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BOARD # 18: WIP: A Methodology for Developing a "Signal Detective" Mindset in Biomedical Engineering Students

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WIP: A Methodology for Developing a "Signal Detective" Mindset in Biomedical Engineering Students

Introduction

Proficiency in signals and systems is essential to a biomedical engineer's (BME) education, as many key technologies in healthcare—such as medical imaging, diagnostic instrumentation, wearable health monitors, and electronic health record systems—depend on digital signal processing. BME students typically find signals and systems courses difficult because they require an intuitive understanding of calculus, differential equations, circuit analysis, and principles of human physiology. In addition, signals and systems courses require application of mathematical formulas to model and analyze signals as well as cognitive flexibility in switching between time and frequency domains [1].

Motivation

Signals and Systems for BME is a required three-credit senior-level course at Wentworth Institute for biomedical engineering students. Over the past eight years, this instructor has taught the course to 15 cohorts, with enrollments ranging between 35 and 70 students per year. Early on, the instructor noticed that the traditional mathematical focus and delivery of the content were difficult for students to grasp and to keep them engaged. Furthermore, the course's lecture-only format, with two 75-minute sessions per week, left little time for problem-solving or lab based instruction. To address these constraints, the instructor developed and implemented the "signal detective" approach to make the fundamental concepts and methods of signals and systems meaningful and relatable without delving too deeply into the math (supplementary materials and readings from the textbook are provided for those students who want to delve deeper into the math). Separately, a series of brief, targeted laboratory exercises have been introduced to reinforce key ideas; these "flash-labs" are detailed by these authors in an earlier publication [2].

Background

In traditional electrical engineering-oriented signals and systems courses, concepts are presented from the perspective of mathematical modeling of systems, where the signals being investigated are primarily periodic and predictable. Such math-focused approaches can deprive students of the critical connections they could be making between theoretical concepts and human physiology [1]. Our course emphasizes the development of fundamental skills that enable students to observe and identify key features of physiological signals, supporting visualization, modeling, and analysis without requiring extensive mathematical derivations. Students apply core principles of digital signal processing to analyze and interpret their own physiological data—such as heart rate, blood pressure, respiration, and muscle activation—which are inherently less predictable and not strictly periodic. This practical, pattern-seeking approach is what we refer to as the "Signal Detective Mindset."

Signal Detective Description and Implementation

The signal detective approach provides a scaffolded framework for analyzing signals (Appendix B). In essence, students begin by examining the data file or data stream—identifying the format, data elements, and structure. Acting as "signal detectives," students focus on observable features like time scale (e.g., milliseconds, seconds), amplitude (e.g., millivolts, volts), and frequency (e.g., subHertz, Hertz, etc.) They also determine the most appropriate analysis domain—time or frequency—based on the signal's characteristics. This hands-on, inquiry-driven process enhances student engagement and fosters the skills and mindset needed to analyze real biomedical signals.

Research Objectives

This paper has two primary objectives: (1) to describe the signal detective approach as a pedagogical tool and (2) to evaluate the effectiveness of the signal detective approach in enhancing students' understanding and application to biomedical signal processing. While the signal detective approach has been previously implemented in the course, it had not undergone formal evaluation until now. During the spring 2025 offering of the course, the authors conducted a systematic assessment to investigate the impact on student learning and development of a signal detective mindset.

Data Collection

Data was collected through four questions on the final exam, which are shown in Table 1 below:

Quantitative	***Qualitative***
Q1: *In the course we analyzed many types of physiological signals using the signal detective approach. Please match each physiological signal type with its corresponding numbered graph on the right.* **Signal matching** (Appendix A).	**Q4**: *Please explain which aspects were most helpful or least helpful in applying the signal detective approach.* **Metacognitive [3]. Thematic Analysis.**
Q2: *How helpful was the signal detective approach in helping you understand and analyze the signals presented in the course?* **5-point Likert scale**.	
Q3: *After taking this course, I am more confident in my ability to analyze signals, in part due to the signal detective approach.* **5-point Likert scale**.	

Table 1. Question summary and data analysis method used.

Methodology and Results

Quantitatively, student performance and self-assessments reflected strong engagement and skill development. Q1—which assessed pattern recognition and signal identification—all 37 students correctly matched physiological signals to their corresponding traces (Appendix A). While this was a relatively straightforward question, it required students to apply foundational skills in pattern recognition and classification, underscoring the practical utility of the signal detective approach when faced with physiological signals. Further insight came from Likert-scale responses shown in Figures 2 and 3. Figure 2 shows that 26 students rated the signal detective method as "helpful" or "very helpful" in understanding and analyzing signals; 10 were neutral, and one had no response. Figure 3 shows that 35 students reported feeling more confident in their signal analysis abilities by the end of the course, with most attributing that confidence, at least in part, to the signal detective approach. Only one student was neutral, one had no response.

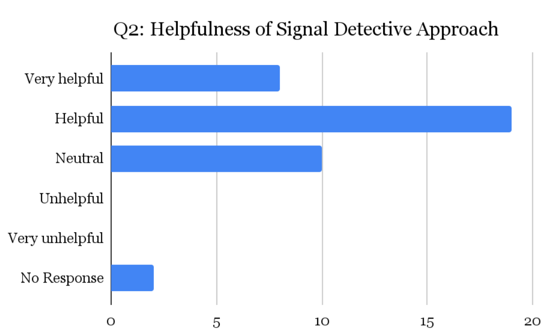

Figure 1. Responses from 37 students to Q2.

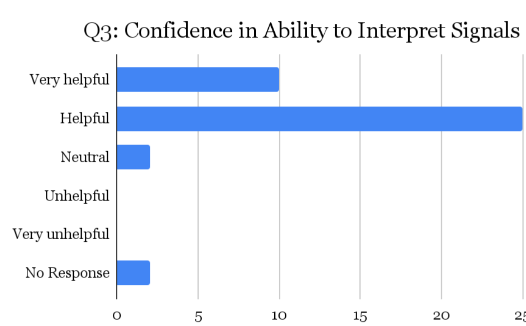

Figure 2. Responses from 37 students to Q3.

Qualitatively, thematic analysis of responses to Q4 from the 33 students who responded reinforced the quantitative findings. Following established coding methods, themes were identified through a five-step process: familiarization with the data, line-by-line coding, initial theme generation, theme development, and review in the context of the full dataset [4][5].. Figure 3 shows that 25 students (76%) indicated that the signal detective approach was helpful in understanding the concepts and in analyzing signals. However, a trade-off was noted: 8 students (24%) commented that time spent on signal identification limited the depth of engagement with the underlying math content, which they wished had been provided more directly in class.

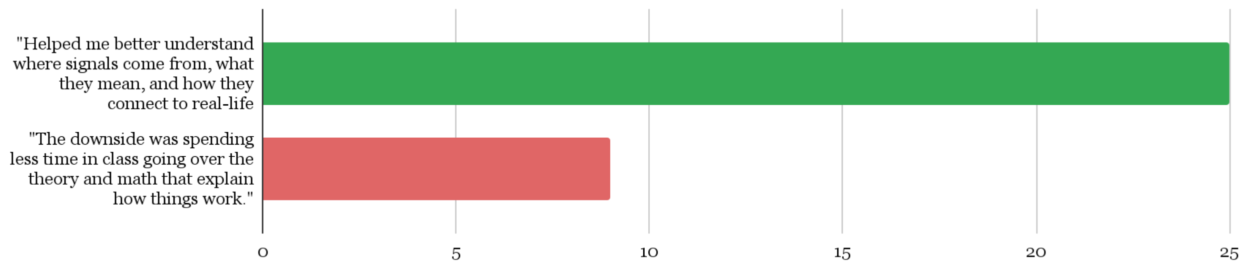

Figure 3. Responses from 33 students to Q4. The data was consolidated into the two main codes shown.

Observations and Discussion

Analysis of the data shows that the effectiveness of the signal detective approach was supported by both the quantitative and qualitative data. Taken together, these results offer strong support for the signal detective approach. Students not only demonstrated measurable skill in signal identification but also articulated how the signal detective method improved their understanding and confidence level in tackling other signals and systems. Students also thought the method helped clarify concepts they had learned in prior coursework as well as signals and data they encountered in their jobs (co-op positions). While the approach prioritizes applied analysis over theoretical mathematical rigor, students appear to appreciate this tradeoff - recognizing that developing intuitive, structured ways of engaging with signals is a critical step in mastering the more abstract dimensions of signal processing.

Conclusions

The signal detective approach offers a novel educational opportunity because it enables BME students to make connections between the underlying concepts of signals and systems and how their own bodies function. The primary goal of this research was to evaluate how the signal detective approach promotes engagement and learning of signals and systems for BME students. Both quantitative and qualitative data supported the efficacy of the signal detective approach. Students overall felt that they became better at interpreting signals, particularly when faced with "scary-looking" mathematical formulas or complex spectral graphs of signals. Also, it appears that this method helps students relate to and internalize core fundamental concepts and are more eager to collaborate with each other. Interestingly, the observed gains in students' signal detective skills were accompanied by a perceived reduction in mathematical rigor—an outcome we did not initially anticipate. In future implementations, we will explore strategies to integrate more mathematical depth while preserving the benefits of the approach.

IRB Statement on Data Usage

The data utilized in this study was anonymized and aggregated and was deemed as "exempt" by our university's IRB committee.

References

[1] Fayyaz, F. “Work-in-Progress: Problems in Learning Related to Mathematical and Graphical Representations of Signals.” American Society for Engineering Education Annual Conference. 2022.

[2] Feldman, U., Ricco, G. D. Work In Progress:“Flash-Labs” as a Tool for Promoting Engagement and Learning in Signals and Systems for Biomedical Engineering Course. Published Proceedings of 2023 ASEE Annual Conference & Exposition. https://peer.asee.org/44114

[3] Wengrowicz, N., Dori, Y.J., and Dori, D. “Metacognition and Meta-assessment in Engineering Education.” Cognition, Metacognition, and Culture in STEM Education. In: Dori, Y.J., Mevarech, Z.R., Baker, D.R. (eds). “Innovations in Science Education and Technology.” Volume 24. Springer. Dordrecht. 2018.

[4] Douglas, E.P., "Beyond the Interpretive: Finding Meaning in Qualitative Data," American Society for Engineering Education Annual Conference. 2017.

[5] Braun, V., and Clarke, V. “Using Thematic Analysis in Psychology. Qualitative Research in Psychology.” 3(2). pp. 77-101. 2016.

Appendix A: Signal identification question from final exam

Q1 *In the course we analyzed many types of physiological signals using the signal detective approach. Please match each physiological signal type with its corresponding numbered graph on the right.*

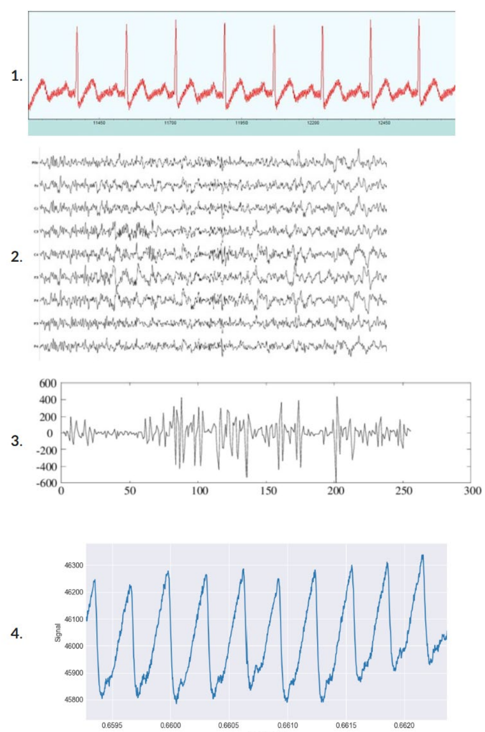

Figure A1: Signal matching question from final exam.

Answers, top to bottom: ECG, EEG, EMG, PPG

Appendix B: Signal Detective Template

Signal Detective Template

Before doing any analysis: Observe and Describe your data set

1. What type of data/signal is it? ECG, RR, PPG, GPA, ERA, RBI, etc. [some of these are not physiological] Refer to Figure 1 below.
2. If you were to plot the data what would you expect it to look like? For example: how many columns per data set, maximum, minimum, scale (V, mV, MV, sec, msec, hours, days, years, whole numbers, decimals, positive, negative, etc.)
3. Which tool would be most relevant to use? Excel, Matlab, pen and paper, others?
4. Have I read the documentation for the specific tool to see what format the data needs to be in order to import it correctly? (Google search for raw data format for import to matlab or Excel for example)

Now begin the analysis

1. Open up your data file with a tool such as notepad (because it lets you see raw files). If you open up with Excel be aware that xls files have invisible formatting characters which many tools don't like, unless the tool specifically states that it can import .xls.
2. Save the appropriate data elements (columns?) in the right format (typically raw, txt, csv, but make sure you know which delimiter is used) to match up the format that the tool expects.
3. Familiarize yourself with the formatting/visualization functions of the tool to make sure you are viewing data at the right location and scale.
4. Experiment with the various formatting layouts available in Excel (bar, line, scatterplot,etc.) until you get the format that you expect and is most illustrative.
5. Select a few points and perform the measurements directly. BTW, excel has a nice feature where if you hover over a data point on a graph it will reveal the x,y coordinates.
6. Do a "sanity check" using a few sample data points. From these calculations, do the numbers make sense?
7. If so, continue with the full analysis.
8. If you followed all the steps above and the tool you are trying does not work, then try a different tool.

Parameter	Range of parameter	Signal frequency (Hz)
ECG Signal	0.5-4 mV	0.01-250
Respiratory rate	2-50 breaths/min	0.1-10
Blood pressure (BP)	10-400 mmHg	0-50
EEG	3-300 µV	0.5-60
Body temperature	32-40^{0}C	0-0.1
EMG (electromyogram)	10 µV to 15 mV	10-500
GSR (galvanic skin reflex)	30 µV to 3 mV	0.03-20

Table A1: Chart with ranges and bandwidth for each type of physiological signal

https://www.researchgate.net/figure/Range-and-Frequency-for-Physiological-Signals-17_tbl2_316748886