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## Using Decoding the Disciplines and Students as Partners to Explore Student Graph Reading

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### Abstract

In this study, we employed two disparate approaches – Students as Partners (SaP) and Decoding the Disciplines (DtD) – to deepen our understanding of how undergraduate students read graphs. Engaging SaP means including student investigators as equal contributors in a collaborative research project. DtD involves interviewing faculty members to uncover the implicit mental processes that they utilize when doing critical disciplinary thinking. Specifically, our (a faculty and student team) goal was to adapt DtD for use by student interviewers with student interviewees. We describe the steps students report that they take in graph reading, which has been identified as a “bottleneck.” Many students indicated that they think of graphs as self-explanatory images and that reading them is not a process. We contrast these steps with those that have been described by faculty. This project demonstrated that both SaP and DtD are powerful approaches for exploring mental processes in non-experts.

**Keywords:** Graph literacy; quantitative literacy; visual data; graphical interpretation, Decoding the Disciplines

## Wie entschlüsseln Studierende Diagramme? Das Potenzial von Decoding the Disciplines und Student as Partners für die Erforschung von Datenkompetenz

### Zusammenfassung

In dieser Studie wurden die Ansätze Decoding the Disciplines (DtD) und Students as Partners (SaP) kombiniert, um die Herangehensweise von Studierenden beim Entschlüsseln von Diagrammen zu untersuchen. SaP integriert Studierende als gleichberechtigte Partner in die Forschung, während DtD die impliziten mentalen Prozesse von Expert:innen offenlegt. Ziel war es, DtD für studentische Interviewer:innen mit studentischen Befragten anzupassen. Die Studie identifizierte Schritte, die Studierende beim Lesen von Diagrammen durchführen, und stellte fest, dass viele Diagramme als selbsterklärend wahrgenommen werden. Diese Ergebnisse wurden den von Lehrkräften beschriebenen Prozessen gegenübergestellt. Das Projekt zeigte, dass SaP und DtD wirksame Methoden sind, um mentale Prozesse beim Lernen besser zu verstehen.

**Schlüsselwörter:** Datenkompetenz; visuelle Daten; Diagramminterpretation, Decoding the Disciplines

## 1 Introduction

Quantitative literacy is a crucial skill for success in many undergraduate programs and is important for the general population. In a world where individuals have nearly unlimited access to data, it becomes even more crucial to understand how to read and interpret graphs, lest one be misinformed by poorly designed graphical displays (Cooper et al., 2003; Woller-Carter et al., 2012). In the field of psychology, the American Psychological Association's (APA) published learning objectives include that psychology undergraduate students should be able to 'interpret complex statistical findings and graphs in the context of their level of statistical significance, including the influence of effect size, and explain these findings using common language' (APA, 2013, p. 21). In the current study, we are particularly interested in graphical literacy, which is the 'ability to understand graphically presented information and includes general knowledge about making inferences from different graphic formats' (Okan et al., 2016, p. 271). There is both anecdotal and empirical evidence that students experience difficulty in interpreting quantitative data (Cameron, 2019; Cameron & Duffy, 2025; Guthrie et al., 1993; Kilic et al., 2012; Robbins et al., 2019). In a systematic analysis recently conducted within our institution's psychology department, 91 cases of student-written responses to an in-class task were examined (Bousson, 2024). In this task, students were instructed to describe a graph with which they were presented. These graphical descriptions were then categorized by errors made, which included omitting relevant variables/introducing unrelated variables, misrepresenting variables, making unwarranted causal/inferential claims, and misinterpreting results. By contrast, faculty in psychological science and many other disciplines are highly proficient in reading graphical data. As in other domains, these faculty experts are likely to approach problems differently than novices in their discipline (Chi et al., 1982).

The primary objective of this project was to explore how students approach reading graphs using disparate approaches, with the ultimate goal of helping them communicate more clearly about the data presented in graphs. We will start by describing several approaches we have used in the past as well as ones that we have adapted in the current study.

### 1.1 Eye-Tracking

One way in which processing graphical data has been examined is through eye-tracking. This is typically used in a laboratory setting with sophisticated instrumentation that can precisely monitor the position of the eye in real time. Position of the eye is thought to be a proxy for underlying perceptual and cognitive processing, and the assumption is that cognitive processes are associated with eye movements because what is seen is rapidly processed at both perceptual and cognitive levels (Emhardt et al., 2020). In our context, this approach is important because several studies have successfully determined what people focus on while reading graphs and found that their eye movements tend to correspond with their descriptions of the data (Carpenter & Shah, 1998; Okan et al., 2016; Ratwani et al., 2008; Sullivan et al., 2011; Woller-Carter et al., 2012).

In a pilot study in our lab, we tracked faculty and students' eye movements with an EyeLink Portable Duo eye-tracking system as they described and interpreted graphical data (Cameron, 2019; Robbins et al., 2019). Our goal was to observe the differences between how faculty members and students viewed graphical data. We found that faculty and students differed in the ways and order in which they scanned graphs. For example, compared to students, faculty, who had higher graph literacy, had longer dwell times and more fixations on graphical features that are crucial to understanding, such as axes, labels, and legends. From these findings, we surmise that faculty spend more time than students engaging with these important features. This also led us to suspect that a lack of attention to key features contributes to the difficulties that faculty members report in students' attempts to describe graphical data (Cameron & Duffy, 2025). Unfortunately, our pilot study revealed that scan patterns were quite idiosyncratic across students and faculty, and it did not reveal conclusively the series of mental processes involved in graph reading; thus, we have turned to Decoding the Disciplines.

## 1.2 Decoding the Disciplines

An alternative approach to revealing the mental processes of disciplinary experts is Decoding the Disciplines (DtD), which can help students in their ‘disciplinary thinking’ by breaking academic tasks down into discrete steps (Middendorf & Shopkow, 2018; Pace, 2017)<sup>1</sup>. DtD was designed for and is typically used by experts in any field where specialized knowledge is developed over time.

In this study, we focused on Step Two in the DtD framework where interviewees break down their mental processes in a ‘Decoding interview’. In a typical Decoding interview, the interviewers (who are typically instructors themselves) ask a faculty expert to explain how they approach a specific academic task, known as a ‘bottleneck,’ in a step-by-step manner. A bottleneck is a task that students struggle to complete, as evidenced by instructor feedback, yet is crucial to their success in the discipline. Previous work has established graph reading as a bottleneck across various academic disciplines (Cameron, 2019; Glazer, 2011).

In a series of three Decoding interviews investigating the mental moves that faculty members make while reading graphical data, we found that faculty members from three disparate disciplines reported utilizing a very similar series of steps (Cameron & Duffy, 2025, in this volume). Cameron and Duffy describe the steps faculty members take as they interpret graphs that their students have struggled with during assessment and class discussions. These faculty interviewees stressed the importance of orienting themselves to the graph by examining axes, considering the method by which data were collected, and only after they understood the context of the graph, did they focus on the trends in the data and determining whether there was statistical significance.

Given the differential responses of students and faculty in the pilot eye-movement study and the data obtained by conducting faculty Decoding interviews, we were interested in examining the underlying mental processes that students report using. To our knowledge, only three other studies have used Decoding interviews with students. The disciplinary tasks examined in these studies include examining how students write literature reviews in political science (Rouse et al., 2017), select credible sources (McBrady, 2022), and comprehend source code in the computer science discipline (Khomkhoana & Nel, 2020).

## 1.3 Students as Partners

In the pedagogical approach known as Students as Partners (SaP) within the scholarship of teaching and learning context, students and faculty work together to investigate ways to improve teaching and learning. Everyone involved is a stakeholder in the research. Partnership is a ‘reciprocal process through which all participants have the opportunity to contribute equally, although not necessarily in the same ways, to curricular or pedagogical conceptualization, decision-making, implementation, investigation, or analysis’ (Cook-Sather et al., 2014, pp. 6–7). In the current study, we have applied the collaborative nature of this approach to our methodology by conducting this work as a faculty-student team with mutual investment in the topic rather than the traditional approach of a faculty member who determines the focus of the research and supervises a student researcher/assistant. We believe that it is important to include students in research that is relevant to their own learning because they bring a valuable perspective that faculty, who are often relatively removed from the experience of being a novice in their discipline, may overlook (Pelnar et al., 2020; McBrady et al., 2021). Students involved in SaP collaborations might feel more comfortable sharing insights from their own experiences than they would in a more traditional faculty-student relationship in a research context. These collaborations can be highly successful given that student partners tend to be highly motivated when working with topics that affect them directly (Pelnar et al., 2020). Furthermore, the use of student interviewers when conducting interviews with student participants, as we have done in this study, is important in minimizing the risk of an unbalanced power dynamic between students and faculty that could impact the way students respond (Pelnar et al., 2020; Rouse et al., 2017).

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1 For more information about Decoding the Disciplines, see <http://decodingthedisciplines.org/>

## 1.4 Objectives and Hypotheses

The goal of the current study was to explore a modification to the traditional approach of DtD with student partners interviewing non-expert graph readers. We expected to find that although students might experience the interview to be challenging, they would be able to describe their mental processes to the interviewers, allowing us to explore their range of mental moves. Given our previous findings (Cameron, 2019; Robbins et al., 2019), we did not expect to find consistent steps or strategies across student participants. Our goal was not to make generalizations about how all students read graphs, rather, we wanted to highlight the inconsistencies we suspected from students in comparison to the consistencies we found in faculty, which are described separately within this volume (Cameron & Duffy, 2025). Ultimately, we wanted to explore the possibility that the integration of two disparate approaches (DtD and SaP) would create a deeper insight into the teaching and learning of graphical literacy that would benefit students and educators alike.

## 2 Method

### 2.1 Participants

Eleven undergraduate students (two males) from a small Midwestern liberal arts college were interviewed for this study. All participants were compensated with their choice of either course credit or a 5 USD gift card. All participants were psychology majors, psychology minors, or enrolled in a psychology course. Two participants were seniors (fourth year), six were juniors (third year), and three were sophomores (second year).

### 2.2 Materials

The first three interviews were conducted in a laboratory setting, but given the COVID-19 pandemic, the remaining interviews were conducted via Google Meet. All interviews were audio-recorded and transcribed by the two student interviewers. These transcriptions are available on the Open Science Framework<sup>2</sup>. There were no systematic differences between in-person and virtual interviews in terms of length of interview, clarity, or amount of information provided.

### 2.3 Procedure

This study was approved by the Carthage College Institutional Review Board (IRB# 1145837). Semi-structured interviews were conducted by two student researchers (including the first author of this paper) in order to reduce power dynamics and maximize the likelihood that students would share their thoughts and challenges honestly. Both student researchers were juniors majoring in psychology. The student researchers had transcribed the faculty interviews (Cameron & Duffy, 2025) and discussed them in-depth with the faculty advisor (the second author), so they were familiar with the steps of DtD, particularly the Interview (Step Two). They also completed a pilot interview and received feedback from the faculty advisor.

Before the interviews began, all participants sketched a graph that they either generated from scratch or that they recalled. Those who were interviewed virtually either described their graphs for the interviewers to draw or held the graph up to the camera so that the interviewers could take a screenshot of the graph. All participants' graphs can be found on Open Science Framework<sup>2</sup>. We asked participants to provide their own graph because in our eye-tracking pilot study (Cameron, 2019; Robbins et al., 2019), the graphs presented to participants were created to mimic those found in an introductory psychology textbook. We found that some participants, including faculty, were unfamiliar with certain graph types and/or variables and as a result, became anxious or frustrated with the task. Thus, we reasoned that having generated their own graph, participants would be more comfortable and confident describing it and their mental processes. Also, because we were more interested in

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2 To see interview transcripts and student graphs, please see [https://osf.io/wmj25/?view\\_only=56a49e0eba9c4ba79dd749beaf98eadd](https://osf.io/wmj25/?view_only=56a49e0eba9c4ba79dd749beaf98eadd)

analyzing each participant's reported thought processes rather than their familiarity with graphs on psychological topics, we thought participants would be able to focus more on describing their thought processes if they were not distracted by topics of our choosing.

As is the practice in DtD, the interviews were semi-structured (Decoding the Disciplines, n. d.). The interviewers started by asking general questions to have participants describe as much of their mental processes as possible without directing the responses. Common questions that the interviewers asked included, 'When first presented with a graph, what is the first thing you do?' 'What do you look at next?' and 'What information are you hoping to get from that?' In many cases, the participants' descriptions did not address all the features within a graph (e. g., titles) or left out specific details. In these cases, interviewers followed up with specific questions about those features. The interviews ended once participants had explained their strategies as clearly and in as much detail as they could.

## 2.4 Data Analysis

The two students who conducted the interviews also transcribed them, and they and the faculty co-investigator ensured that the transcriptions were accurate. A set of codes were established based on the findings of the eye-tracking pilot study (Cameron, 2019; Robbins et al., 2019) and the faculty Decoding interviews (Cameron & Duffy, 2025). The codes included evidence of orientation to the graph, focus on trends or specific data points, use of title, and consistent strategy. See Table 1 for a description of the codes and examples of each. After coding each transcription, the student and faculty researchers agreed by consensus on each application.

**Table 1:** Codes Used for Data Analysis

Code	Description	Example
Evidence of orientation	Did participants indicate that they start by orienting themselves to the variables instead of trying to analyze the data immediately?	Yes: 'I start by looking at the y-axis so that I know what is being measured.' OR No: 'I start by looking at the direction that the data points are going in.'
Focus on trends or specific data points	Do participants indicate focusing on the overall trend in the graph rather than trying to analyze individual data points?	Yes: 'I look at the direction that the line is going and how much it increases.' OR No: 'I look at each point and see where it is on the y-axis.'
Use of title	Do participants utilize the title and for what purpose?	Yes: 'I look at the title first to get a sense of what the graph is about.' OR No: 'The title does not tell me anything that I cannot figure out on my own, so I do not really pay attention to it.'
Consistent strategy	Do the participants show evidence that they have a clear and consistent strategy?	Yes: 'Well whenever I look at a graph, I start by trying to figure out what the research question is.' OR No: 'I guess I start by looking at the title and then my eyes just move across the graph.'
<i>Note.</i> The examples listed are not actual quotes from participants, rather they are hypothetical quotes created by the researchers to demonstrate the themes we were looking for when coding.		

## 3 Results

All participants completed the Decoding interviews with student interviewers, which ranged from five to 20 minutes in length and resulted in 136 minutes of audio recordings. As is sometimes observed in faculty Decoding interviews, some students had difficulty describing their mental processes.

ses. Many participants indicated that they had never before been asked to perform a metacognitive task such as describing their own mental processes in the context of graph reading. Moreover, there was much variability in the types, completeness, and complexity of graphs drawn by interviewees. Examples of such graphs include bell curves without axis labels, bar graphs displaying a frequency distribution of favorite colors, and a multivariate line graph with abstract labels. Some participants listed their series of steps with too little detail and/or with multiple steps combined, while others needed quite a bit of prodding. It was difficult for many participants to articulate their own mental processes while imagining reading a graph, and even with student/peer interviewers, many participants admitted to being nervous.

Six participants finished explaining their self-generated list of steps without mentioning features (e.g., titles and figure captions) that the researchers had previously identified as key features of a graph. When this happened, the interviewers waited until the participants indicated that they were done explaining their mental processes and then asked the participants about these features. Many participants indicated, once they had been reminded, that these features were important to their understanding of quantitative data. They would then indicate where they thought they would find that feature in the order of steps they had identified. Table 2 highlights the variability in the number and order of steps that each participant reported using while reading graphical data. For comparison, we included the steps reported by faculty in the last row (Cameron & Duffy, 2025). It is important to note that Cameron and Duffy found consistency in the steps and order reported by three faculty members. The same was not true for students, who differed greatly in their reported processes. Furthermore, none of the students reported a series of steps that matched those of the faculty.

Despite the difficulties that some students had when trying to articulate their mental processes, sometimes a student's vagueness revealed as much as another's detailed account. For example, when asked why they start by examining the 'data display,' P4 stated,

I think it's just the outcome of why I'm looking at this graph. I think I'm just trying to understand- I'm trying to understand it better, so I'm not looking at it with no clue. I'm just trying to look at it so then I know what I'm looking at.

Such vagueness and circularity indicate difficulty both in talking about graphical data and in breaking down their own mental processes. The students struggled metacognitively to understand how they approach data as they realized it is not as self-evident as they may have previously believed.

**Table 2:** Participants' Self-Reported Order of Steps During Graph Reading

Participant (class/major)	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
1 (senior/ psychology & neuroscience)	Figure caption	x-axis label	Visual data	y-axis label	y-axis scale	Other features	Title
2 (senior/ psychology & neuroscience)	Title	Axes labels	Visual data	Axes scales			
3 (junior/ psychology)	Figure caption	y-axis	x-axis label	x-axis scale	Visual data		
4 (junior/ psychology & neuroscience)	Visual data	x-axis label	y-axis label	Title	Axes scales		
5 (junior/ psychology)	Axes	Individual data points	Trends	Figure caption	Back to visual data		
6 (sophomore/ psychology)	Visual data	Axes	Legends	Outliers	Other relationships	Title	Figure captions

(Continuing table 2)

Participant (class/major)	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
7 (junior/ psychology)	Background info	y axis label	y axis scale	x-axis label	x-axis scale	Conditions of independent variables	Figure caption
8 (sophomore/ psychology & environmental science)	Title	x-axis	Clusters; visual data	y-axis label	Visual data	Statistics	
9 (sophomore/ English)	Title	Variables	Background information	Figure caption	Visual data		
10 (junior/ psychology & sociology)	Data starting point	Title	Axes labels	Trends	Figure caption		
11 (junior/ criminal justice)	Title	Figure caption	Visual data	Variables	Outliers		
Faculty example (Cameron, 2024)	Y-axis	X-axis	Visual data	Title	Figure caption	Statistics	

*Note.* We have included class standing and major for each participant, but our sample size is not large enough to draw any conclusions about how these factors may have affected each participant's reported graph-reading process.

### 3.1 Variability in Graph-Reading Steps

While there was plenty of variability in the students' ability to break down their mental processes, the Decoding interviews were largely successful in that they provided insight as to how students attempt to read graphical data. The number of steps participants identified in interpreting graphical data ranged between four and seven, with an average of five steps (see Table 2 for the list of these steps). Some students, such as P7, described their graph-reading process in great detail. For example, they specified that looking at the x-axis label, y-axis label, x-axis scale, and y-axis scale are their own discrete steps in their mental process. This was rather uncommon, as most participants tended to speak about the labels and scales as a single or two steps as opposed to four. On the contrary, P2 listed only four steps in their graph-reading process. They grouped looking at the axes labels as one step and the axes scales as another, purportedly looking only at those, the title, and the data trends.

### 3.2 Consistent Strategy Among Students

Although participants did identify a list of steps that they use, only five of the participants interviewed appeared to have a consistent strategy for reading graphical data. The interviewers inferred a participant's consistency through clearly articulated descriptions of steps and the use of words such as 'always' that indicate regularity. These participants could seamlessly describe their mental steps to the interviewers as well as explain why they did each step. P7 explained, 'I think as far as steps, I keep the same steps for the most part.' Likewise, P8 very confidently described their strategy indicating that,

I would always start by looking at the x-axis, like what A1 and A2 are because then I know if I'm looking at like time points or if I'm like, looking at heights or any kind of variable. I always look at that first to see what I'm measuring of the other variable across. And then I look at each individual line that's on the graph to see what that variable is.

In contrast, the remaining six participants did not seem to have a consistent set of steps or strategies for reading graphical data. Several of the participants came to realize that they had not previously thought of graph reading as a process. They described looking at surface-level elements (i. e., titles

and overall trends), but could not describe how they gather information that is not self-evident. These participants did not know how to go beneath the surface of a visual display to truly understand the meaning of the data. P6 became slightly frustrated when they were prompted to break down their mental processes and struggled to do so. They stressed,

Because I don't know if I have a specific order. I think, most of the times, I start by looking at the graph and trying to see if there's a relation and then I'm like, "Oh well I need more information," so then I look around- look around the graph and it's kind of just where my eyes go.

P4 was also unable to clearly describe their thought process. During the interview, they became overwhelmed and started to contradict themselves, stating,

Normally, when I look at a graph- there's a lot of information in front me, so I kind of- I don't know where to look so I first look at the figures, like if there are lines, there's little graphs or something like that. After that, I start analyzing it, or the information that I know about the graph. I look at the x-axis, the y-axis to see what information there is there and what it's trying to say. I try not to look at the title because I feel like it can sometimes be a little bit misleading or it doesn't tell you what I want to know- it does tell me like, what it's about, but it doesn't tell me like the information. After that, I just start looking at the information one-by-one.

### 3.3 Other Reported Mental Processes

Several other aspects of students' approaches became apparent in the Decoding interviews. Seven of the participants indicated orienting themselves to the graph before analyzing the data (see Table 2). They described doing so by looking at elements like the variables, title, and figure captions before looking at the visual display of the data. P2 explained that this makes interpreting the graph much easier because the title and axis labels assist in 'understanding what [the researchers are] looking for in their data.' The remaining four participants indicated that they prioritize looking at the relationships between the variables. For this reason, they examine the visual display of data before trying to figure out what the variables represent.

Another difference among participants' mental strategies was whether they focused on the overall trends in the data or on specific data points. The majority (nine) of participants indicated that they do not focus on individual data points. When examining the visual data contained within a graph, they try to understand the main trend and disregard individual data points unless the graph contains outliers. The remaining two participants indicated that they like to examine each individual data point before drawing conclusions about the trend.

In terms of graph titles, nearly half (five) of participants considered them to be important, citing them as the first or second feature that they view. P2 stressed the importance of looking at the title during their graph-reading process. They exclaimed, 'Obviously, I read the title!' when asked what their first step is. Two other participants indicated that the title was important to their graph-reading process but explained that they looked at it last. P1 explained, 'I probably look at the title last. I try to examine what's going on first and make my own conclusions.' In their graph-reading process, reading the title last helped them verify their conclusions about the graph. Conversely, three participants indicated that they do not look at titles at all considering that many graphs do not contain titles, and in their perspective, titles are often self-evident

### 3.4 Additional Insights

One important insight is that many participants highlighted that they often do not view graph reading as a procedure with distinct steps. One participant (identified as P2) described graph reading as something that people 'just do it. Like you don't actually think about it.' This suggests that such students view graph reading as self-evident. They take in obvious features within the visual display but do not delve into the meaning and significance of the data that the graph is conveying.

## 4 Discussion

The aim of the current study was to explore the use of Decoding interviews with non-expert interviewees as well as student interviewers. We believe there is much to gain from these two methodologies and hope to see their use expand in novel ways, just as we have done in this study. Ultimately, we hope to give students and faculty alike more insight into the graph-reading processes and the ways that these could be more effectively taught and learned.

Overall, the application of Decoding interviews by student partners with non-experts was successful as we were able to complete all 11 interviews and gain insight into students' unique processes, knowledge, and challenges in graph reading. While the level of metacognition required during Decoding interviews was difficult for our participants, a majority of them were able to convey their thought processes to interviewers with the help of prompting questions. Students provided less information about their mental processes than faculty as evidenced by the fact that the student interviews lasted a maximum of 20 minutes, whereas faculty interviews lasted approximately an hour (Cameron & Duffy, 2025). We do not think this reflects negatively on the approach, but rather, that students simply have less to say about their graph-reading processes.

While students have been interviewed using the 'think-aloud' procedure in the past (e. g., Trickett & Trafton, 2007), the use of Decoding interviews with students is a unique approach and, to our knowledge, has been applied in only three studies (Khomokhoana & Nel, 2020; McBrady, 2022; Rouse et al., 2017). Whereas the 'think-aloud' procedure involves participants guiding the interviewer through the logic of their explicit responses as they complete a task, Decoding interviews ask students to introspect and make explicit their implicit mental processes. During Decoding interviews, students in the current study were able to articulate a series of steps in their graph reading, and there was a great deal of variability in the steps reported. We found that many students did not report a consistent strategy in their reading of graphical data. Many revealed that they had not previously conceived of graph reading as a task requiring a set of discrete steps. The findings of this study contrast with those of a study of faculty, who appear to use and can describe a consistent set of mental processes in graph reading (Cameron & Duffy, 2025). These faculty also recognized the importance of delving into the significance of the data beyond that which is self-evident.

In Decoding interviews, faculty members stressed the importance of two steps: (1) Orienting oneself to the graph, and (2) Focusing on trends rather than individual data points (Cameron & Duffy, 2025). They also cited, anecdotally, that these two steps were often missed by many of their students, in accord with Zucker et al (Zucker et al., 2015). Likewise, in a systematic analysis of student responses to an assignment that involved reading a graph and providing a description of it, some of the most common mistakes that students made revolved around orientation to the graph (Bousson, 2024). This included issues of omitting relevant variables, introducing unrelated variables, and misrepresenting variables. Interestingly, we found that most students in the current study (seven) described orienting themselves to the graph and nine out of eleven indicated that they do not focus on individual data points. This is encouraging, but begs the question: Why did faculty highlight these issues? With respect to orienting to the graph, one possibility is that while students recognize that they need to do so for themselves, they are less likely to orient their audience when communicating about graphical data, the situation on which the faculty may have been reflecting. Explicitly orienting the audience to a graph may be a step that requires more direct instruction, especially when we also consider the increased amount of time that faculty spent looking at orienting features (i. e., axes, labels, and legends) in the pilot study (Cameron, 2019; Robbins et al., 2019). With respect to both orienting to the graph and not focusing on individual data points, it is also possible that there is a sampling bias and that these 11 students (the majority of whom were juniors and seniors) had already developed these skills. Thus, the faculty may have been reflecting on the performance of less advanced students. Future research could focus on the development of these skills over the undergraduate years.

Our merging of Decoding and SaP approaches created a unique opportunity for both students and instructors to learn about the graph-reading process (McBrady et al., 2021). Both the student inter-

viewers and some of the interviewees expressed that the Decoding interviews helped them begin to reflect on their own mental processes more clearly and led them to consider adopting a more strategic approach to graph reading. We agree with Glazer (2011) that explicit instruction on graph reading, and perhaps on the importance of describing graphs to an audience, is warranted. Interestingly, two psychology undergraduate students in the current study indicated that they would benefit from, or already had benefited from, being taught how to read a graph more explicitly and in a step-by-step manner. Additionally, after reading the transcripts of the Decoding interviews and discussing them with the student interviewers, faculty involved in this project gained crucial insight into the perspectives of students. For example, student partners were able shed light on the important role of motivation when it comes to students taking the needed time to fully understand a graph. As student partners pointed out, a lack of understanding may sometimes reflect a lack of motivation. Graph reading develops incrementally and cannot be assumed to be a competency acquired in secondary education (Borner et al., 2019).

We also would like to emphasize the importance of SaP work as it is rewarding for all involved (Pelnar et al., 2020). Students are given the chance to engage in work that is directly related to their own learning and acknowledge that they are contributing a valuable perspective to the research. Students involved learn about their own understanding as well as how to improve their skills and knowledge, while the faculty involved have the opportunity to learn about the efficacy of different teaching approaches. Moreover, faculty can gain insight into the student perspective, which typically, they are far removed from themselves after achieving ‘expertise’ in the field. Both authors of this paper benefited from this collaboration in that they developed greater insight into how they interpret (first author) and teach (second author) quantitative data.

#### 4.1 Limitations

Conducting Decoding interviews presents some challenges. Some people may be less willing to explore and describe their mental processes than others. Indeed, faculty interviews lasted much longer than those with students. That is not to say that the difficulty in Decoding interviews is unique to students, as faculty sometimes also struggle and ‘get stuck’ (D. Pace, personal communication, November 2, 2020). During some of the interviews, the interviewers struggled to maintain a conversation with the participants. These participants made it clear that graph reading was not something that they consciously thought about and being asked to do so was a difficult task. Some participants either struggled to understand the questions that were being asked of them or could not articulate their thoughts clearly.

Although the sample size in this study ( $n = 11$ ) may appear to be small and to limit our ability to generalize, it is consistent with other DtD studies, in which the goal of the study is to investigate individual mental processes in depth. In fact, our sample size is in line with the other studies of this type (e. g., McBrady, 2022; Rouse et al., 2017). Notwithstanding this limitation, our data do indicate variability in graph-reading skill, with some but not all students identifying clear and consistent steps. This supports our contention that further explicit instruction would be valuable, at least for psychology undergraduate students.

#### 4.2 Future Directions

Given the trends in previous literature surrounding DtD and SaP work, further research using these two approaches is likely to be fruitful. Thus far, they appear to yield promising utility and valuable insight. However, research into merging these approaches remains limited. Future work expanding the use of DtD and SaP, either alone or in tandem, will further our understanding of learning and collaboration in educational settings and beyond.

In this and another study (Cameron & Duffy, 2025), we have completed Steps One and Two of DtD. First, graph reading has been identified as a ‘bottleneck’ in student learning (Cameron, 2019; Glazer, 2011; Pace, 2017). Second, we have identified the steps that faculty experts (Cameron & Duffy, 2025) and students (the current study) utilize. Here we have provided evidence of a lack of consistent

strategy among students. As noted previously, many students do not perceive graph reading as a stepwise task. The findings of this study could be leveraged to help students recognize the important function that these metacognitive steps serve. In Step Three of Decoding, instructors model a skill for their students and in Step Four, students practice this task. That work is currently underway in our lab and classroom. Our current efforts are directed at identifying teaching methodologies that can most effectively help students overcome the bottleneck of graph reading. This requires balancing time spent on course content and developing skills.

In the future, we hope that more instructors might consider decoding their own mental processes, particularly in graph reading, and use it to inform their modeling of this crucial skill. While it will initially take some time for the educator to model a task and have students practice completing it, this will save time in the future as students will overcome the bottleneck and be able to complete the task more quickly and effortlessly in future lessons and courses. Future research should also investigate whether some methods of modeling are more effective than others.

## Notes

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