, I'll give an example from when I first got started with this [working with students on communicating about data] which was having students do online laboratories, where, outside of class, they were doing a cognitive task on a computer that collected data and the online program then provided them with a graphical representation of the data from all the students in the class. Their assignment was to both write about the data and speak in class – present to their peers – an analysis of the data. Only the graph, nothing statistical. Simply, "here's a graph and here's a representation of the data we collected". And it seemed to me that **students had a hard time describing those data to me and to their peers, and also had a difficult time writing about it** ... and it seemed to me that they often missed steps. **There would be simple things they didn't do to help orient people to the graph and to the axes and to what they were actually showing.** So, they acted, sometimes, so as though it was sort of self-evident and they would blow right through, **without giving a clear description**. So, for me that was the starting point. [Emphasis added.]

In fact, in all interviews, faculty indicated that if we could help students improve the simple *description* of data, we would feel that we had made progress. The *interpretation* of data was only a consideration after the basic graphical information had been understood. For example, LC responded to PR's description of a bottleneck and made a distinction between *interpretation* and *description* of data:

> I actually heard three things in there. One had to do with an **expectation** of what the data will look like, in other words a **hypothesis**, a prediction of what might happen. There was clarity in **describing** the data, and then there was **interpretation** of the data. <u>**And I think I was starting with just "Could we get a de-**</u>

> **scription of the data?."** A clear description of the data, maybe even before the hypothesis and the interpretation. [Emphasis added.]

In terms of articulating more precisely the problem that students have, in her interview, LC indicated that she thought students miss many of the critical foundational steps to understanding graphical data. After describing how she believes that she works through trying to make sense of the axes on a graph, which was what she thought was her first step, LC said:

> … what I was finding with students is that they were skipping everything that we've just described. Right? They don't tell you what's on the axes. And then they move directly to what I would say, now, after having done all that work, the meat of the matter which is: is there a difference? Which is a statistical question. But they've moved entirely beyond that without doing this other more basic work.

In the course of the interview, LC realized that the bottleneck was perhaps more basic than the "interpretation" of graphical data:

> … now this has helped me clarify that the problem, I don't even want them [the students] to go yet to the problem of whether or not there's something important**… I just want them to describe what is there**…. And if I got there, I think I would be really quite happy.

Likewise, PR indicated "I feel like it [the graph] has not been described by the students." LC responded to PR saying "That's exactly right, and they speak as though it's self-evident" and continued later to say "And, again, they do this thing where they start, you know, three-quarters of the way into the explanation as opposed to stepping back [i. e., to provide a basic description of the axes]."

Further, DP (interviewer) suggested that "They can see the number but they can't read the axis because they aren't doing the things that you just did" and that "students tend to want to do things too fast." LC responded that when that happens:

> … I'm frustrated because I feel that they've missed that, they've gone right to the meat and they're not able to really understand the meat because they didn't understand the foundation.

The articulation of the bottleneck that was provided to the interviewees in Interviews 2 and 3 evolved slightly. To TE, the interviewer LC described the bottleneck this way: "they [students] have difficulty reading graphs, not even necessarily talking about interpreting, but even describing what's there and maybe understanding where the data come from." To SR, she said that the bottleneck involved: "… reading, kind of interpreting and reading graphical data and communicating clearly about those graphical data."

At the end of Interview 3 with SR, LC (as interviewer) says:

> And I do think there is some agreement that that's what we want students definitely to be able to do because the interpretation is about the discipline and it's not necessarily what they need carrying forward, right? That they can do the former. Then it doesn't matter what context they're in, they will have that skill. That is the bottleneck, right? So, the bottleneck is the description and not so much the interpretation, at least in my mind, I've changed from thinking it was interpretation to thinking, "no, it's really what I was calling 'description' of the data."

3.2 Decoding the Disciplines Step 2: The Interviews

3.2.1 Steps to Graphical Interpretation

An analysis of the transcripts led to the following summaries of steps that each faculty described that they take as they read graphical data. It is important to note that although there are some discrete steps in graph reading, the faculty all described a process that is iterative and not linear. It is worth highlighting that the interviews lasted about an hour to describe a process that happens in seconds.

That is, graph reading is so automatic for faculty experts, and we were not aware of all of the steps that we make effortlessly. The fact that it might help our students if we were more explicit about these steps became increasingly clear as *decoding* took place. For example, during the interviews, we noticed some of the assumptions of student understanding that we take for granted may not be warranted, at least not for all students.

LC (Psychological Science)

1. "...start with... what are the axes?"
   a. *Look at the y-axis, in particular the labels, and consider what is being measured (i. e., the dependent variable)*. In the interview it became clear that an understanding of the dependent variable relies on some prior knowledge, which may include the experimental method used to collect the data and an understanding of what the numbers represent. DP accurately reflected back "So there's a story behind the y axis."
   Further, LC indicated that interpretation of the data would include consideration as to whether or not the data were "within the realm of possibility" or met some expectation. Were they reasonable (e. g., were there measurement errors)? Also, implicit in this analysis is a consideration of variability and inherent noise in the data.
   b. *Look at the x-axis and consider what is being manipulated (i. e., the independent variable)*. In this step, the type of graph (e. g., line, bar, scatterplot, etc.) is important to understand how many independent variables and conditions of the independent variable(s) there were in the study. Again, there was a need to refer back to the experimental method to understand the manipulations.
2. *Look for the pattern in the data*. In this step, LC discussed looking for *differences* between data points, such as the *difference* in height between two bars on a bar graph (perhaps the simplest comparison to make). This step is important because students often seem to get caught up describing extraneous details about the data (e. g., specific data points) and miss the relationship among the data points.
3. *Consider statistical differences, meaningful differences and confounding variables*. Once the pattern of the data is understood then whether that pattern is statistically significant is an important step in reading a graph. Although this is critical scientific data analysis, it is a step beyond the bottleneck of interest and the focus of the current study, which is a clear description of data.

TE (Chemistry)

1. *Look at the title and the "figure caption"*[3]. TE described first looking for *words* in the graph. For example, he indicated that he looks for words like "reaction rate" and perhaps some other information like units or how measurement happened. TE described *preparing the foundation* or *doing the groundwork* before even looking at data. He talked about establishing the *big picture* and recalling deductions he had made before. As in the interview with LC, TE used the phrase "back and forth" or doing "more than one read", indicating that graph reading is not a linear process.

3 TE actually used the word "legend." During the interview, we understood him to mean "figure caption." We confirmed, after the interview, that we had correctly understood him.

2. *Look at the y-axis*. TE said at this point he would be looking for whether the numbers were increasing or decreasing because "I have already absorbed the *words* associated with the axes." He indicated that he would look at whether the axis is linear/logarithmic or exponential.
3. *Look at the trend(s)/pattern(s) in the data*. When TE got to the data themselves he immediately described looking for the **trend(s)**. He talked about trying to *describe* the **pattern** in his mind or in writing.
4. *Interpret the data*. The final step described was the interpretation of data. In the interview this occurred very quickly at the end and seemed of secondary importance. The vast majority of time in the interview was focused on getting to a clear *description* of data, which TE considered the most important skill for students to develop.

SR (Environmental Science)

1. *Look at the y-axis*. SR indicated that she "look[s] at the y-axis first because that's typically the dependent axis and that's usually what it is that we're measuring and that feels more fundamental to me." SR pointed out that you can use the axes to find variables, and she teaches her students to do that.
2. *Look at the x-axis*. SR indicated that "So the next question is, "OK so what's, you know, causing that to vary? What's the other variable that we are comparing that to?" And again, that would typically be on the *x-axis*."
3. *Look at the data/pattern/trend*. In her words,

   > So, once I know what I'm comparing, the next step is actually to look at the data itself. In other words, I think I would then go from the axes to the actual graph, and that the first thing I'm looking for is a pattern … there's probably a hidden step in there, which is, a pattern looks different for different graph types. So, there's a part of my brain, I think I'm not catching that is distinguishing which is which. But I think the next step would be to sort of look at the pattern or the trend. Is this, you know, is it increasing? Is it decreasing? …. does it fit my mental image of what's (right), so you know, a simple one would be "is it increasing over time?" Is it – you know, you could say that's [a] positive slope or, that's something I could draw with my hands. If there is a trend line, look at that and not at individual points.

   SR also noted, when thinking about details in the graph later: "The story is not about whether the concentration is 200 or 400. The story is the trend, right, the story is that this is increasing over time." Further she indicated that "I think some of the times I actually formulate a sentence like that. You know, the y depends on x."
4. *Iterate on the axes*. SR described coming back to look at the details of the axes for the scale, for example. She indicated that she would look at the title and figure captions last. She also indicated that perhaps she would look at outliers to see if it is an error, random or something meaningful.
5. *Consider statistical significance*. SR indicated that the last thing she would look at would be error bars and statistics.

3.2.2 Synthesis of Interviews

There was remarkable similarity in the series of steps of graph reading that these three faculty members, from different disciplines, described. All three described looking at the y- then x-axis and that orienting themselves to the graph was a critical first step. They then looked at the *pattern* of the data as opposed to getting caught up in individual data points. Coming to an understanding of the pattern of the data made up the bulk of the mental work that the faculty described. Moreover, the pattern of the data was considered by all three to be much more fundamental and important in teaching than considerations about statistical significance and interpretation or putting the data into the broader context of the scientific literature. That is not to say that interpretation is not essential, but interpretation is impossible if there is not an understanding of the data. Moreover, there was an appreciation for the fact that the ability to interpret data depends upon some prior knowledge. We (faculty) approach graphs with some expectations of what they might be like and what is in the realm of possibility. SR suggested that perhaps we are comparing the graph to a template, like a "filter" (e.g., "it's positive, it's negative, there's no relationship") and also indicated that we probably have expectations for any type of plot, regardless of the topic of the graph. Again, there is likely important work to be done to fully appreciate faculty's ability to interpret data and there is, undoubtedly, deep knowledge about data and disciplinary-specific knowledge that come into play in those mental processes. Future research in decoding in that domain could be illuminating.

The steps faculty described in graph reading are represented in Figure 1. The figure highlights the fact that the process is not linear but rather involves iterating on the steps to deepen an understanding of the data. The red lines in the figure represent the initial flow of processing described, and the blue indicate that the faculty described returned to previous steps as they worked towards an understanding of the data.

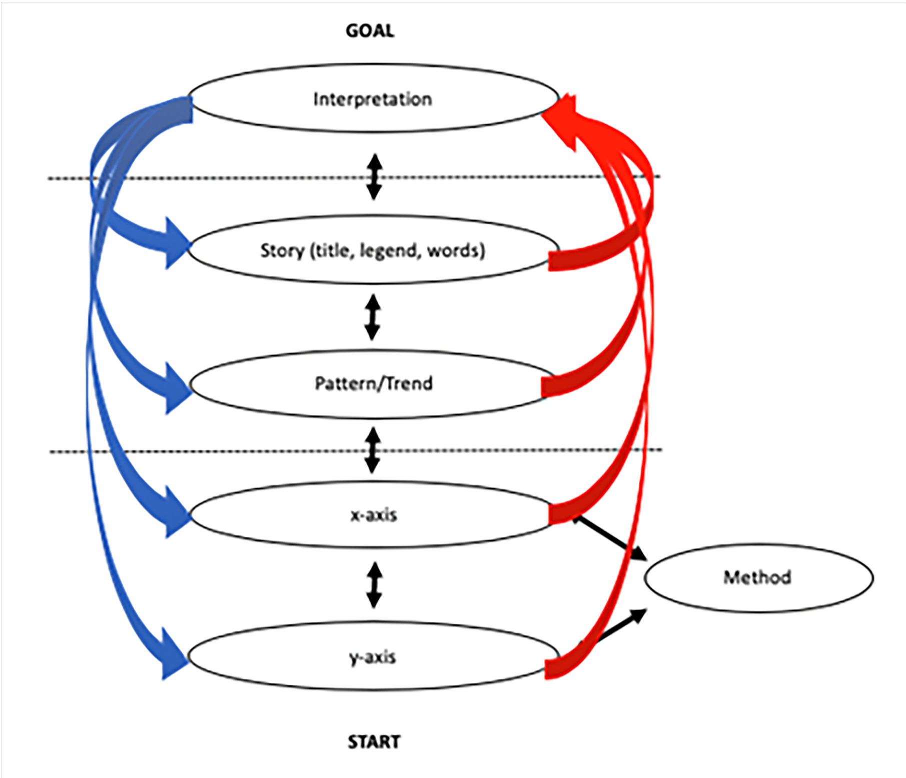

Figure 1: Graphical Representation of the Steps Taken by Faculty in Reading Graphs Note. The arrows are meant to demonstrate the iterative, non-linear nature of the graph-reading process

4 Discussion

The *decoding* interviews revealed remarkable similarities in the steps that three faculty members from diverse disciplines take in reading graphs. The interviews also uncovered a number of aspects of graph-reading that may contribute to the challenges that students face in communicating clearly about them. This work has made clear to us that the problem we face in teaching students to communicate more clearly about graphical data stems from the challenge they face in providing a basic description of the data even before more complex interpretation. This point was made clear from the evolution of our bottleneck.

The faculty interviews revealed that orienting to the graph (i.e., looking at axes and identifying variables) is an important first step to reading a graph. This is consistent with the literature on experts and problem solving, which shows that experts get off to a slow start in problem solving because they take the time to orient themselves and figure out how best to set up the problem (e. g., Lesgold, 1988). Interviewee TE (#2) described this as *preparing the foundation* or *doing the groundwork*. Much of the *decoding* interview with interviewee LC (#1) also revolved around gathering the information necessary to understand the y-axis. Given the consensus among the faculty interviewees, it is worth explicitly *teaching* this step to students.

This mental work is important both for reading a graph and communicating clearly about the data depicted in a graph. We have observed students describe graphical data without providing information that orients their audience to the data (Cameron & Duffy, 2015). Anecdotally, we have observed that scientists and teachers sometimes do the same thing. This is, in fact, at the core of the bottleneck that we wanted to address in our work. Sometimes the lack of important information provided may be the result of the "curse of knowledge" – the speaker has simply forgotten that not everyone is familiar with the data they are presenting – but it is a habit that often reduces the clarity of the presentation of data. Developing this skill in students would certainly help them communicate more clearly and, in fact, may assist with their comprehension of data. This point is related to the issue that students sometimes seem to think that results, such as those presented in graphical form, are "self-evident." While a picture may be worth a thousand words, it is sometimes necessary to use plenty of words to fully describe graphical data.

At the core of the bottleneck of interest in the current study, clarity in describing the graphical data is essential. Clarity requires an understanding of where the data came from, or, in other words, the methods that were used to generate the data. Moreover, clarity requires a description of *differences* or *patterns* in the data. It is important not to "get caught in the weeds." As SR indicated "They [students] always grab – and I've seen it too – where they grab the outliers first." The faculty members were in agreement that if students could successfully *describe* the pattern in the data, that would be a significant achievement and a move past the bottleneck.

The final stages of graph reading include an *interpretation* of the data, including how they fit within a broader context, and an assessment of the *significance* of the data (statistically and in terms of meaningfulness). This requires an understanding of statistical concepts, such as variance and the consideration of confounding variables. These final two steps require a level of analysis that is quite sophisticated and students might struggle with these steps. As noted above, they are issues that go beyond the bottleneck of interest here. That is not to say that the interpretation of data and a deep understanding of statistics is not important. Rather, that discussions of those important concepts may be lost on students if they have not mastered the more basic understanding and ability to describe graphical data.

The interpretation of graphical data is probably more difficult if the reader has no expectation of what the data *should* look like, or, at least, what is in the realm of possibility. For example, it is helpful to know what range of values one might expect to see represented in a graph of manual reaction times. Depending on the context (for example, for data that the student has collected), it might be important to scrutinize the data to see if something is amiss in the data (e. g., an error was made in measurement) or whether there is a pattern of results that might require some explanation (e. g., there is an unexpected finding). For this reason, perhaps we should not expect undergraduate students, with limited disciplinary knowledge, to recognize unexpected results. So, there is orienting to the graph and mathematical possibilities and then also content-specific knowledge that sets one up for a different sort of processing. Indeed, as Harsh et al. (2019) indicated, "a large body of research demonstrates that the ability to make sense of and use graph data and learn interpretive skills is strongly influenced by one's prior knowledge and experience with the content/context of the graph" (p. 2). As SR indicated, faculty do "a little bit different kind of prioritizing that comes from content knowledge." Moreover, SR indicated that "when I see a really regular pattern in environmental data, I'm thinking *something has to be going on there* because a lot of our data isn't regular." For example, she described an occasion in which she figured out that there was a regular pattern to data that was not an artifact and said "… when I first saw what it meant, I just thought: *This is interesting. This seems important.* And then

I'm going to come back later and try to figure out what's happening and why." Noting what is interesting or important requires some disciplinary knowledge, which could be the topic of further research. Asking undergraduates to interpret data is inappropriate if they don't have the relevant disciplinary knowledge.

Increased disciplinary knowledge is probably essential for a complete understanding of data. But in terms of graph reading per se, there are hidden mental processes, such as considering the *method* by which the data were collected that seem to occur in proficient graph-readers and that could be taught. Recently we have conducted similar *decoding* interviews with students, also published in this volume (Pelnar & Cameron, 2025). We have found that students are much less consistent in the steps they describe using when reading graphs and they sometimes underestimate the level of cognitive effort required. Note that in that study, we did not examine how well students could describe graphical data, but rather what steps they thought they used in order to read the graphical data. We (e. g., Cameron & Duffy, 2015) and others (e. g., Darcy, 2025, also published in this volume) have shown the difficulties that students have in reading and communicating about graphical data.

Helping students communicate clearly could be aided by articulating and modeling the series of steps faculty use in reading graphs. Students might be well-served by faculty explicitly describing the mental work involved in, for example, going back and forth between data and method and demonstrating that graph-reading does not occur effortlessly. Faculty also benefit from *Decoding* as it can help them overcome the *curse of knowledge*, reminding them of their own invisible disciplinary thinking. The goal of *Decoding* is to teach students to move quickly through this step to be able to do more advanced disciplinary thinking. In other words, the ability to "read" a graph is a bottleneck that, when overcome, will help improve students' understanding of their discipline.

In this study we have uncovered the way that three faculty experts read graphical data. Although there were remarkable similarities and the series of steps were broadly consistent with those that have been described for pre-college instructors (Zucker et al., 2015), there are likely multiple routes to understanding graphical data. Moreover, some graphs are more complicated than others and may require additional processing.

We encourage faculty, whose disciplines rely on an understanding of graphical data, to consider whether the steps described here might be useful to them in explicitly teaching students how to understand and talk about graphical data. Perhaps even better, we encourage others to undergo a decoding interview to uncover the mental moves they make in reading graphs.

In this paper we have focused on the first two steps of the decoding process (identifying a bottleneck and conducting decoding interviews to make explicit the implicit steps faculty use in completing a task). The next several steps in *Decoding* with respect to reading graphs involve modeling the steps faculty take when they read graphs and teaching them to students. We are currently exploring the effectiveness of modeling the steps of graph-reading that we have described to students and providing them with opportunities to practice using those steps themselves.

Literature

American Psychological Association. (2023). *APA guidelines for the undergraduate psychology major: Version 3.0.* https://www.apa.org/about/policy/undergraduate-psychology-major.pdf

Bihun, J., & Handelsman, M. M. (2018). An exercise to assess student understanding of bottleneck concepts in research methods. *Teaching of Psychology*. http://teachpsych.org/page-1603066#social https://doi.org/10.1086/261651

Camerer, C., Loewenstein, G., & Weber, M. (1989). The curse of knowledge in economic settings: An experimental analysis. *Journal of Political Economy, 97*(5), 1232–1254. https://www.jstor.org/stable/1831894

Cameron, E. L. (2019, June 13–14). *Using methods from cognitive psychology to elucidate mental processes.* Proceedings of the European Conference of Scholarship of Teaching and Learning, Bilbao, Spain. https://www.ehu.eus/documents/8301386/10560621/Actas-EuroSoTL-Conference-2019.pdf/1a7d5867-e222-4aab-6f92-a7948f1fbd67

Cameron, E. L., Zerban, C., Engle, P., Mackey, A., Reyes, G., Sehgal, K., & von Borstel, M (2016, February 26–27). *Student-faculty partnership in the scholarship of teaching and learning (SoTL)*. [Oral presentation]. Annual Meeting of the Midwest Institute for Students and Teachers of Psychology, College of Du Page, Glen Ellyn, IL.

Cameron, E. L., & Duffy, K. L. (2015, June 8–9). *Issues in teaching students to talk clearly about data.* [Poster Presentation] Inaugural European Conference on the Scholarship of Teaching and Learning (Euro-SoTL), Cork, Ireland.

Coil, D., Wenderoth, M. P., Cunningham, M., & Dirks, C. (2010). Teaching the process of science: Faculty perceptions and an effective methodology. *CBE-Life Sciences Education, 9*(4), 524–535. https://doi.org/10.1187/cbe.10-01-0005

Darcy, T. (2025) Application of the Decoding the Disciplines Paradigm to Enhance Graphical Interpretation by Introductory Biology University Students. *die hochschullehre,* Jahrgang 11/2025.

Friel, S. N., Curcio, F. R., & Bright, G. W. (2001). Making sense of graphs: Critical factors influencing comprehension and instructional implications. *Journal for Research in Mathematics Education, 32*(2), 124–158. https://www.jstor.org/stable/749671 https://doi.org/10.2307/749671

Gurung, R. A. R., & Schwartz, B. M. (2010). Riding the third wave of SoTL. *International Journal for the Scholarship of Teaching and Learning, 4*(2), Article 5. https://doi.org/10.20429/ijsotl.2010.040205

Glazer, N. (2011). Challenges with graph interpretation: A review of the literature. *Studies in Science Education, 47*(2), 183–210. https://doi.org/10.1080/03057267.2011.605307

Harsh, J. A., Campillo, M., Murray, C., Myers, C., Nguyen, J., & Maltese, A. V. (2019). “Seeing” data like an expert: An eye-tracking study using graphical data representations. *CBE-Life Sciences Education, 18*(3), ar32. https://doi.org/10.1187/cbe.18-06-0102

Harsh, J. A., & Schmitt-Harsh, M. (2016). Instructional strategies to develop graphing skills in the college science classroom. *The American Biology Teacher, 78*(1), 49–56. https://doi.org/10.1525/abt.2016.78.1.49

Kruger, J., & Dunning, D. (1999). Unskilled and unaware of it: How difficulties in recognizing one's own incompetence lead to inflated self-assessments. *Journal of Personality and Social Psychology, 77*(6), 1121–1134. https://doi.org/10.1037/0022-3514.77.6.1121

Lesgold, A. (1988). Problem solving. In R. J. Sternberg & E. E. Smith (Eds.), *The Psychology of Human Thought* (pp. 188–213). Cambridge University Press.

Okan, Y., Galesic, M., & Garcia-Retamero, R. (2016). How people with low and high graph literacy process health graphs: Evidence from eye-tracking. *Journal of Behavioral Decision Making, 29*(2–3), 271–294. http://eprints.whiterose.ac.uk/89159/ https://doi.org/10.1002/bdm.1891

Pace, D. (2017). *The Decoding the Disciplines paradigm: Seven steps to increased student learning.* Indiana University Press. https://doi.org/10.2307/j.ctt2005z1w

Pelnar, H. (2019, April). *Scan patterns and graph interpretation in psychology students and faculty.* [Poster presentation] *Annual Meeting of the Midwestern Psychological Association*, Chicago, IL.

Pelnar, H., & Cameron, E. L. (2025). Decoding the mental processes in undergraduate student graph reading. *die hochschullehre,* Jahrgang 11/2025.

Picone, C., Rhode, J., Hyatt, L., & Parshall, T. (2007). Assessing gains in undergraduate students’ abilities to analyze graphical data. *Teaching Issues and Experiments in Ecology, 5*, 1–54.

Pinnow, E. (2016). Decoding the Disciplines: An approach to scientific thinking. *Psychology Learning and Teaching, 15*(1), 94–101. https://doi.org/10.1177/1475725716637484

Robbins, A., Pelnar, H., & Cameron, E. L. (2019, August 18–22). *Similarities and differences in eye movements between professors and students during graph reading.* [Poster presentation] European Conference on Eye Movements, Alicante, Spain.

Trickett, S. B., & Trafton, J. G. (2007). A primer on verbal protocol analysis, In D. Schmorrow, J. Cohn, & D. Nicholson (Eds.), *Handbook of Virtual Environment Training* (pp. 332–346). Praeger Security International. https://doi.org/10.5040/9798216002468.0037

Zucker, A., Staudt, C., & Tinker, R. (2015). Teaching graph literacy across the curriculum. *Science Scope, 38*(6), 21–24. https://doi.org/10.2505/4/ss15_038_06_19

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