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Applying *Decoding* Methodology to Psychological Statistics and Other Applications

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Abstract

This article summarizes a recent study of *Decoding the Disciplines* applied to psychological statistics and explores the methodology behind the scenes that facilitated the project. The first part of the paper will summarize the study. The second part will highlight aspects of the *Decoding* methodology that enhanced the research project, a non-interview form of *Decoding* and the advantage of cross-disciplinary collaboration. The third part of the paper points to other applications of the methodology and discusses numerous ways instructors have used *Decoding* methodology and theory in their SoTL (Scholarship of Teaching and Learning).

Keywords Decoding the Disciplines; analogy; pedagogy; methodology; bottlenecks; SoTL; teaching methods

Anwendung der Decoding-Methode auf Statistik in der Psychologie und weitere Kontexte

Zusammenfassung

Dieser Artikel fasst eine Studie über die Adressierung von Lernhürden von Studierenden in einem Statistikkurs im Kontext von Psychologie zusammen und stellt vor, wie Decoding the Disciplines als Konzept eingesetzt wurde, um den Kurs zu verbessern. Im ersten Teil des Artikels wird die Studie zusammengefasst. Im zweiten Teil werden Aspekte der Dekodierungsmethodik genauer beschrieben, die zur Reflexion der Lernhürden beigetragen haben, konkret die Nutzung von Analogien in einem interdisziplinären Kontext. Der dritte Teil des Artikels weist auf weitere Anwendungen der Methodik hin, indem er Möglichkeiten beschreibt, wie die Decoding-Methodik und -Theorie in verschiedenen Stadien des Konzepts eingesetzt wurden.

Schlüsselwörter Decoding the Disciplines; Analogien; Methodik; Lernhürden; SoTL; Lehrmethoden

1 Introduction

Instructors who use *Decoding the Disciplines* report anecdotally that it improves student learning, but few published studies have shown quantitative evidence that learning improves with *Decoding*. For readers who are unfamiliar with *Decoding*, an in-depth description of the methodology can be found in Middendorf and Shopkow (2018), Miller-Young and Boman (2017), and Pace (2017). Three studies (Pinnow, 2016; Lee-Post, 2019; Elliott & Middendorf, 2024) demonstrate a statistically significant difference in student learning when the *Decoding the Disciplines* method is used to develop course materials. Specifically, Pinnow (2016) taught an introduction to psychology class and used *Decoding* to create new curriculum addressing the cognitive bottleneck-"applying the scientific method." She tested three subtasks within this bottleneck and found that the *Decoding* curriculum increased student learning significantly. As Pinnow (2016) suggested, student understanding of the scientific method in psychology determined mastery of an understanding of psychology as a science.

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Lee-Post (2019) taught a business operations analytics course and used Decoding to address one cognitive and one affective bottleneck. The cognitive bottleneck-"building models" and the affective bottleneck-"low self-efficacy in numeracy," as well as the pre-conception that the course is demanding, were addressed across two semesters: summer and fall. Lee-Post found that students in either of the Decoding classes had significantly higher test scores than students who were in the regular classes. And as Lee-Post (2019) noted, self-efficacy and a course's challenging reputation can be detrimental to student learning when left unaddressed.

In Elliott and Middendorf (2024), Elliott taught an introduction to psychological statistics course and used Decoding to address five cognitive bottlenecks and student attitudes (including affective bottlenecks) towards the course[1]. The bottlenecks were addressed in the first four weeks of class with Decoding lessons. Previously, the instructor had taught four weeks of introductory definitions and beginning research. Because the authors will describe aspects of the methodology that guided the psychological statistics study, an example of one of the lessons, variability, will be outlined here. However, readers are encouraged to consult the original published article.

To show how Decoding the Disciplines functions at every step of a bottleneck lesson, Figure 1 delineates in brief the steps of the variability bottleneck lesson. Following Figure 1, we describe how the methodology applies to the variability lesson. Following that is a transcription of the authors' conversation to illustrate the depth of work and the cross-disciplinary collaboration necessary for the analogy approach to creating a Decoding lesson.

1 The initial draft of this paper was originally presented at the first *Decoding the Disciplines* conference in Aachen, Germany in November 2023 (Elliott & Middendorf, 2023).

1. Bottleneck: Difficulty visualizing variability patterns in the data.
2. Decode: Visualize the distance between the numbers in the data sets to reveal the pattern within and across the groups.
3. Model: Like the combination of notes and spaces in music, both the distance between the numbers and the regularity. Is it a steady beat like a marching drum or is it improvisational like jazz? OR like viewing the patterns on dice or dominoes at a glance, without counting by ones.
4. Practice: Students make a "human graph" by standing close together or far apart to emphasize the spacing in between a given set of numbers (Wentworth, n. d.).
5. Motivate: To avoid math phobia and to address a feeling of competency with numbers, use numbers less than 100 in the first weeks. Practice together in class.
6. Assess: Pre- and post-test with multiple choice questions on variability. Muddiest point CAT (Angelo & Cross, 2012).
7. Share: Presenting this paper at Aachen *Decoding* Conference (Elliott & Middendorf, 2023).

Figure 1: An Overview of the Variability Bottleneck Lesson

To create this lesson, the authors followed these explicit steps which are slightly different from other versions of *Decoding*. *Decoding* required new thinking at each of the steps to develop this lesson, which we are explaining in detail.

Step 1 – Determining the bottleneck. A bottleneck lesson starts at a place in the course where the instructor notices that students repeatedly struggle to understand something; in this example, the concept of variability. For this bottleneck, students struggle to recognize the patterns in the data that indicate significance. Subitizing is a sub-bottleneck of variability; by focusing on the problematic sub-bottleneck, that is, breaking the problem into its parts, learning can be better scaffolded, and students can take on more difficult tasks (Middendorf & Shopkow, 2018).

Step 2 – Decoding the mental move. The instructor as specialist quickly visualizes the spaces between the numbers in the data sets, examining the distance and regularity within and between the numbers that determine variability. The specialist can visualize the spaces between the numbers without counting or measuring them to tell if the spacing is far apart/not far apart and regular/or irregular. Once the spacing is determined, the next 4 steps of *Decoding the Disciplines* use pedagogical theory to suggest instructional strategies.

Step 3 – Modeling. The instructor presents an analogy for the mental move, placing it in a familiar context so that the pattern of significance would be evident to students through the relational structure.

Step 4 – Student practice. Both in-class and out-of-class practice exercises allow students to try out the mental move, not just passively watch the instructor perform it.

Step 5 – Motivate. Students often need help to persist in trying a new mental move. Building new neural connections is difficult, possibly even painful work, and takes repeated practice built into the course structure to solidify them. The motivation step encourages instructors to check for any spots in the course that are notably difficult or that students especially resist-and make a plan to get through these most difficult of difficulties.

In this course there were affective bottlenecks of self-efficacy and math anxiety. For the first part of the course, the restructured lesson plans aimed to avoid math anxiety. Thus, all numeric examples involved numbers less than 100. For self-efficacy, students practice problem-solving exercises in teams with their whole selves and interact with classmates, such as the human graph, whereby people stand along a number line to represent a numeric answer or their attitude toward a controversial

idea (Wentworth, n. d.). The social engagement allows students to try out new concepts before working on individual homework, thus building confidence in use of statistical concepts.

Lee-Post (2019) noted that in a key business course, students struggled with both cognitive bottlenecks and affective bottlenecks. For the cognitive bottlenecks, students struggled with quantitative modeling. For the affective bottlenecks, students believed that the course was demanding and not relevant and argued that these should be addressed simultaneously. The authors of the current study took a different approach to a similar affective bottleneck.

Middendorf & Shopkow (2018) argue in *Overcoming Bottlenecks* Chapter 5 that even with strong modeling and practice of the cognitive bottlenecks, if student learning difficulties persist, affective obstacles, also known as emotional bottlenecks, may be prohibiting students from resolving the cognitive bottlenecks. With a focus on the Motivation Step, the instructor can assess key motivational factors. Are disciplinary procedures or worldviews impeding the learning? These types of challenges, which can be assessed, appear in the pre-existing narratives students bring to the course. The instructor is then in a better position to address student resistance by, for example, explaining the reasons for certain disciplinary procedures to students (such as daily homework or following the desired routine for problem-solving). If the results of the assessment reveal the worldview as the source of resistance, the instructor may need to begin by addressing student prior self-beliefs, such as "I'm not good at math" or "this class is too hard for me." If not addressed, affective/emotional bottlenecks can continue to interfere with learning.

Step 6 – Assessment. Student competence was measured on the bottleneck of variability through open ended qualitative questions and multiple-choice quantitative questions.

Step 7 – Sharing. *Decoding the Disciplines* eases entry into scholarship of teaching and learning (SoTL) (Middendorf & Pace, 2008). During the session in which this paper was originally presented, conference participants were invited to discuss *Decoding* studies in their fields, which resulted in a wide-ranging discussion. Even novice instructors can build and assess a 7-step bottleneck lesson, or even for simplicity's sake choose to use just one or two steps of the model as the basis for a study.

The methodology used to create the variability bottleneck was similarly followed for the other four bottlenecks in the study (probability, central limit theorem, independent/dependent variables, and degrees of freedom) and these bottleneck lessons are available from the authors on request.

2 Advantages of the Methodology for Students

Qualitative data from student responses (Elliott & Middendorf, 2024) suggested that the *Decoding* lessons helped alleviate anxiety towards the course material. The results described a decrease in students' anxiety, and increase in confidence in their own competency, and a more favorable perception of the course. One student wrote:

> "Making mistakes is a part of learning, so it is okay to make them. However, you must learn from them. Redoing assignments allows you to have more practice and learn from the mistake you made.... Finally, the other main thing you do is understand the conceptual parts of the analyses. Understanding the conceptual parts of the analyses will make them much easier to understand and complete..."

Another student had a similar response:

> "... I am sure everyone has heard that 'statistics is so hard,' I would know because I used to say that despite not having any knowledge of the concepts of stats... Don't allow the stigma around stats being so difficult influence you from succeeding in this course."

The *Decoding the Disciplines* method resulted in lessons that significantly improved student learning on the five core concepts. Informal feedback suggested that students felt the course was more enjoyable and that they felt confident in their ability to perform statistical analyses.

3 Advantages of the Methodology for Instructors

As the *Decoding* lessons took place in the first few weeks of the course, the instructor assumed that these concepts would have to be retaught as the individual statistical tests were taught. This was how the course progressed in the past; students would forget what they learned in the first four weeks and how that applied when they actually did the analyses. The instructor observed that this was no longer the case. Students had retained what variability meant so when the discussions of the different types of measures of variability ensued (e. g., standard deviation, standard error, mean square error, etc.) students understood the concept in general and focused on how variability was calculated in a specific type of statistical analysis. This saved the instructor time and additional teaching effort. This was a novel and unexpected by-product.

4 Comments on the Decoding Methodology

Besides highlighting the use of all seven steps of the methodology, the authors believe two aspects of their collaboration also merit reflection because they are key to the success of the methodology: The non-interview, analogy-trading approach to *Decoding* the mental move; and the value of cross-disciplinary teamwork.

4.1 The Non-interview Analogies Methodology for Uncovering Mental Moves

The authors used a non-interview form of *Decoding* for this project, which is explained in detail.

In *Decoding* interviews, the interviewer probes the specialist, again and again, to get the specialist to further analyze their implicit critical thinking into its parts. But there are other forms of *Decoding* that can achieve the same results. Step 2 *Decoding* involves unpacking someone's implicit mental processes, where the specialist can do a lot of things fast and in large chunks (Chi et al., 2014), yet it is not readily available to the specialist to examine what is going on in their own mind. Analogies can shine a light on a specialist's critical reasoning because analogies can offer clues to understanding hidden mental models (Elliott & Foltz, 2005). Analogies are also effective in communicating difficult concepts. For example, medical professionals concerned that patients do not understand probability enough to make an educated decision about treatment options have turned to analogies (among other non-numeric explanations) to communicate the probability of different health outcomes to their patients (Galesic & Garcia-Retamero, 2010).

For this project, the authors traded analogies to uncover the mental move. Not being a STEM scientist herself, and without a co-interviewer from within the discipline, Middendorf was not confident that a *Decoding* interview would make the mental moves clear. Also, she finds the trading analogies approach more enjoyable, stress-free, and effective at uncovering the mental move.

To start, Elliott explained the mental move to Middendorf the best she could and, to check Middendorf's understanding, Middendorf offered her an analogy for it. Is it like this? Whatever analogy popped into her mind. With the variability bottleneck, Elliott had started from an example about a tomato gardening experiment that featured two treatments, one with fertilizer and one without, looking for variability in the data results. To create the analogy, Middendorf took what she perceived as the mental move, removing it from one context and placing it in a different context. Below is the transcript of one of our discussions when trading analogies for the variability lesson described in the study above.

Middendorf: Can the two treatments be like comparing a holiday meal to a regular meal?

Elliott: No, it isn't like that. I don't know how you show the effect size for a holiday meal versus a regular meal. It's more like black boxes between the numbers in the data. If the numbers were (5, 10, 15, 20, 25) compared to another data set where the results were (3, 10, 11, 20, 24), the specialist visualizes the black box patterns (the spaces) in between the numbers.

Middendorf: It's like black boxes?

Elliott: Maybe that's not clear enough for you. It's like matching lids on Tupperware where it'll just snap together. When you look at those spaces between the numbers, you need the right fit.

Middendorf: It's like matching the lids for Tupperware to the containers? Hmm.

Elliott: It must be exact, and it'll just snap together. When you look at those spaces between the numbers, you need the right fit.

Middendorf: I'm looking for the right lid to Tupperware between the numbers?

Elliott: Maybe it's more like reading musical notation. Someone who can read the musical notes on a page and hear the music can hear the difference between quarter notes and 16th notes and know that the spaces between the notes mean something, that was like the spacing between the numbers for (5, 10, 15, 20, 25) which is 5-5-5-5--very regular, same amount of spacing, while the spacing in between the other seven numbers (3, 10, 11, 20, 24) are 7-1-9-4 is jumping all over, then you could see wow, there's a significant difference between these two data sets.

Middendorf: Is it like seeing the patterns on dominoes or dice, where we don't count by ones to see what number we have, but group numbers and see the pattern all at once?

Elliott: That works, because humans can only subitize 3–5 items at most, so they group numbers into clusters and then combine them for a total.

Middendorf has learned to place the mental move in a different context, even if the new context is far from the mark as a starting point. Very often, when suggesting an analogy, the receiver of the analogy will automatically either critique the analogy, or offer another analogy in reply, and that refines her idea of the mental moves. It's like a game of "Hot and Cold" with the analogy getting closer to the mental move and the specialist being the one who has a sense of when the analogy is getting warmer. Both Middendorf and Elliott enjoyed the experience, and it further uncovered the mental move.

- In addition to analogies, other forms of non-interview *Decoding* (Middendorf & Shopkow, 2018) include the following:
- Bottleneck writing tour: a reflective writing process with rounds of reiterative writing about the bottleneck and the mental move (Lahm, 2016).
- Concept or mind mapping or flow charting: drawing the steps or parts of mental move.
- Three-dimensional modeling: Using simple materials such as playdough, Legos, or sticks and grass from the garden to build a physical model of the mental move.
- Rubric building: Starting from a list of frequent mistakes students make and creating a corresponding list of the opposite of each mistake-a list of what the specialist does to avoid each mistake (Shopkow, 2017).

All the alternative *Decoding* methods involve conversation with an interlocutor, preferably one from a different discipline.

4.2 The Importance of Cross Disciplinary Dialogue

Some educational leaders encourage instructional support to come from specialists in the same field, such as a psychology specialist to support a psychology researcher or instructor. Decoding encourages the opposite, because an expert from the same field may find it difficult to notice leaps a specialist makes in their reasoning that may leave learners behind. Cross-disciplinary dialogue is powerful. Varpio and MacLeod (2020) note that when scholars from different traditions work together, each has a unique perspective on the world, and they each must "articulate their reasoning, theories, and values" (p. 687). The different traditions of working together combine the strengths of each field. Sometimes the more dissimilar the foundations are from each other, the better the end product that will emerge. This cross-disciplinary dynamic was at work in this project.

With *Decoding the Disciplines*, there is typically at least one person from inside the discipline, the specialist whose bottleneck and tacit critical thinking will be *decoded*, and at least one person from outside the discipline. The outside-the-discipline interlocutor's strength lies in not knowing, with continued probing, and not faking understanding that they do understand when they do not. This person (no matter what discipline they are from) trusts the *Decoding* process, and continues to uncover assumptions, until no assumption remains unturned.

As Varpio and MacLeod (2020) note, that intersection of the minds can be threatening but powerful. One person must be comfortable not knowing; while the other must be confident knowing yet not being able to describe what is going on in their mind until the mental move has been re-amateurized by unpacking their expertise so it may be scaffolded for the students. The process rewires the instructor's or specialist's brain to see disciplinary concepts from the learners' viewpoint and value that viewpoint. *Decoding the Disciplines* method takes cooperation and trust.

When the collaboration is going well, the work may be difficult but not overly taxing; more like two mules harnessed together pulling a load downhill, not uphill; a shared partnership with no one person carrying more of the effort. We came out of the project with each of us feeling like the other author had made most of the effort.

Social norms such as gender perceptions and disciplinary norms can interfere. Both parties must understand that parsing assumptions can be somewhat uncomfortable or frustrating but leads to a better understanding. Patience and openness to new ideas from outside of one's discipline are key.

Applying the *Decoding* theory and methodology enabled the authors to identify difficult bottlenecks in learning psychological statistics, to uncover the "secret knowledge" of the statistics specialist by communicating through analogies, and to open up the insider knowledge for learners by taking advantage of the outside author's non-disciplinary viewpoint to re-amateurize the difficulties and question unopened assumptions about the critical reasoning to get through them. Through collaborating on this study, the instructor has improved the learning on the key bottlenecks in psychological statistics and learned to teach from a theory, one that allows her to confidently notice where the students are struggling, to frequently assess the stuck places, and to scaffold the mental moves with the pedagogical tools of analogies, practice, and motivational considerations. Thus, *Decoding* can guide her teaching in the future. Other instructors and SoTL researchers can use the *Decoding* methodology to enhance their work.

5 Other Applications of *Decoding* Methodology

The final step of the *Decoding* model, Step 7 Sharing, is the SoTL step. It encourages analysis and reflection of what one has learned from applying *Decoding* to one's teaching or research and includes going public with the results. The psychological statistics study exemplified a *Decoding* study that utilized all the steps of *Decoding the Disciplines*. Sometimes instructors or SoTL researchers choose to focus a *Decoding* study on one step only. A small representation of the discussion of these kinds of studies organized by the *Decoding* methodology, are listed below.

Step 1 Bottlenecks. McMillen and Magner (2023) studied pre-service elementary teachers who recognized their own bottlenecks in mathematical teaching and understanding.

Step 2 Decoding. Lindstrom et al. (2023) explained the *Disrupting the Disciplines* interview as an approach to reveal how disciplines may be upholding colonialism, racism, and assimilation of diverse identities.

Step 3 Modeling. In a tech-heavy course, Lee and Kramer (2023) modeled examples from outside of the technology to explain a piece of code to students.

Step 4 Practice. Mondelli (2023) combined *Decoding the Disciplines* with game design to ensure the practice efforts of a game were aimed specifically at the mental moves.

Step 5 Motivation. To lessen resistance and shift to a student-centered classroom, Wegner (2023) applied the students-as-partners approach through student-led *Decoding* interviews. In contrast, Nel (2023) showed the results of exploring emotional/affective bottlenecks using Social Dream-Drawing Techniques.

Step 6 Assessment. Darcy (2025) translated *Decoding* interviews into a checklist for interpreting biology graphs that, when surveyed, 79 % of beginning students in a large biology class found useful.

While elements of the *Decoding the Disciplines* model in the examples above with Steps 1–6 are valuable for SoTL and teaching, some researchers took a different approach, extending *Decoding* theory through complementary theories. For example, Yeo and Stalheim (2023) combined *Decoding* and hermeneutics to make the familiar strange in teacher education. Taczak et al. (2023) compared transfer and *Decoding the Disciplines* frameworks to promote lifelong learning. Brase et al. (2023) connected *Wissenschaftsdidaktik* (i. e., the scientific teaching methods) with research and teaching in the disciplines.

Some of the researchers explored further development of *Decoding the Disciplines* in new contexts, such as in teacher education (D'Sena, 2023; Beam et al., 2023), educational development (Riegler, 2023), and for new methods in Collaborative *Decoding* (Barnat & Foltz, 2023). These are just a few examples of the ways that by going public with findings, Step 7 of *Decoding* encourages analysis and inquiry in SoTL.

In summary, *Decoding* provides a methodology for instructors to teach based on theory that has demonstrated an improvement in student learning and gives an accessible entry point to SoTL by providing a theoretical framework. The psychological statistics study described in the article was an example that the authors used to explain their experiences with the *Decoding* methodology, in particular the use of analogies to uncover tacit mental moves in a beginning psychological statistics course and the usefulness of outsider-insider positionality in exploring disciplinary understanding.

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