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Exploring the Use of Approximations of Practice in the Context of Elementary Teachers' Attempts at Implementing Engineering Design-based Science Teaching

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Abstract

The purpose of this comparative case study is to analyze the highly complex practice of implementing instructional activities and classroom organizational structures of five grade four teachers learning to teach science using engineering design. Using the theoretical framework of ambitious teaching, researchers identify core instructional practices that align with national science academic standards and the tenets of engineering design to analyze teachers' pedagogical actions of leveraging student thinking during design. Data were gathered via formal multi-day classroom observations, semi-structured interviews, teacher reflections, and student work (i.e., design notebook entries, artifacts, and performance on unit assignments). Observation data were analyzed using event mapping of core instructional practices across time within one design task. Data timelines offered a visual comparison of the range of activities over time as well as the approximate length of each. Segments of data for each classroom event map were classified and labeled based on explicit engineering design phases expressed in the teacher's instruction as well as discrete instructional activities enacted by the teacher. Data from interviews, reflection and student work were analyzed using content analysis. Triangulation of all data sets ensured confirmation of recurring patterns and emerging themes about how elementary school teachers approximate their practices with elements of ambitious engineering design-based pedagogies. Results indicated that teachers' approximations of practice are tied directly to the content, goals, and implicit nature of the design tasks as well as how teachers specify and explicate the structure and complexity of their teaching practice. Findings from this work serve as a new set of working considerations for uncovering teachers' struggles and success in taking up ambitious engineering design-based teaching and establishes an agenda for supporting teacher development with reformed-based science teaching.

Introduction

As individual states adopt the new science standards, there is greater need for understanding how teachers implement engineering practices, how to support teachers implementing these practices, and how students learn science through engineering practices. Compounding this effort is the growing challenge of identifying and characterizing effective engineering design-based science teaching while still capturing its complexity. In other words, what does engineering design-based science teaching look like and how can we capture teachers' strategies? Drawing from the tenets of ambitious teaching, this study utilizes what have been called "high leverage" or "core" practices [1] [2]. Core practices are moves, skills, and strategies that teachers do in high frequency and have been shown in research to be linked to improvement in student achievement [3], [4], [5]. Approximations of practice refer to opportunities for teachers to engage in practices that are more or less proximal to the practices of effective teaching [6]. Mapping teachers' approximations with engineering design-based science teaching requires precision and insight of an observation tool that aligns with national reform documents, the nature of the engineering design process, and the discrete components of a teacher's practice [1]. In this study, we profile the highly complex practice of five elementary school teachers new to teaching science through engineering design and further identify, characterize, and analyzing each teachers' instructional strategies moves through the engineering design process. Problem scoping, for example, involves multiple components, including identifying essential elements of a problem, asking key questions, and facilitating whole class discussion. This process of analysis is referred to as "decomposition" of practice – breaking down complex practice into its constituent parts for the purposes of teaching and learning [6]. If decomposing practice enables teachers new to engineering pedagogies to "see" and support them in enacting practice, then they may be able to enact elements of practice more effectively. Conversely, if a defined set of engineering design-specific high leverage practices could be articulated, observed, and communicated, the broader community of engineering and science educators could collectively refine these practices and generate new tools and resources to support teachers' appropriation of engineering design-based science instruction at the elementary school level.

Purpose of the study and research questions

The purpose of this study is to identify, describe and analyze high leverage practices elementary school teachers utilize when implementing engineering design-based science instruction. By decomposing each teacher's implementation of a standards- and engineering design-based science experience, we aim to uncover the complex interplay of a teacher's instructional strategies across each phase of the design process, and further compare and contrast teachers' enactment of ambitious engineering design-based science instruction.

The questions guiding this study include the following: (a) What instructional strategies do elementary school teachers enact when implementing an engineering design task? (b) How do we capture and map teachers' strategies over the course a design task? and (c) To what extent do the observed high leverage practices coincide with the nature of the design task?

Theoretical framework

This study draws upon the literature on ambitious teaching. The idea of ambitious teaching has been developed by researchers in multiple subject matter areas including science, mathematics, and secondary literacy [2], [6], [7]. Ambitious teaching involves structuring opportunities for learners to reason about key subject matter ideas, participate in the discourse of the discipline, and solve authentic problems [8]. In the science classroom, this means that students learn how to generate coherent explanations of natural phenomena; they understand how claims are justified; how to represent their thinking to others; critique one another's ideas; and revise their ideas in response to evidence and argument. The hallmark of this pedagogy is its adaptiveness to students' needs and thinking, and examples of this approach have set new standards for rigor and equity in practice across several subject matter areas [6] - [9].

Windschitl, Thompson, Braaten, and Stroupe [2] define four high-leverage practices for science teaching that make up what they refer to as "the core repertoire of ambitious teaching" (p. 880). These practices include constructing big ideas (planning of a science lesson); eliciting and interpreting students' ideas; encouraging students to make sense of their observations gleaned from their investigations; and assisting students in collectively constructing evidence-based scientific explanations and models. Underpinning each of these discourse practices is the teacher’s iterative steps of engaging students in productive discussions about their ideas, questions, observations, and explanations and propelling students forward to more complex ways of scientific thinking and reasoning.

Based on prior work, we contend that the pedagogical actions of leveraging student thinking in the science classroom translate well in the context of an engineering design-based science task [1]. Pedagogical features that characterize ambitious teaching, such as responsiveness to students’ thinking and reasoning, are quintessential to engineering design-based science instruction. The hallmark of engineering design-based science teaching is a teacher’s capacity to adapt his/her instruction to students’ ideas, needs, and thinking as students progress from one design phase to the next. Accordingly, we have defined a series of high leverage practices for engineering design-based science teaching (see Table 1). These features represent explicit strategies teachers enact when engaging students in an engineering design problem. Supplementing these practices are guiding questions or what we refer to as “discourse tools” teachers use when facilitating student engagement during each phase. These questions are not designed to be prescriptive but rather serve as guiding and supportive options for teachers to draw out students’ thinking that could be built upon or challenged in productive ways throughout the design process [1].

Table 1. Guiding questions teachers use during different phases of the engineering design process to promote productive classroom discourse.

Design phase	**Guiding questions**	**Features of Ambitious Engineering Design-based Science Teaching**
Problem scoping and information gathering	*What is the problem?* *What is the setting?* *Who is the user or client?* *What are the constraints?* *What do existing solutions look like?* *What other kinds of information do you need to know?*	Eliciting students’ ideas with the goal of the design task in mind Eliciting students’ ideas and prior knowledge about the context of the problem and big ideas
Solution formulation	*What are your ideas?* *What are others’ ideas?* *What materials will you need?* *What will your team measure?* *What do you know about [big idea] that could help inform your design?*	
Solution production and performance	*How will your team create a prototype, model, or solution?* *To what extent does your solution match the team’s original plan?* *How will you record results from testing?* *How could [big idea] explain your results?*	Eliciting and building upon students’ ideas with the goal of helping students reason through their design solutions Inviting diverse solutions and supporting a range of understandings
Communication and documentation of results	*How did your model, prototype, or solution perform?* *What did you observe or notice about your design?* *How did the performance of your design compare to the performance of other design teams?* *Were there any patterns? What do these patterns tell us?* *What feedback did your team receive?*	Encouraging students to make sense of their observations gleaned from constructing and testing Assisting students in collectively constructing evidence-based scientific explanations and models Encourage students to share and reflect on their solutions and performance

	How will you use this feedback to inform your model or solution? *How could [big idea] explain your results?*	results and their interpretations of these results
Optimization	*How will you improve your solution?* *What are the results from your retest?* *Which solution best addressed the problem?* *How could what you know about [big idea] explain what happened?*	

Context of the study

This study is part of a larger project entitled, *Science Learning through Engineering Design* Partnership and is situated within a multi-year, school and university, math and science partnership located in the Midwest region of the U.S. The primary goals of the SLED Partnership include the following: 1) build a partnership of university STEM faculty, teachers, and community partners to improve science education in grades 3-6; 2) increase the quality, quantity, and diversity of teachers who participate in the partnership; 3) develop and refine standards- and engineering design-based tasks; and 4) produce evidence-based outcomes of how teachers learn to teach science through design and how students learning science through design.

SLED teachers participate in an intensive two-week summer professional development that focuses on the integration of engineering design in the elementary/intermediate (defined here as grades 3-6) school through immersion of design experiences [10] [11]. The summer professional development is facilitated by interdisciplinary teams of university STEM faculty and practicing teachers experienced in engineering design-based pedagogies. Each design team creates, pilot tests, and revises standards-based, cognitively appropriate design experiences and then implement these tasks during the summer professional development. In addition, teachers participate in mini-workshops on lesson plan development, math and literacy connections, and assessment. Teachers submit formal, multi-day implementation plans and calendars; formative reflections on implementation expectations and anticipated challenges; and proposed action plan to address challenges. Teachers continue to participate in ongoing professional development throughout the academic year during after school and half-day follow sessions for a total of 85 hours of professional development across the calendar year.

Design experience

The grade 4 task featured in this study is Slow Boat [12]. The aim of the task was to devise a way to slow down the speed of a boat while fishing. Emphasis was placed on creating ways to add drag under or around the sides of the boat while in the water (rather than drag in the form of air resistance on the top of the boat). The primary big ideas included the relationship between energy and forces and how these ideas interact with the design of a solution to the original design problem [13]. This task also reinforced the crosscutting concept of identifying, testing, and using cause and effect relationships to explain changes students observed in the performance of their boat design solutions. In design teams, students evaluated, re-evaluated and tested their prototypes and gathered evidence to construct explanations about how well their prototypes met the needs of the original problem.

Methods

This research is a comparative case study of five elementary school teachers across three schools within the same suburban school district [14]. Each "case" is bound by the amount of time each teacher has participated in the partnership; the type of design task implemented; and by his/her school setting [14]. Due to the large amount of contact time and personnel required to conduct formal classroom observations, the research team purposefully and strategically identified five elementary school teacher participants who served as our cases of significance. This sampling was based on the following criteria: 1) each teacher participant completed full implementation of at least one design task; 2) each teacher participant and his/her students consented to all research activities; and 3) each teacher participant implemented the same design task.

The teacher participants include one male (Harold) and four female grade 4 teachers (Opal, Pam, Kate, and Tina). Pseudonyms were used to protect the anonymity of the participants. All the teacher participants were Caucasian and ranged in teaching experience from 6 to 25 years of teaching experience. Harold, Pam, Kate, and Tina had one year of experience in the partnership and had implemented at one design task within the year prior to the study.

Data collection

For each teacher, we conducted field site visits where up to two researchers observed each teacher's implementation of a multi-day engineering design-based science lesson ranging from four to seven 45-minute class sessions of instruction (n = 30 hours, total). In addition, we conducted 45-minute, semi-structured interviews at the beginning and end of each school years (n = 4 interviews, total). The teacher participants completed a comprehensive reflection prior and to after the implementation of each design experience. Lastly, the research team utilized each teacher's implementation plan as a frame of reference when preparing to conduct classroom observations, conduct semi-interviews, and analyze results.

Observations

Observers met weekly to carefully review and verify elements of their observation notes and codes. This involved a critical examination of lesson events with matching start and end times, agreement of classroom organization codes, level of engagement codes, and engineering codes (see [1] for complete observation protocol). Additional attention was given to the discrete verbal practices (e.g., directing the students to open their design notebooks) and experiences with different engineering design practices (e.g., identifying and recording the constraints, criteria, end user, and client's needs within the design problem). Lesson Event codes such as INSTR indicated instruction that the teacher provided by giving information, activating students' prior knowledge, or calling on students for their answers. Codes such as PROB DEF, CLNT, CONSTR represented engineering design codes of problem identification, client, and constraints (see Table 2). Classroom organization codes indicated how the class of students was structured during the lesson with W denoting whole class, P denoting pairs, T denoting small teams, and I indicating individual. These codes represent a subset of codes, lesson events, and classroom organization structures identified in the Engineering Design-Based Science Observation Protocol (EDSTOP) [1].

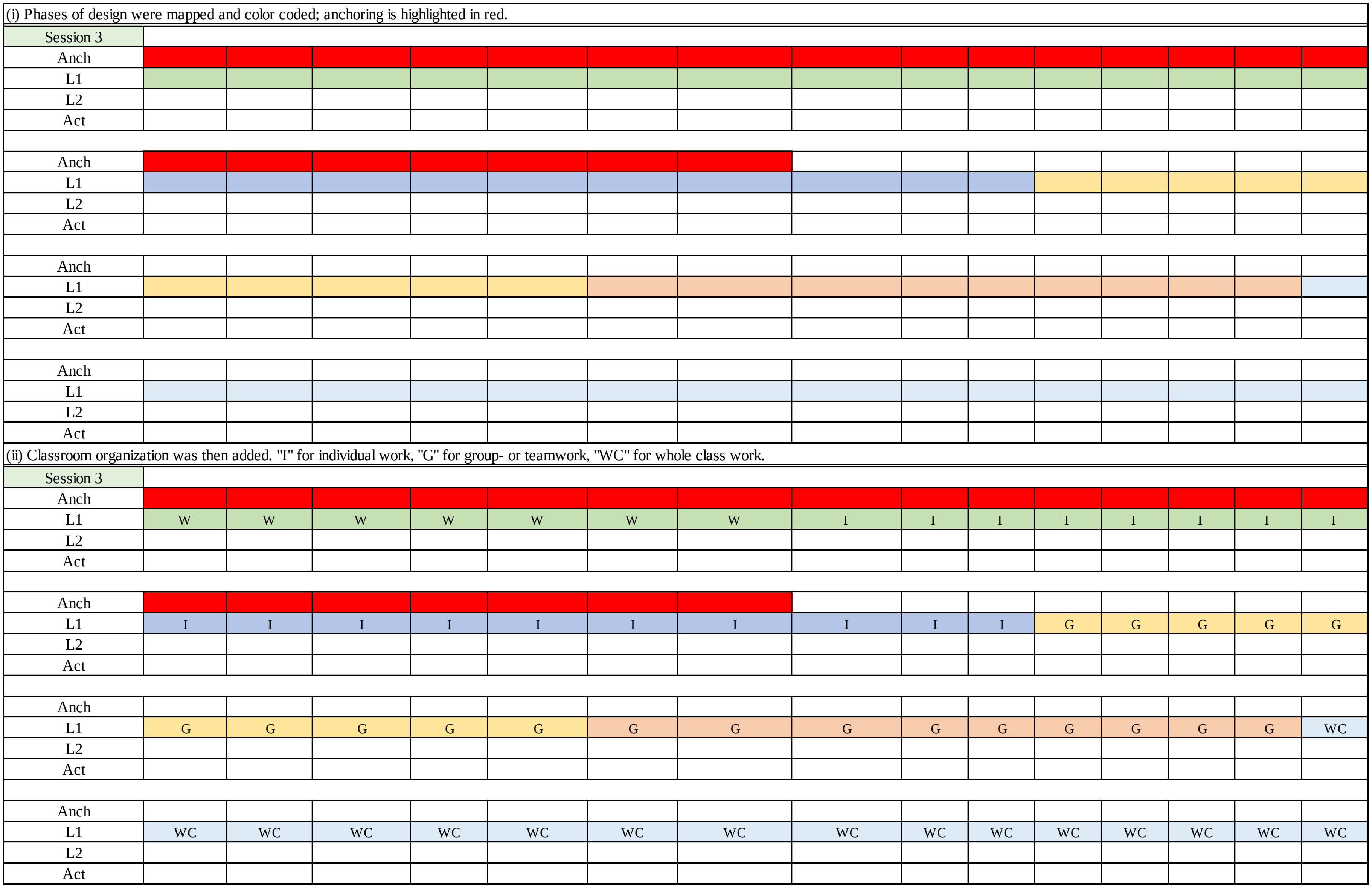
Table 2. Engineering Design-based Science Teaching Observation Protocol (EDSTOP) [1] Observation Codes and Alignment with Engineering Design literature and NGSS Framework.

Engineering Design Phase	***CODE***	***Description***	***3-5 Engineering Design (NGSS Lead States, 2013) Practices & Disciplinary Core Ideas***
Problem Scoping and Information Gathering	**CONTX**	Teacher provides the context of the problem by providing a design brief or presenting the scenario from which students will work on the task.	Asking Questions and Defining Problems *ETS1.A: Defining and Delimiting Engineering Problems* *ETS1.B: Developing Possible Solutions*
	PROB DEF	Students define the problem	
	GOAL	Students identify the goal of the problem	
	CLNT	Students identify or recognize the client	
	END USR	Students identify or recognize the end user	
	CONSTR	Students identify the constraints (i.e., time, money, materials)	
	CRIT	Students identify the criteria	
	MATLS	Students identify or acknowledge the materials	
	BRAIN **- IND** **- TM**	Students brainstorm ideas or possible solutions, individually and in a team	
	ASK	Students ask questions to clarify the problem, use of materials, and/or challenge an existing solution.	
	RES	Students gather relevant information by conducting research using electronic databases, library resources, and experts.	
Solution Formulation	**PLAN** **- IND** **- TM**	Students develop individual and team plans.	Planning and Carrying Out Investigations
	NEG	Students negotiate their ideas and finalize a unified plan	
Solution Production and Performance	**CONST**	Students carry out the development or construction of their prototypes (artifacts) or process.	
	TEST	Students test the artifact	
Communication and Documentation of Performance Results	**ANZ**	Students analyze and interpret results (data) from testing	Analyzing and Interpreting Data
	COM **-TM** **-CLASS**	Students evaluate and communicate results to another team and/or whole class	Constructing Explanations and Designing Solutions *ETS1.B: Developing Possible Solutions*
Optimization	**IMP**	Students identify one or more feature(s) to improve upon	*ETS1.C: Optimizing the Design Solution*
	REDES	Students redesign	

Data analysis

Observation data were analyzed using event mapping of core instructional practices across time and design task (see Figure 1). Data timelines offered a visual comparison of the range of activities over time as well as the approximate length of each. Segments of data for each classroom event map were classified and labeled based on explicit engineering design phases expressed in the teacher’s instruction as well as discrete instructional activities enacted by the teacher. Analysis of the observation data consisted of mapping instructional events in detail [15] [16]. We began by constructing timelines of each observation for each respective teacher and focusing on the activities and teacher’s instructional movements as they unfolded in classroom activities. The timelines offered a visual comparison of the range of activities over time as well as the approximate length of each. Segments of data for each classroom event map were classified and labeled based on explicit engineering design phases expressed in the teacher’s instruction as well as discrete instructional activities enacted by the teacher (See Figure 1). For example, when the teacher instructed students to open their design notebooks and record what the problem, criteria and constraints were, we identified the design phase as problem scoping (PS) and the instructional activity as notebooking (NB). The instructional activities, such as notebooking and reflection, represented purposeful, instructional activities designed to engage and re-engage students throughout the design process. When the teacher instructed students to share their individual plans with members of their teams, we identified the design phase as team planning and the activity as discussion.

Data from interviews and reflections were analyzed using content analysis. Triangulation of all data sets ensured confirmation of recurring patterns and emerging themes about how elementary school teachers approximate their practices with elements of ambitious engineering design-based pedagogies.

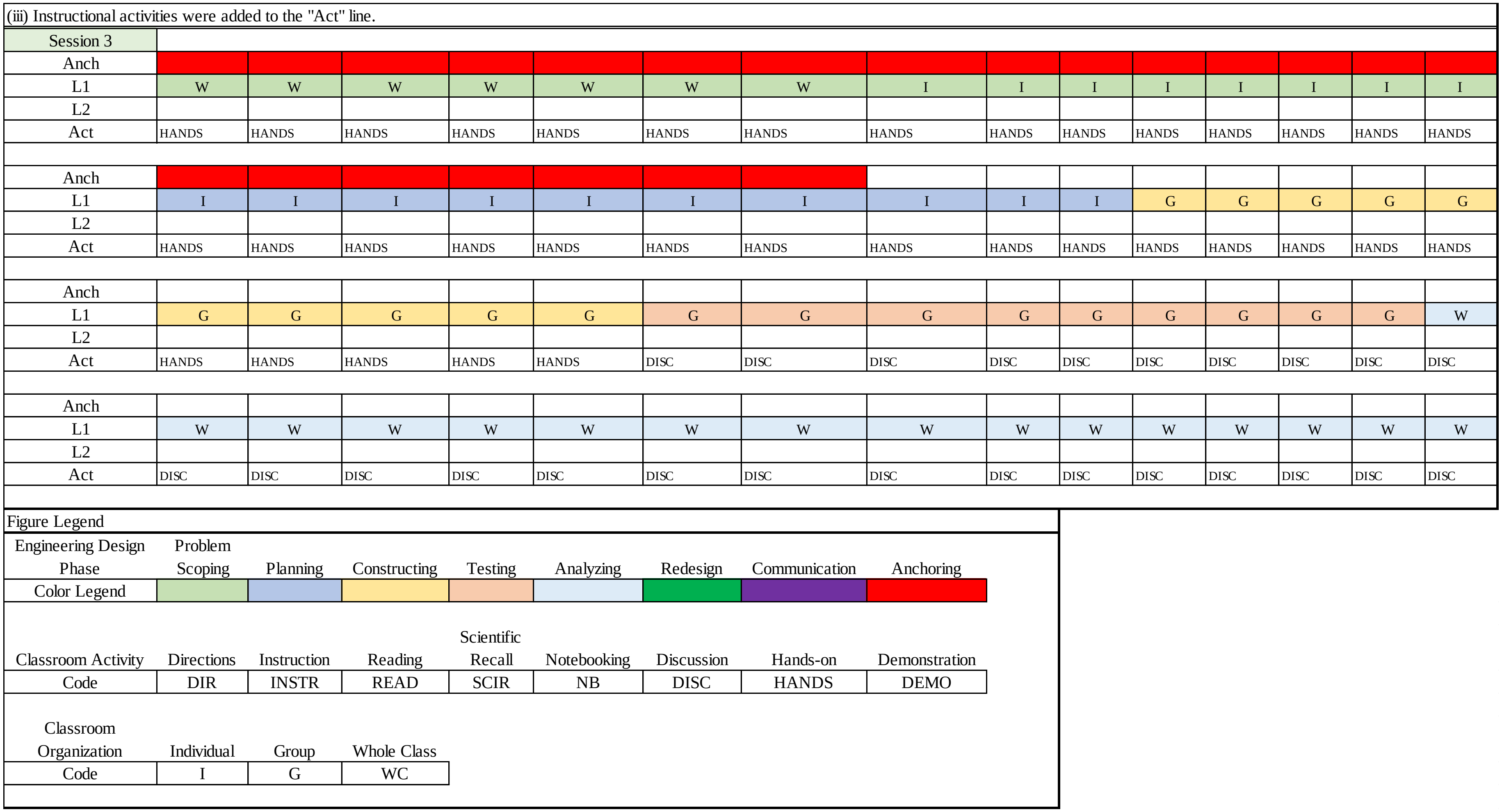


(i) Phases of design were mapped and color coded; anchoring is highlighted in red.

Session 3															
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
L2															
Act															
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥								
L1	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟨	🟨	🟨	🟨
L2															
Act															
Anch															
L1	🟨	🟨	🟨	🟨	🟨	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	▨
L2															
Act															
Anch															
L1	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
L2															
Act															

(ii) Classroom organization was then added. "I" for individual work, "G" for group- or teamwork, "WC" for whole class work.

Session 3															
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	W	W	W	W	W	W	W	I	I	I	I	I	I	I	I
L2															
Act															
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥								
L1	I	I	I	I	I	I	I	I	I	I	G	G	G	G	G
L2															
Act															
Anch															
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	WC
L2															
Act															
Anch															
L1	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC
L2															
Act															



(iii) Instructional activities were added to the "Act" line.

Session 3															
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	🟩 W	🟩 W	🟩 W	🟩 W	🟩 W	🟩 W	🟩 W	🟩 I	🟩 I	🟩 I	🟩 I	🟩 I	🟩 I	🟩 I	🟩 I
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥								
L1	🟦 I	🟦 I	🟦 I	🟦 I	🟦 I	🟦 I	🟦 I	🟦 I	🟦 I	🟦 I	🟨 G	🟨 G	🟨 G	🟨 G	🟨 G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch															
L1	🟨 G	🟨 G	🟨 G	🟨 G	🟨 G	🟧 G	🟧 G	🟧 G	🟧 G	🟧 G	🟧 G	🟧 G	🟧 G	🟧 G	⬜ W
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC
Anch															
L1	⬜ W	⬜ W	⬜ W	⬜ W	⬜ W	⬜ W	⬜ W	⬜ W	⬜ W	⬜ W	⬜ W	⬜ W	⬜ W	⬜ W	⬜ W
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC

Figure Legend

Engineering Design Phase	Problem Scoping	Planning	Constructing	Testing	Analyzing	Redesign	Communication	Anchoring
Color Legend	🟩	🟦	🟨	🟧	⬜	🟢	🟪	🟥

Classroom Activity	Directions	Instruction	Reading	Scientific Recall	Notebooking	Discussion	Hands-on	Demonstration
Code	DIR	INSTR	READ	SCIR	NB	DISC	HANDS	DEMO

Classroom Organization	Individual	Group	Whole Class
Code	I	G	WC

Figure 1. Shows the breakdown of an event map, by: (i) phase of design and anchoring, (ii) classroom organization, and (iii) instructional activities; with legend

Results and Discussion

Deconstruction

In an effort to best represent the results of teachers' enactment of high leverage practices in engineering design-based science instruction, it is important to deconstruct or "decompose" the practice. In the following section, we break down the complex practice of each teacher participant using maps of the classroom events. First, we identify the instructional activities the teacher implemented. Second, we present event maps of teachers' strategies over the course of the design task. Lastly, we discuss the ways the observed practices coincide with the nature of the design experience.

Instructional activities observed during the Slow Boat task

Table 3 represents the instructional activities enacted by the five teacher participants and identified by observers. These codes represent a subset of codes, lesson events, and classroom organization structures identified in the Engineering Design-Based Science Observation Protocol (EDSTOP) [1]. The codes describe what is happening verbally and physically in the classroom. Anchoring and notebooking were unique to the teachers' employing engineering design-based pedagogies. Anchoring occurred most often when the teacher initiated the design task by asking students one or more key questions about the design problem: What is the problem? Who is the client? Who is the end user? What are the constraints, criteria, etc.? In some cases, we observed teachers use the design brief as an instructional anchor, asking students these questions again during planning, constructing, and/or analyzing. Notebooking occurred throughout each teachers' implementation of the design task. We observed students use the design notebook as an interactive account of their design thinking.

Table 3. Observed instructional activities by five grade 4 teachers during the Slow Boat design task.

Instructional Activity	**Code**	**Description**
Anchoring	ANCH	Occurs when teacher encourages students to identify the essential features of the design problem (i.e., problem, goal, constraints, client, and end user). May occur throughout student engagement in the design problem
Demonstration	DEMO	Occurs when the teacher demonstrates actual phenomenon for students.
Directions	DIR	Occurs when teacher gives explicit direction(s).
Discussion	DISC	Occurs when students share their own ideas with each other and respond to each other's input.
Hands on	HANDS	Occurs when students independently or collectively manipulate phenomena in class or manipulate scientific instruments and can include collecting and recording data as part of this manipulation.
Instruction	INSTR	Occurs when teacher activates prior knowledge from previous lesson, calls on students for "correct answer", or provides information.
Notebooking	NB	Occurs when students write in or share notebooks to/with others.
Reading	READ	Occurs when students are reading silently or aloud.
Scientific recall	SCIR	Occurs when teacher encourages students to recall scientific information.

Frequency of instructional strategies during the Slow Boat task

After determining teachers' core instructional practices, we wanted to determine the frequency of these practices across the five teacher classrooms. Figure 2 illustrates the relative percentage of time each teacher spent using the instructional strategies. Hands on, discussion, and notebooking were common strategies each teacher employed. On the other hand, less teachers used demonstration, direct instruction, and scientific recall. We contend that this variability in implementation of design-based pedagogies across the different classrooms reflects how each teacher was approximating his/her existing practice with new instructional strategies distinct to engineering design.

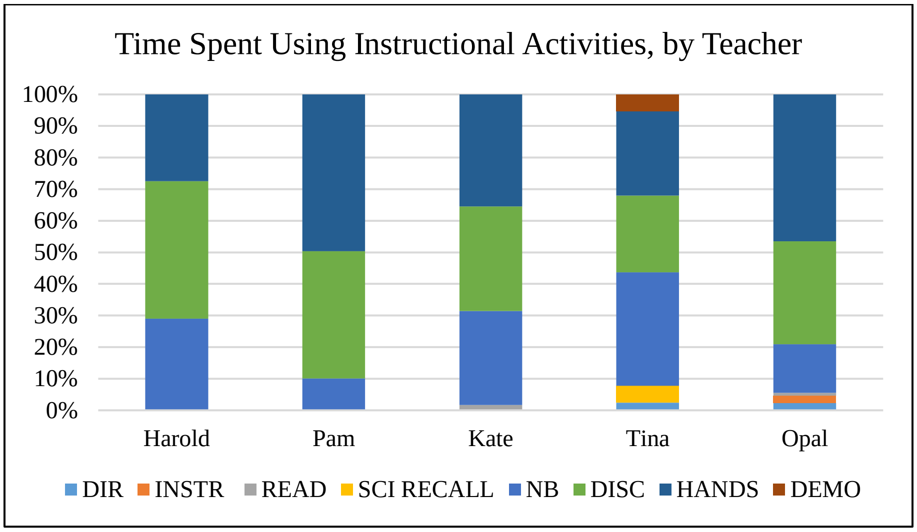
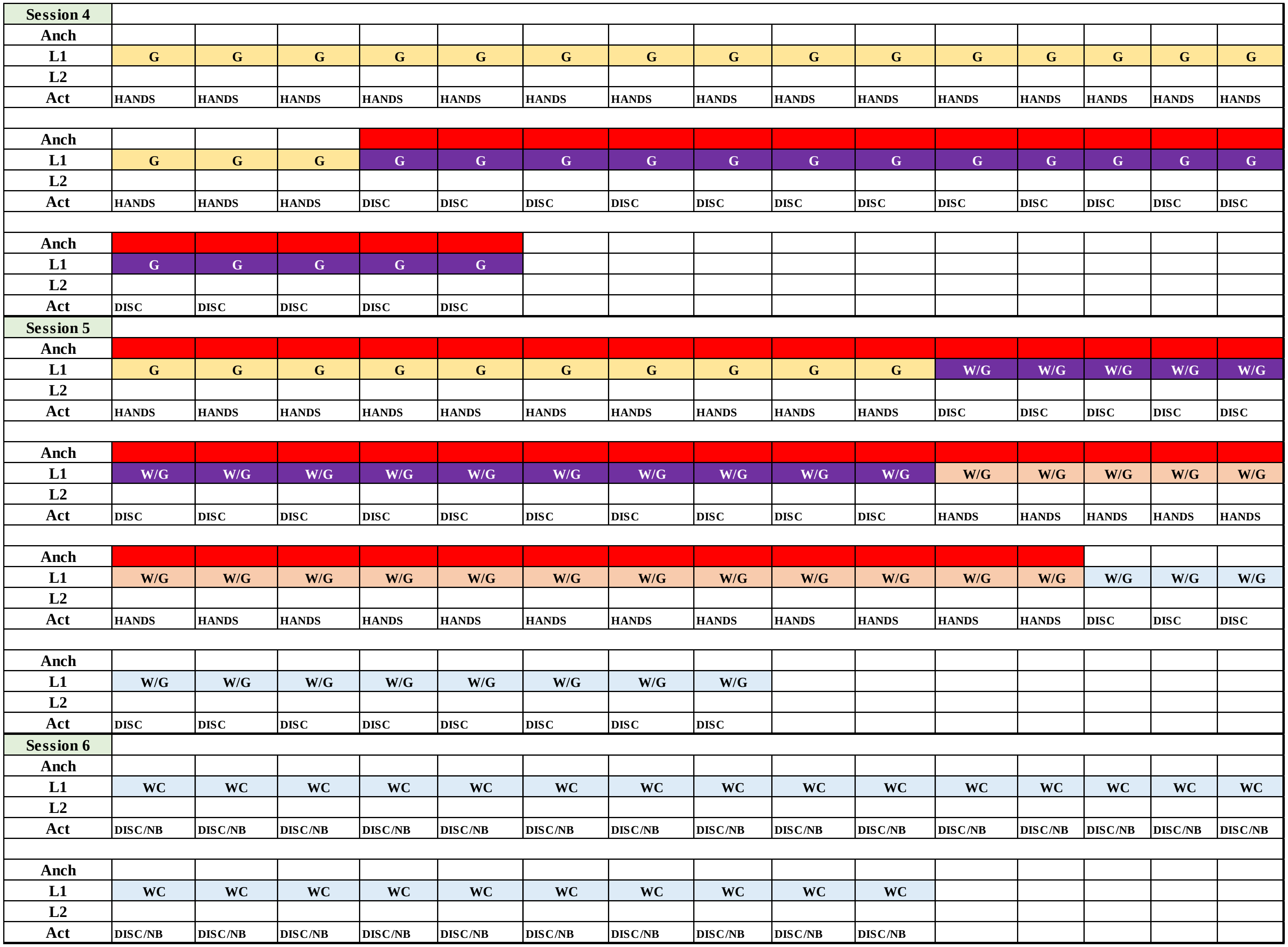


Figure 2. Relative percentage of time each teacher spent using the instructional strategies during the Slow Boat task.

Mapping teachers' approximations of instructional strategies during the Slow Boat task

To further examine teachers' approximations of engineering design-based practice, we created event maps that depict teachers' instructional moves across each phase of the engineering design task. Figure 3 illustrates Harold's lesson events across all of the design phases.

Session 1	Time (1 minute intervals)														
Anchoring															
L1	WC	WC	WC	WC	WC	I	I	I	I	I	I	I	I	I	I
L2															
Activity	DISC	DISC	DISC	DISC	DISC	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB
Anch															
L1	I	I	I	I	I	I	I	I	I	I					
L2															
Act	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB					
Session 2															
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
L2															
Act	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	I	I	I	I	I	I	I	I	I	I	I	I	G	G	G
L2															
Act	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	DISC	DISC	DISC
Anch	🟥	🟥	🟥	🟥	🟥										
L1	G	G	G	G	G										
L2															
Act	DISC	DISC	DISC	DISC	DISC										
Session 3															
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥			
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	HANDS	HANDS	HANDS
Anch															
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch															
L1	G	G	G	G	G										
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS										



Session 4															
Anch															
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch				🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	HANDS	HANDS	HANDS	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC
Anch	🟥	🟥	🟥	🟥	🟥										
L1	G	G	G	G	G										
L2															
Act	DISC	DISC	DISC	DISC	DISC										
Session 5															
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	G	G	G	G	G	G	G	G	G	G	W/G	W/G	W/G	W/G	W/G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	DISC	DISC	DISC	DISC	DISC
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	HANDS	HANDS	HANDS	HANDS	HANDS
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥			
L1	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	DISC	DISC	DISC
Anch															
L1	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G							
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC							
Session 6															
Anch															
L1	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC
L2															
Act	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB
Anch															
L1	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC					
L2															
Act	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB	DISC/NB					

Figure 3. Event map of Harold’s Implementation of the Slow Boat design task.

Results from Harold's event map indicate that notebooking, discussion, and hands-on were instructional strategies used throughout his implementation of the design task. Harold employed anchoring during individual and team planning, communication, and analysis. These results suggest that Harold used multiple instructional activities across each phase while progressing through the entire design process.

This map was distinctly different from other maps (See Appendix A for event maps). For example, Opal also progressed through an entire cycle of the design process but used a wider range of instructional activities (Figure 2). Tina also utilized various instructional activities, but did not allow students time to communicate their designs (Appendix A). Pam's enactment was similar (no time for communication), yet she employed a narrower range of instructional strategies. Kate used a limited number of instructional strategies as well, while having students communicate their designs *before* testing them. Collectively, these trends reinforce our claim that teachers are approximating their practice.

Distribution of instructional strategies during the Slow Boat task

After reviewing teachers' event maps, we questioned *when* teachers employed the instructional activities and if they were possibly giving priority to one or more strategies during specific phases of the engineering design process. Figure 4 shows the relative distribution (usage) of instructional activities during each phase of the engineering design process. Results illustrate that strategies, such as hands on, were used predominantly during constructing, testing and redesign while discussion was used mainly during analysis and communication. Notebooking was used primarily during problem scoping and planning. These results suggest that teachers strategically used novel instructional strategies during discrete phases of the design process. Phases, such as problem scoping and planning illustrated the greatest variability in usage of instructional strategies. These trends prompted us to question the extent to which teachers' approximations with these instructional activities aligned with the nature of the design task.

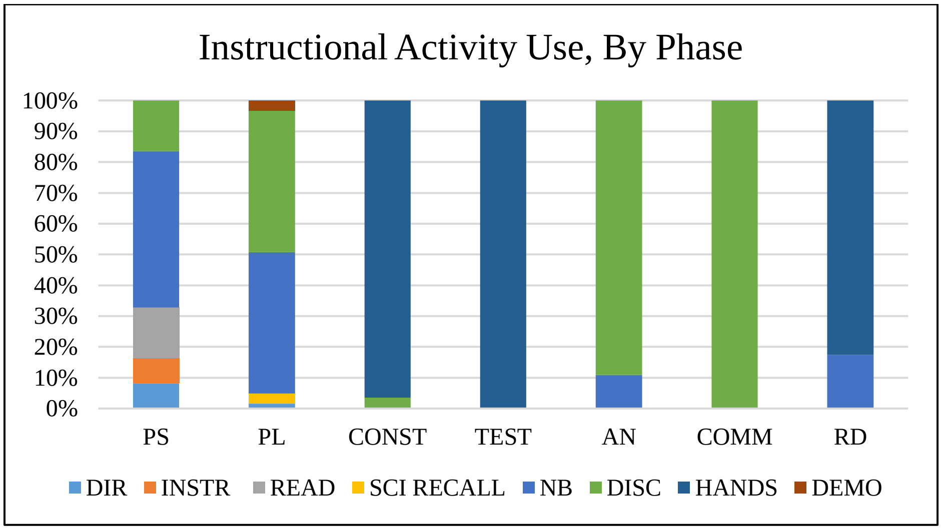


Figure 4. Relative distribution of instructional activities by teachers during the Slow Boat task.

Relationship of teachers' instructional activities and the nature of the design task

When examining teachers' approximations with engineering design-based science teaching, the nature of a given design task must be considered [17]. In this study, the Slow Boat task was developed whereby emphasis was based on testing, analysis, communication, and redesign. Students were required to develop and test a prototype that would increase underwater drag to slow down the boat. This is a relatively open-ended design task resulting in multiple solutions. Testing consists of running the boats in real-time (in small tubs in the classroom), yielding a range of data (e.g. boat times and speeds). All prototypes provide data points (run times) regardless how designs perform, providing a rich opportunity for students to reflect upon and discuss their designs as they relate to their performance. Furthermore, given the range of possible solutions and data, design teams can optimize their prototypes, hence, providing more opportunity for hands-on engagement.

Based on these specific features, the research hypothesized that teachers' instructional strategies would correlate with these features. Testing the boat in the water, for example, would correlate well with the use of hands-on instruction and/or a verbal explanation of students' designs. Recording and analyzing a large amount of data and wide-ranging solutions would be reflected by notebooking and discussion. Communication of test results would be facilitated via teacher-student discussion or in the students' own notebooks. Engaging in redesign would call for re-sketching and re-construction using a combination of notebooking and hands-on instructional strategies.

Based on our analysis of teachers' event maps and a comparison of these results with the design features of the task, we concluded that teachers used instructional practices such as hands-on instruction, discussion, and notebooking more often during key phases that corresponded to the nature of the task. Furthermore, results from teacher interviews and reflections indicated that teachers were purposeful in *how* and *when* they utilized instructional activities within phases. For example, teachers facilitated whole class discussions during the analysis of data and when students were communicating their designs. Teachers also implemented hands-on activities in connection with testing and redesigning students' boats (e.g. testing and redesign) more often than other phases. Notebooking was purposefully utilized during the creation of design sketches and data collection (e.g. planning; analysis; redesign).

In short, the teachers' instructional activities were analogous to the essential engineering practices inherent in the Slow Boat design task. As a result, teachers in this study were effectively enacting elements of ambitious engineering design-based science teaching [1]. Compared with previous reform-based science instruction, these core instructional practices were novel strategies and distinct to engineering design-based science instruction (e.g. notebooking; discussion; hands-on instruction) [1, 13].

Conclusion and implications

The aim of this study was to examine and characterize how elementary school teachers approximated their engineering design-based science instruction by deconstructing elementary teachers' implementation of a standards- and engineering design-based science task. Results indicated that fourth grade teachers in this study used a range of instructional strategies, including discussion, notebooking, and hands on activities. Results demonstrated that teachers' approximations aligned directly to the content, goals, and implicit nature of the design task, as well as to the structure and complexity of their teaching practice.

While instructional activities differed across teacher classrooms, teachers in this study organized these activities by design phases, thereby, exhibiting deliberate approximations of their practice. Furthermore, while variation in strategies occurred during problem scoping and planning, teachers' choices of instructional activities aligned well with the design practices required by the design task. This suggests that teachers are noticing and responding strategically to students' needs as they worked collaboratively through the design process. This is indicative of the tenets of ambitious engineering design-based science teaching [1].

It is important to consider the limitations of the study. One limitation is the emphasis placed on collecting data relative to one engineering design task. Additional studies might include teachers' enactment of multiple design tasks and examining trends among teachers' instructional moves across different design experiences. A second limitation is the sampling of teacher participants. Unlike quantitative research that advocates for random sampling or selection of a large number of participants and sites, we purposefully selected participants who implemented the same design task so that we could maximize the opportunity to observe the complete enactment of one task across multiple classrooms. However, attention could be given to broadening the sample size and selection criteria to include a larger and more diverse sample of teacher participants. The last limitation is the challenge we faced as researchers with effectively representing the overlap of teacher moves and instructional strategies among multiple design phases. This often took place when teachers instructed student teams to present their designs. Students were not only testing their designs and communicating their results, but also analyzing the performance of their designs. To address this challenge, we added multiple rows within our event maps to account for different classroom organizational structures, instructional strategies, and classroom events when constructing our event maps [10].

This leads us to several implications of the study. Our results complement existing studies that claim teachers should possess an adaptiveness and disposition to work within ill-defined design parameters [19]. This means that both science and engineering teacher educators need to invest in more systematic experimentation with the instructional activities and associated high leverage practices presented in this study so that practicing teachers can gain the knowledge, skills and disposition necessary to approximate their engineering design-based instruction. As in any simplification of practice required for approximations, the nature of the simplification matters. How teachers are exposed to and engage in engineering design-based science instruction must be calibrated accordingly. In this study, we provide a durable framework of instructional activities that can provide novice teachers and teacher educators multiple opportunities to enact in their professional development experiences and in their classrooms.

Lastly, results in this study suggest a shift in research on engineering pedagogies of enactment. Previous studies have placed emphasis on the valuable role pedagogical content knowledge plays in teachers' enactment of engineering practices [19] [22] – [24]. To extend this research, we advocate for an alternative yet complementary perspective. Engineering education researchers may focus more on the discrete core practices employed by teachers and monitor how teachers navigate through these novel strategies as well as how students actively respond to these practices. This may invite a focus on how teachers' approximations change or are sensitive to different design contexts, including types of design tasks, populations of students, or time allotted to implement design tasks in their classrooms. Subsequently, researchers can identify the challenges teachers encounter and the risks teachers take to create new proactive and reflective dimensions of engineering design-based science teaching.

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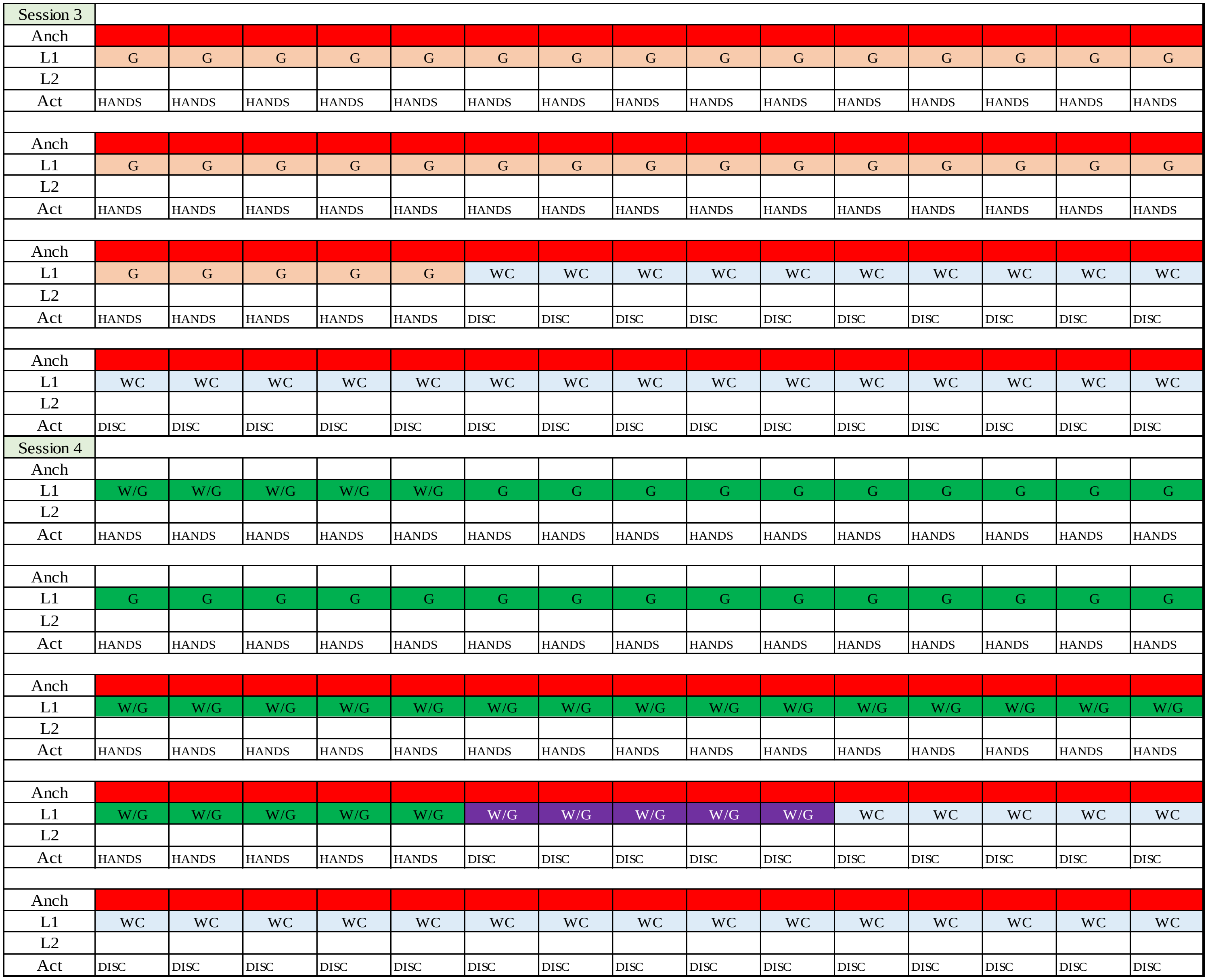
Appendix A

Event maps for Opal, Tina, Kate, and Pam’s enactment of the Slow Boat engineering design task in their classrooms

Session 1	Time (1 minute intervals)														
Anchoring															
L1	W	W	W	W	W	W	W	I	I	I	I	I	I	I	I
L2															
Activity	INSTR	INSTR	INSTR	INSTR	INSTR	READ	READ	NB	NB	NB	NB	NB	NB	NB	NB
Anch															
L1	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
L2															
Act	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB
Anch															
L1	I	I	I	I	I	I	I	I	I	I					
L2															
Act	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB					
Session 2															
Anch						🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	W	W	W	W	W	G	G	G	G	G	G	G	G	G	G
L2															
Act	DIR	DIR	DIR	DIR	DIR	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	DISC	DISC	DISC	DISC	DISC	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch	🟥	🟥	🟥	🟥	🟥										
L1	G	G	G	G	G	WC	WC	WC	WC	WC					
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	DISC	DISC	DISC	DISC	DISC					



Session 3															
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	G	G	G	G	G	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC
Session 4															
Anch															
L1	W/G	W/G	W/G	W/G	W/G	G	G	G	G	G	G	G	G	G	G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch															
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	WC	WC	WC	WC	WC
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC

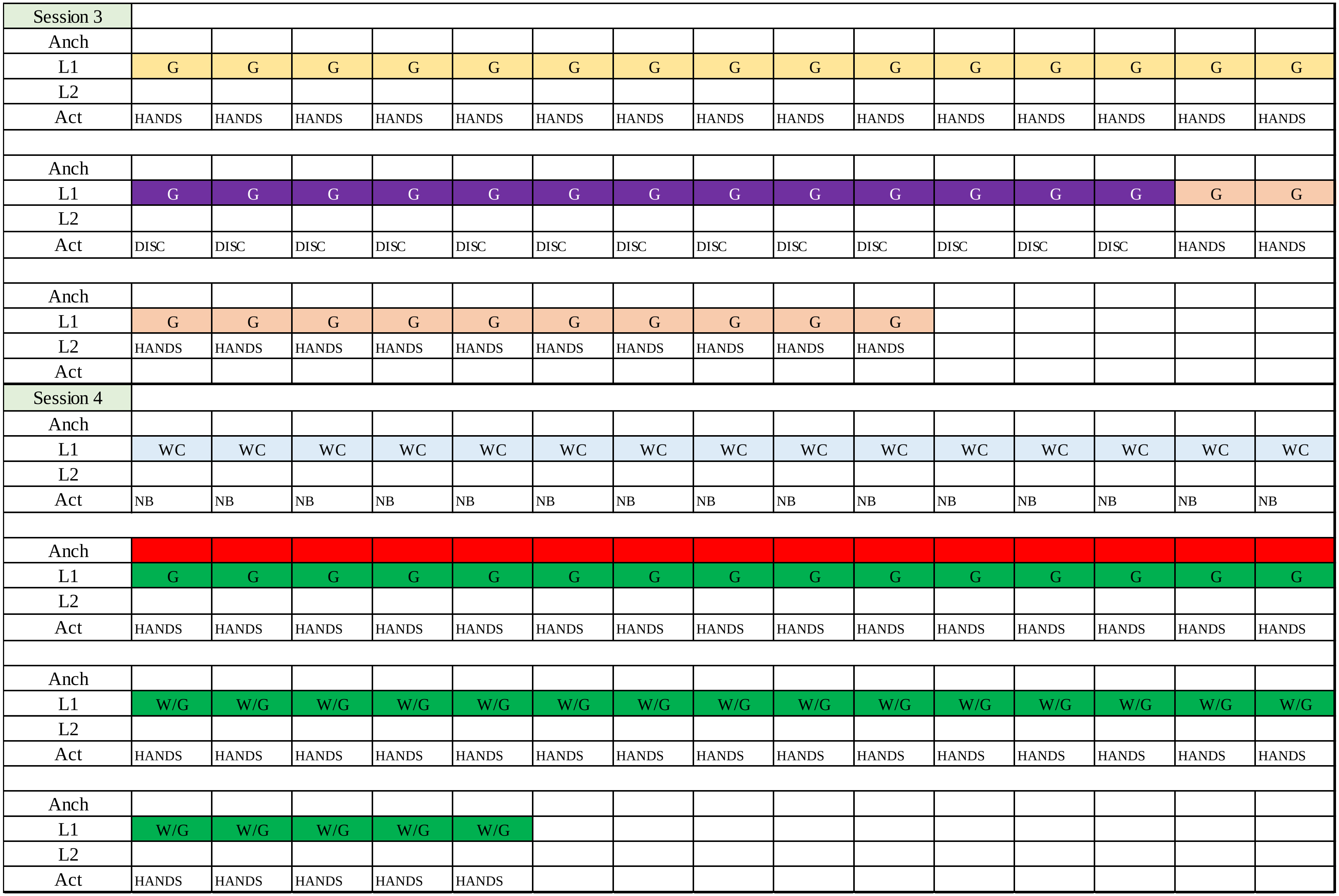
Figure A1. Shows Opal’s enactment of Slow Boat.

Session 1	Time (1 minute intervals)														
Anchoring															
L1	W	W	W	W	W	I	I	I	I	I	I	I	I	I	I
L2															
Activity	DIR	DIR	DIR	DIR	DIR	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB
Anch															
L1	I	I	I	I	I	I	I	I	I	I					
L2															
Act	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB					
Session 2															
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
L2															
Act	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥					
L1	I	I	I	I	I	I	I	I	I	I					
L2															
Act	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB					
Session 3															
Anch															
L1	W	W	W	W	W	W	W	W	W	W	W	I	I	I	I
L2															
Act	DEMO/SCI RECALL	DEMO/SCI RECALL	DEMO/SCI RECALL	DEMO/SCI RECALL	DEMO/SCI RECALL	DEMO/SCI RECALL	DEMO/SCI RECALL	DEMO/SCI RECALL	DEMO/SCI RECALL	DEMO/SCI RECALL	DEMO/SCI RECALL	NB	NB	NB	NB
Anch															
L1	I	I	I	I	I	G	G	G	G	G					
L2															
Act	NB	NB	NB	NB	NB	DISC	DISC	DISC	DISC	DISC					
Session 4															
Anch															
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC
Anch															
L1	G	G	G	G	G	G	G	G	G	G					
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC					

Session 5															
Anch															
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Session 6															
Anch															
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch															
L1	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch															
L1	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G					
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS					
Session 7															
Anch															
L1	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC
Anch															
L1	WC	WC	WC	WC	WC	I	I	I	I	I	I	I	I	I	I
L2															
Act	DISC	DISC	DISC	DISC	DISC	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB
Anch															
L1	I	I	I	I	I	I	I	I	I	I					
L2															
Act	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB					

Figure A2. Event map showing Tina’s enactment of the Slow Boat design task.

Session 1	Time (1 minute intervals)														
Anchoring				🟥	🟥	🟥	🟥	🟥							
L1	W	W	W	W	W	W	W	W	I	I	I	I	I	I	I
L2															
Activity	READ	READ	READ	DISC	DISC	DISC	DISC	DISC	NB	NB	NB	NB	NB	NB	NB
Anch															
L1	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
L2															
Act	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB
Anch															
L1	I	I	I	I	I										
L2															
Act	NB	NB	NB	NB	NB										
Session 2															
Anch															
L1	I	I	I	I	I	I	I	I	I	I	G	G	G	G	G
L2															
Act	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	DISC	DISC	DISC	DISC	DISC
Anch															
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC
Anch															
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC
Anch															
L1	G	G	G	G	G										
L2															
Act	DISC	DISC	DISC	DISC	DISC										



Session 3															
Anch															
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch															
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	HANDS	HANDS
Anch															
L1	G	G	G	G	G	G	G	G	G	G					
L2	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS					
Act															
Session 4															
Anch															
L1	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC	WC
L2															
Act	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch															
L1	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch															
L1	W/G	W/G	W/G	W/G	W/G										
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS										

Figure A3. Shows Kate’s enactment of the Slow Boat design task.

Session 1	Time (1 minute intervals)														
Anchoring															
L1	W	W	W	W	W	I	I	I	I	I					
L2															
Activity	READ	READ	READ	READ	READ	NB	NB	NB	NB	NB					
Session 2															
Anch															
L1	I	I	I	I	I	G	G	G	G	G	G	G	G	G	G
L2															
Act	NB	NB	NB	NB	NB	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC
Anch															
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC
Anch															
L1	G	G	G	G	G										
L2															
Act	DISC	DISC	DISC	DISC	DISC										
Session 3															
Anch															
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch											🟥	🟥	🟥	🟥	🟥
L1	G	G	G	G	G	G	G	G	G	G	W/G	W/G	W/G	W/G	W/G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥					
L1	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G	W/G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	DISC	DISC	DISC	DISC	DISC
Anch															
L1	W/G	W/G	W/G	W/G	W/G	W/G									
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC									

Session 4															
Anch											🟥	🟥	🟥	🟥	🟥
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	NB	NB	NB	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS
Anch	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥			
L1	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
L2															
Act	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	HANDS	DISC	DISC	DISC
Anch															
L1	G	G	G	G	G	G	G	G							
L2															
Act	DISC	DISC	DISC	DISC	DISC	DISC	DISC	DISC							

Figure A4. Shows Pam’s enactment of the Slow Boat design task.