EXAMINING DESIGN KNOWLEDGE AND PRACTICE AMONG STEM FACULTY-DESIGNERS USING VISUAL LESSON BLUEPRINTS

by

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ABSTRACT

KIRAN BUDHRANI. Examining Design Knowledge and Practice Among STEM Faculty-Designers Using Visual Lesson Blueprints.
(Under the direction of DR. FLORENCE MARTIN)

Attention is being given to improving the design of undergraduate gateway courses (i.e., entry-level, introductory) in the fields of science, technology, engineering, and mathematics (STEM), particularly those facing challenges of large enrollment and high failure rates. Effective course design has been noted as a key strategy for improving the quality of higher education teaching. The science of design has a goal of studying how people design, what they design, and what knowledge is drawn upon during design work. This embedded case study systematically investigated how faculty design knowledge influences design practice. Three faculty individually participated in a 6-hour course modeling workshop and used the Learning Environment Modeling (LEM) toolkit to generate 13 visual lesson blueprints while engaging in design discussions and interviews. A two-phased, hybrid inductive-deductive analysis approach was used for data collection, data preparation, and data analysis. Results discuss the (1) the variety, frequency, and distribution of lesson elements in visual lesson blueprints, (2) six “design patterns of practice” emergent among activity sequences and lesson sequences; (3) the 18 contextual factors that influence STEM faculty design decisions, and (4) granularity and scale as two key influencers to faculty design knowledge and design practice. The findings of this study contribute to existing literature on STEM faculty design knowledge and design practice examined through visual lesson blueprints and design toolkits. The study offers implications to qualitative and visual research methods as well as to university centers for teaching and learning as key stakeholders in supporting faculty as designers.

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helping me weave a coherent methodology that combines an authentic design workshop for faculty with a reliable data collection process for the dissertation study. Your expertise and feedback at various stages of my dissertation helped improve my thinking, writing, and perspectives on instructional design and faculty development; the red pen markings were needed and went a long way. Thank you for truly supporting me from day one and recognizing those days when I needed encouragement or help connecting the dots.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

STEM	Science, Technology, Engineering, and Math
LEM	Learning Environment Modeling
LEML	Learning Environment Modeling Language
SF	Student frame
TF	Teacher frame
CF	Course frame
LEF	Learning environment frame
IF	Institutional frame
DF	Disciplinary frame

CHAPTER 1: INTRODUCTION

1.1 Faculty as Designers

Attention is being given to improving the design of undergraduate gateway courses (i.e., entry-level, introductory) in the fields of science, technology, engineering, and mathematics (STEM) (Auerbach & Andrews, 2018; Beach et al., 2012; Dass, 2015; Freeman et al., 2011, 2014; Henderson et al., 2011; Koproske, 2017; Leibovich et al., 2017; Weaver et al., 2015). Universities have ignited course redesign efforts among departments and faculty, with a push to incorporate more relevant pedagogical approaches to increase student success and graduation rates, particularly in STEM gateway courses where students have large enrollment and high failure rates. Gateway courses show failure rates as high as 30 to 60 percent, creating obstacles on retention and time-to-degree completion (Koproske, 2017). High attrition, low motivation, and low enrolment continue to be big challenges for STEM higher education (Sithole et al., 2017).

Effective course design has been noted as a key strategy for improving the quality of higher education teaching (Goodyear, 2015; Laurillard, 2012). A review of STEM literature found that compared to traditional lecturing, undergraduate students perform better in courses that use active, collaborative, cooperative, and problem-based teaching approaches (Auerbach & Andrews, 2018; Beetham, 2013; Blanchard et al., 2010; Chen et al., 2018; Dehbozorgi et al., 2018; Freeman et al., 2014; Knight & Wood, 2005; Prince, 2004; Prince & Felder, 2006). Shifting from passive learning to active, hands-on learning reduces attrition among undergraduate students in STEM (Mervis, 2010). It has been suggested that higher education institutions must take a more active role in promoting change in faculty practice and faculty beliefs about design (Antunes et al., 2021). Higher education institutions need to become more design-savvy and build design capacity among faculty to ensure large-scale, sustainable change such that the institution becomes a “congenial home for design” (Goodyear, 2015, p. 37).

As design evolved into a formal profession, it has garnered a workforce of design professionals in various fields including higher education. Pedagogical and technological innovations have influenced the roles of faculty to expand from teaching, research, and service, into the role of a *designer* (Beetham & Sharpe, 2013; Reigeluth, 2011). In this research, a faculty who enacts the role of a course designer is denoted as a “faculty-designer.” The reference to the role of faculty as designers in higher education is still unfamiliar. Many faculty “do not know how to design” (Conole, 2013, p. 102) nor know how to engage in a productive design process. It is an undeveloped, yet necessary skill for faculty. However, course design is becoming a core, natural, and routine work that faculty perform as part of their professional practice (Dalziel et al., 2016; Goodyear, 2015; O’Donnell, 2008).

Design work is often initiated by a design need: to maintain or review courses, to improve or re-design existing courses, or to create new courses (Bennett et al., 2011; Laurillard et al., 2013; Stark, 2000). As faculty are involved in the constant design or redesign process, they are essentially in an ongoing loop of being *designerly* (Cross, 2011; Goodyear & Dimitriadis, 2013; Newstetter et al., 2001), where they are thinking about course design or performing some type of course improvement. Faculty have the responsibility to be intentional in their course design (Subramanian & Budhrani, 2020), however, higher education courses are challenging because they are content-heavy, dependent on prerequisites, contain a wide range of activities and assessments, sequenced over multiple lessons, spanning multiple months.

It is not surprising that researchers often refer to the design process as a multi-layered, fuzzy, complex, messy, ill-defined, and wicked process (Masterman, 2013; Masterman & Manton, 2011). Design is often felt as an ambiguous problem-solving mental process that lives purely in the mind of the faculty (Falconer & Littlejohn, 2009; Gibbons & Rogers, 2009; Sanders, 2008). It is an internal, siloed process that starts and ends with the faculty themselves. Design decisions made throughout the design process are *invisible* and left as *tacit* design knowledge (Carvalho & Goodyear, 2014; Dodd, 2016; Dodd & Gillmore, 2018).

Under the larger umbrella of the field of learning design, design artifacts (e.g., blueprints), design representations, and modeling toolkits have attracted renewed attention, placing a focus on supporting course design work among faculty-designers (Nguyen & Bower, 2018; Stefaniak et al., 2022). Blueprints are central to the work of professional designers and these require high levels of modeling skills such as problem framing, ideation, modeling and manipulation, communication, planning and organizing, testing and evaluation (Shepard, 2017). Lesson blueprints (Dodd, 2016, 2018, 2019; Dodd & Gillmore, 2018; iLED, 2017) have been used in higher education by instructional designers, but less by faculty. The role of a lesson blueprint is to "capture pedagogy" (Dalziel et al., 2016, p. ix), essentially to model and codify faculty pedagogical plans visually so that it can be documented, communicated, shared, revised, or reused (Britain, 2006; Falconer & Littlejohn, 2009; Persico & Pozzi, 2015). In effect, modeling lesson blueprints can help make design knowledge *explicit* and design practices *visible*.

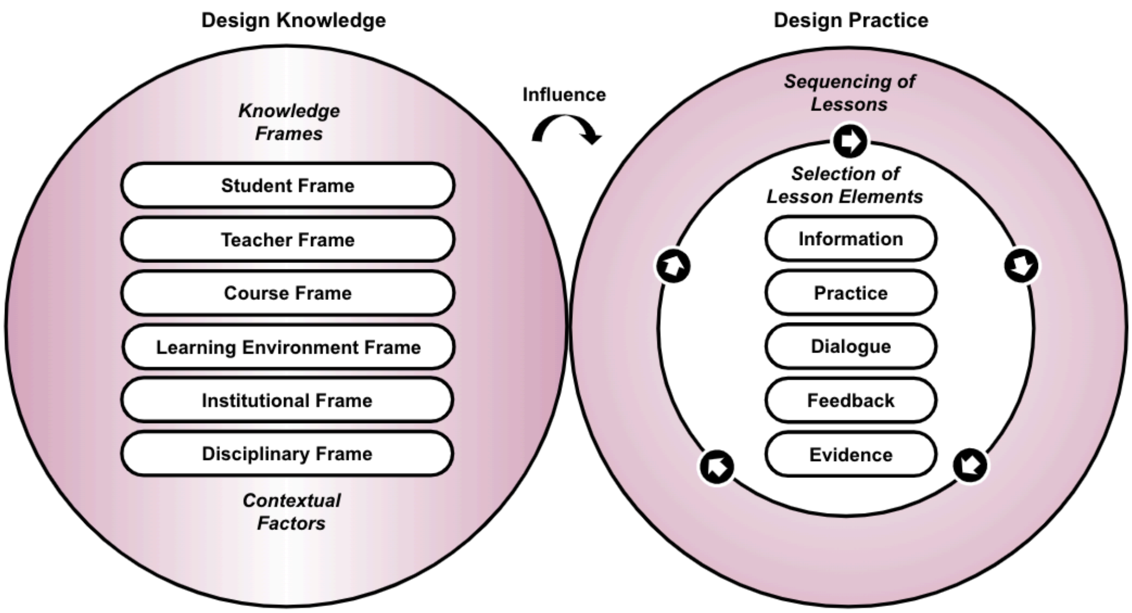
1.2 Conceptual Framework

The *science of design* (Cross, 2006; Goodyear & Dimitriadis, 2013; Newstetter et al., 2001) has a goal of studying how people design, what they design, and what knowledge is drawn upon during design work. This research study examines how faculty design knowledge influences their design practice through visual lesson blueprints. As faculty engage in course design work, they undertake cognitive acts of design thinking and utilize *design knowledge* (Bennett et al., 2018; McKenney et al., 2015a). The epistemic knowledge model of Markauskaite and Goodyear (2014) is adapted for this study, which describes design knowledge as the pieces of knowledge that are mentally activated when working on design tasks (Goodyear & Markauskaite, 2009). Design knowledge is examined in two constructs: knowledge frames and contextual factors. Knowledge frames are defined as the mental frames of reference that faculty-designers think about or consider when engaged in a design process while contextual factors refer to the rationale that drive design decisions (Hammer & Elby, 2002; Kali, Goodyear, et al., 2011; Markauskaite & Goodyear, 2014). Six knowledge frames were adapted from the research of Markauskaite and Goodyear (2014) including: (1) student frame (SF), (2) teacher frame (TF), (3) course frame (CF), (4) learning environment frame (LEF), (5) institutional frame (IF), and (6) disciplinary frame (DF) (see Figure 1).

Design practice is examined as the design tasks that faculty-designers partake in during lesson design, specifically: selection of lesson elements and sequencing of lessons. Applying the Learning Environment Modeling Language (LEML) from the LEM toolkit, this study denotes lesson elements as the five core building blocks which can be modeled to represent lesson sequences in visual blueprints. Information (I), Dialogue (D), Feedback (F), Practice (P), and Evidence (E) (iLED, 2017).

Figure 1

Conceptual Framework on Design Knowledge and Design Practice



1.3 Research Purpose

Multiple researchers have investigated faculty design knowledge and practice in higher education, looking into how faculty design lessons, why they make certain design decisions in their courses, and what informs their design thinking (Agostinho et al., 2018; Bennett et al., 2008, 2011, 2015, 2017, 2018; Bibi et al., 2012; Cameron, 2017; Goodyear, 2015; Goodyear et al., 2010; Goodyear & Markauskaite, 2009; Hativa & Goodyear, 2002; Markauskaite & Goodyear, 2014; Masterman, 2013; Nguyen & Bower, 2018; Stark, 2000, 2002). Empirical evidence is emergent at macro-design perspective (i.e., mapping course goals, content, activities, assessments, materials) but significant work is needed to build a comprehensive knowledge base on how faculty design knowledge influences design practice at a micro-design perspective (i.e., lesson elements and lesson sequencing). Common understanding about faculty design knowledge and practice have been classified between "teacher-centered" and "student-centered" conceptions, however additional axes of pedagogical conceptions need to be explored based on the context faculty are situated in (Markauskaite & Goodyear, 2014).

Additionally, various research methods have been applied to elicit design knowledge and practices among faculty such as retrospection interviews (Agostinho et al., 2018; Bennett et al., 2008, 2011, 2016, 2017; Brogt, 2009); think aloud sessions (Goodyear & Markauskaite, 2009; Markauskaite & Goodyear, 2014), observations in routine or natural settings (Jones, 2015; Prince & Felder, 2006; Smith et al., 2013); and teacher logs (Glennie et al., 2017). There is minimal research that examines how design knowledge influences design practice in visual blueprints among STEM faculty as they select lesson elements and sequence lessons.

Given this, the purpose of this study is to examine how design knowledge influences design practice among STEM faculty-designers through visual lesson blueprints. The following research questions are posed:

1. Design Practice: How do STEM faculty-designers select lesson elements and sequence lessons in visual lesson blueprints?
2. Design Knowledge: How do knowledge frames and contextual factors influence STEM faculty-designers as they engage in lessons design?

1.4 Methodology

1.4.1 Research Design

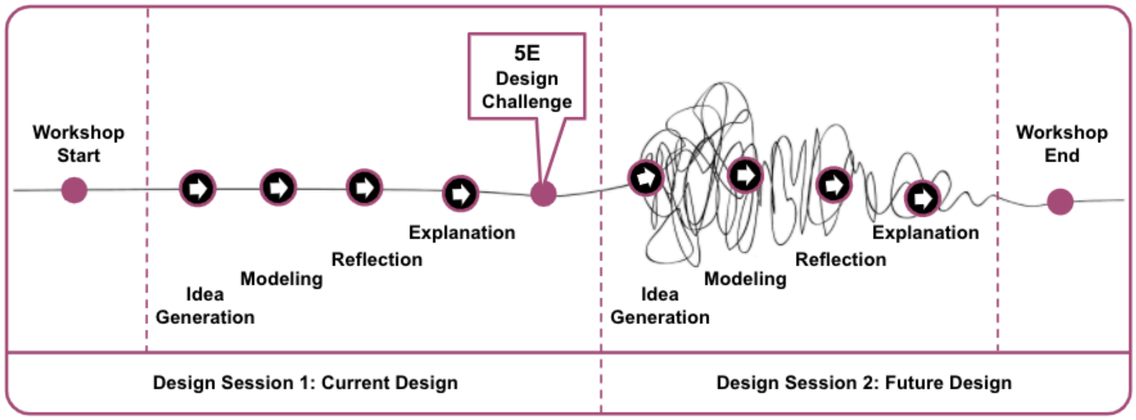
This qualitative research applied an embedded case study design (Yin, 2014) to examine how design knowledge influences design practice among STEM faculty-designers within the context of a south-eastern university. Yin (2014) indicates that the distinctive need for case study research is to focus on drawing real-world perspectives on small group behavior. The "case" in this study is denoted by university faculty who were engaged in a course modeling workshop to redesign STEM gateway courses.

1.4.2 Research Procedure

This research employed a workshop format. The course modeling workshop included two design sessions with a 4-step design process of idea generation, modeling, reflection, and explanation to allow for deep design discussions between the faculty-designer and the researcher (who also served as the workshop facilitator) (see Figure 2). Design session 1 (3 hours) began with an orientation and consultative pre-interview to build rapport between the researcher and faculty-designer and to gain a deeper understanding of the faculty design experience, teaching experience, and the course selected for redesign. The pre-interview was followed by the four steps of the design process, requiring the faculty-designer to focus on modeling a "current lesson design" through visual lesson blueprints. Design session 2 (3 hours) was scheduled on a different day and required the faculty to apply the 5E learning cycle as a design challenge to modify or improve their lessons. The faculty similarly followed the four steps of the design process with a focus on modeling a "future lesson design." Semi-structured interviews were conducted as a culmination activity of design session 2.

Figure 2

Course Modeling Workshop Design



A workshop format was selected for several reasons. First, it allowed the researcher to be situated in multiple, real-life, interactive design sessions with faculty. Through this, the researcher could examine faculty design activities over several design iterations. Second, a modeling workshop with visual lesson blueprints allowed the researcher to gain extensive and thorough reflections and explanations as close as possible to the design event. Lastly, the workshop format allowed the researcher to gather a combination of textual, verbal, and visual data sources for the research study.

1.4.3 Research Participants

A purposive sample (Creswell, 2013) of three STEM faculty participated in the course modeling workshop. After having received IRB approval, a letter of invitation was sent to select STEM faculty teaching gateway courses at a south-eastern university, requesting their participation. The selection criteria included faculty who:

(1) Are planning to or were already partaking in a course redesign process for a STEM gateway course at their university;

(2) Have taught the course to be redesigned at least once; and

(3) Were willing to participate in all phases of the course modeling workshop.

1.4.4 Data Collection

The data collection process was guided by the “Say-Do-Make” framework (Sanders, 1999, 2001, 2002), which facilitated the collection of multiple sources of data from each faculty-designer in textual, verbal, and visual forms through the course modeling workshop. These provide a deep and rich contextual understanding underlying the design experience of faculty-designers.

Textual and visual data were collected from faculty-designers’ lesson blueprints from the two design sessions of the course modeling workshop. Faculty-designers used the Learning Environment Modeling (LEM) course modeling toolkit (Dodd, 2016, 2018, 2019; Dodd & Gillmore, 2018; iLED, 2017) to create visual lesson blueprints. Dr. Bucky Dodd from the LxStudio (https://lxstudio.com/) at the University of Central Oklahoma granted permission to use the proprietary LEM modeling toolkit for this research. A total of 13 lesson blueprints were generated among three faculty and analyzed for this study. Each lesson blueprint was mapped to one class session.

Verbal and visual data were collected from design discussions throughout the two design sessions and a semi-structured interview conducted at the end of design session 2. While the course modeling workshop integrated a 4-step design process (idea generation, modeling, reflection, and explanation), only design discussions held during the reflection and explanation steps were used for data analysis because it was in these steps where faculty-designers reflected and explained their visual blueprints, describing their selection of lesson elements, lesson sequencing, rationale for making decisions, and factors or considerations that guided their decisions. Design discussions were video-recorded to capture both verbal explanation and visual data referencing the visual blueprint. Semi-structured interviews were audio-recorded using Audacity. Over 12 hours of audio-visual data was analyzed for the study.

1.4.5 Data Analysis

This study utilized a two-phased hybrid analysis approach combining inductive and deductive methods (Fereday & Muir-Cochrane, 2006; MacCarthy, 2021) (see Figure 3). During the first phase, a seven-step inductive analysis process was conducted to examine how STEM faculty-designers select lesson elements and sequence lessons in 13 visual lesson blueprints. Six design patterns of practice were derived from Phase 1 and were used as a priori codes to guide the six-step deductive analysis process in Phase 2. A thematic map was developed to map design patterns of practice to emerging themes on contextual factors. Chapter 3 provides a detailed description of the methodology and each phase.

Figure 3

Two-Phased Hybrid Inductive-Deductive Approach

	Phase 1 **Inductive Analysis of Lesson Blueprints**	**Phase 2** **Deductive Analysis of Design Discussions and Interviews**
Data Collection	**Step 1:** Modeling lesson blueprints	**Step 1:** Conducting interviews and design discussions
Data Preparation	**Step 2:** Digitizing blueprints	**Step 2:** Transcribing and reviewing interviews and design discussions
Data Analysis	**Step 3:** Flowcharting blueprints **Step 4:** Schematizing blueprints **Step 5:** Timelining blueprints **Step 6:** Abstracting blueprints **Step 7:** Defining design patterns of practice	**Step 3:** Initial deductive coding **Step 4:** Identifying themes **Step 5:** Reviewing themes **Step 6:** Defining contextual factors and mapping knowledge frames

1.5 Terminology

Operational definitions of selected terminology in this research study:

1. **Design knowledge:** pieces of knowledge that are mentally activated during a design process
2. **Knowledge frames:** mental frames that faculty-designers think about or consider when engaged in a design process (e.g., student frame (SF), teacher frame (TF), course frame (CF), learning environment frame (LEF), institutional frame (IF), disciplinary frame (DF))
3. **Contextual factors:** rationale that drive design decisions
4. **Design practice:** design tasks that faculty-designers engage in during lesson design, specifically the selection of lesson elements and sequencing of lessons
5. **Faculty:** personnel in a higher education institution responsible for teaching across all subject disciplines, whether teaching is their main responsibility or a part of their responsibilities
6. **Faculty-designer:** a faculty who enacts the role of a course or lesson designer in higher education
7. **Visual lesson blueprint:** a visual learning design representation of a lesson sequence
8. **Learning Environment Modeling (LEM):** a course modeling toolkit with a common notation system for selecting lesson elements and drawing lesson sequences

9. **Lesson elements:** building blocks of lessons; common course activities prescribed in the LEM toolkit including Information (I), Dialogue (D), Feedback (F), Practice (P), and Evidence (E)
10. **Lesson segment:** a chunk of time allocated to one or more lesson elements
11. **Activity sequence:** a combination or set of lesson elements arranged into a learning activity
12. **Lesson sequence:** a combination of activity sequences arranged into a lesson
13. **Design patterns:** common activity sequences and lesson sequences observed in visual lesson blueprints; also referred to as "design patterns of practice"
14. **Gateway courses:** introductory courses in a program of study, often the first credit-bearing college-level course

1.6 Limitations

This study examined faculty experiences of design practice and design knowledge in the context of a single, south-eastern public university. All faculty participants were from STEM fields, which in turn, implies that findings may not be generalized or applied to other fields. Due to data collection constraints, the study is limited to a short timeline which supported a small scope of lesson design rather than a full course design during the course modeling workshop. Faculty who participated in the workshop still needed support from instructional designers or workshop facilitators on using the LEM modeling toolkit for designing lesson blueprints. This may serve as a limitation in future replications of this study. Lastly, the data collection and workshop event for this study took place prior to the peak of the COVID-19 pandemic; findings from replication of this study may yield different findings.

1.7 Significance of the Study

There is much to be learned from faculty themselves as they are interacting with learners and the learning environment daily (Masterman, 2013). This study contributes to the broader field of design epistemology in the context of undergraduate STEM faculty in higher education as they engage in design work. Results on the lesson elements provide a nonthreatening way to identify what activities make up their class time and help evaluate how they are spending their time. Results on design practice can lead to the development of design templates that could be reused, shared, and documented. Results on contextual factors and knowledge frames offer the field a deeper understanding of the underlying thinking that guides STEM faculty as they make design decisions. Overall results from the study also benefit centers for teaching and learning towards identifying faculty professional development needs related to design literacies in higher education and developing new programs, processes, and toolkits that support faculty as designers.

1.8 Summary

This chapter established a background to the research study with an overview of the emerging role of faculty as designers in higher education. The conceptual framework, research purpose, methodology, terminology, limitations, and significance of the research were explained to establish a high-level view of the research study. The next chapter presents the literature review.

CHAPTER 2: LITERATURE REVIEW

The chapter begins with a discussion of faculty as designers, followed by a review of the literature on design knowledge and design practice that support the conceptual framework for this research. The last section expands on the use of modeling and visual lesson blueprints to support course design work.

2.1 Faculty as Designers

Design is a natural human ability (Cross, 2000, 2011). People are engaged in design all the time, whether we are conscious of it or not. Design is so pervasive that everything around us has been designed by a designer. The quality of a design effort affects the quality of how we experience the effort. Therefore, it is important that designers have the ability to produce designs that are effective and engaging (Cross, 2011). As design evolved into a formal profession, it has garnered a workforce of design professionals in fields like architectural design, industrial design, engineering design, graphic design, software design, fashion design, including higher education and learning design. Designers from various design fields can relate to other designers because they all strive for the same goal – adding or modifying something in real world practice (Nelson & Stolterman, 2003). There is no one definition for the concept of design, but generally, to design is "to change one set of circumstances into another, from one point in time to another" (Keirl, 2017, p. 23). Design is also intentional and future-oriented such that designing means to conceive an imagined future *which-does-not-yet-exist* and to make plans before executing (Keirl, 2017; Otto & Smith, 2013; Stolterman & Löwgren, 2007).

Pedagogical innovations in course design have impacted the broader higher education learning culture to include: (1) the use of student-centered, constructivist, active learning strategies like project-based learning and inquiry-based learning in which students can work individually or in groups; (2) the blending of formal and informal learning, allowing students to take greater control and responsibility for their learning; (3) use of smart mobile devices and wearable technologies among students and faculty to access virtually infinite online resources; (4) the massive range of learning resources available in the form of websites, multimedia, e-books, online libraries, learning apps, instructional video, and open educational resources (OERs) that can be embedded into learning management systems (LMS) like Canvas or Moodle; (5) the redesign and expansion of traditional spaces for teaching and learning in schools, universities, and libraries into open, active, and technology-enhanced learning spaces; and (6) the shift of traditional assessments to non-conventional exams, oral presentations, group projects, formative assessments, and peer evaluations for more realistic and meaningful student learning experiences (Espiritu & Budhrani, 2019). These pedagogical innovations in technology, pedagogy, and course design have influenced the role of the faculty to expand from teaching, research, and service, into the role of a *designer* (Beetham & Sharpe, 2013; Reigeluth, 2011). It is noted in this research that a faculty who enacts the role of a course designer is denoted as a "faculty-designer."

Course design is becoming a core, natural, and routine work that faculty perform as part of their professional practice (Dalziel et al., 2016; Goodyear, 2015; O'Donnell, 2008). In practice, course design work goes beyond creating a syllabus and a schedule for each semester. Course design needs are of three types: to maintain or review courses, to improve/redesign existing courses, or to create new courses (Bennett et al., 2011; Laurillard et al., 2013; Stark, 2000). A course design need is triggered by either a perceived problem identified or a change deemed necessary (i.e., an addition, modification, or removal) in teaching. This could be related to refreshing content, changing how lessons are taught, or updating a course previously taught by another faculty (Bennett et al., 2017). It is common for faculty to use student outcomes and feedback from students and/or peers to identify areas for improvement in the course (Bennett et al., 2017). When faculty are involved in the design or redesign process, they examine and reflect on existing activities and materials, set goals for re-designing activities, discuss and change activities to meet their goals, and plan how to implement the re-designed activities (Cviko et al., 2014; Kali, Goodyear, et al., 2011; Kali et al., 2015). McGee and Reis (2012) describe that in a redesign process, faculty need to be willing and able to see beyond and reconceptualize what has been done in the classroom. With this, faculty are essentially in an ongoing loop of being *designerly* (Cross, 2011; Goodyear & Dimitriadis, 2013; Newstetter et al., 2001), where they are constantly thinking about course design needs, improvements or solutions, and performing some type of design work.

Higher education courses are structurally complex to design because they contain a wide range of elements that can be arranged in various sequences (Quintana et al., 2018; Seaton, 2016). The focus of design work is often based on what students need to do and how activities map to learning outcomes (Goodyear & Carvalho, 2016; Goodyear & Dimitriadis, 2013; McGee & Reis, 2012). While course design is somewhat routine for faculty, the actual thinking and practice that underlies it is not easy, primarily because no design is ever the same. This idea overlaps with the nature of faculty-designers being *artisans*, where products are *handmade*. Each semester, each day, or each hour that faculty design is contextually unique to the instance of *when* and *where* the design is taking place, and *for who* the design is for.

The *science of design* (Cross, 2006; Goodyear & Dimitriadis, 2013; Newstetter et al., 2001) has a goal of studying how people design, what they design, and what knowledge is drawn upon during design work. Multiple researchers have systematically investigated faculty *design knowledge* and *design practice* in higher education—that is, looking into how faculty design lessons, why they make certain design decisions in their courses, and what informs their design thinking (Agostinho et al., 2018; Bennett et al., 2008, 2011, 2015, 2017, 2018; Bibi et al., 2012; Cameron, 2017; Goodyear, 2015; Goodyear et al., 2010; Goodyear & Markauskaite, 2009; Hativa & Goodyear, 2002; Markauskaite & Goodyear, 2014; Masterman, 2013; Nguyen & Bower, 2018; Stark, 2000, 2002).

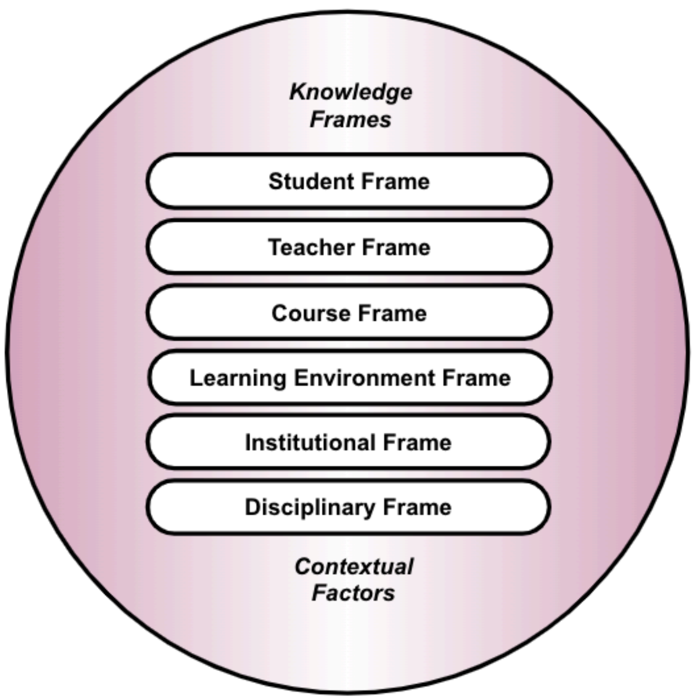
2.2 Design Knowledge

As faculty engage in course design work, they undertake cognitive acts of design thinking and utilize *design knowledge* (Bennett et al., 2018; McKenney et al., 2015a). *Design knowledge* refers to the pieces of knowledge that are mentally activated when working on design tasks such as selecting lesson elements and sequencing lessons (Goodyear & Markauskaite, 2009). It includes the "tacit and explicit aspects of knowing that underpin their capacity to engage skillfully in design work across situations and contexts, including capacity to learn to design in new unfamiliar situations" (McKenney et al., 2015, p. 183).

In this research, the conceptual framework on design knowledge is examined in two constructs: knowledge frames and contextual factors (see Figure 4). Knowledge frames are defined as the mental frames of reference that faculty-designers think about or consider when engaged in a design process (e.g., student frame (SF), teacher frame (TF), course frame (CF), learning environment frame (LEF), institutional frame (IF), and disciplinary frame (DF)) while contextual factors refer to the rationale that drive design decisions (Hammer & Elby, 2002; Kali, Goodyear, et al., 2011; Markauskaite & Goodyear, 2014). These two constructs are elaborated in the next subsections.

Figure 4

Conceptual Framework on Design Knowledge



2.2.1 Knowledge Frames

One view in design knowledge epistemology is that faculty-designers having a "personal theory of teaching" (Markauskaite & Goodyear, 2014, p. 248) and are strongly influenced by their personal proclivity from individual knowledge, pedagogical beliefs, and prior teaching and learning experiences such that they may have developed a predisposed tendency or approach when making design choices (Khlaif et al., 2019; Masterman, 2013).

However, Markauskaite & Goodyear (2014) suggest alternate view where faculty design knowledge is not predisposed to personal theories or pedagogical beliefs (i.e., an orthodox view), but that faculty as designers respond to demands from a particular context (Bennett et al., 2008, 2015; Kali, Goodyear, et al., 2011; Norton et al., 2005) and that they have working knowledge that serves as "intuitive pedagogy" and functionally guides their rationale for decision making in particular situations (Markauskaite & Goodyear, 2014, p. 239). Markauskaite & Goodyear (2014) describe faculty design knowledge as "knowledge-in-pieces" that occur or develop in various contexts rather than as a uniform, systematic personal theory or belief (p. 239). With this, design knowledge is dynamic, can co-evolve within the context the faculty is situated in, and has the potential to gradually develop as faculty encounter new ideas and experience diverse pedagogical interventions (Kali, Goodyear, et al., 2011; Markauskaite & Goodyear, 2014).

This research study adapts the epistemic knowledge model of Markauskaite and Goodyear (2014) which breaks down design knowledge into multiple fine-grained *knowledge frames*, which they refer to as "frames of reference" (p. 242). Six knowledge frames were closely adapted from the research of Markauskaite and Goodyear (2014) but renamed for clarity and consistency for the conceptual framework (see Figure 5). These include: student frame (SF), teacher frame (TF), course frame (CF), learning environment frame (LEF), institutional frame (IF), and disciplinary frame (DF). The institutional frame was made explicit for this research study as uniquely surfaced in prior research

(Agostinho et al., 2018; Bennett et al., 2008, 2011, 2015, 2018; Entwistle & Peterson, 2004; Kali, Goodyear, et al., 2011).

Figure 5

Theoretical Basis of Knowledge Frames

Markauskaite and Goodyear (2014)		**Knowledge Frames** (This research)
Students	➔	Student frame
Teacher How people learn How to teach	➔	Teacher frame
Course	➔	Course frame
Educational environment	➔	Learning environment frame
	➔	Institutional frame
Disciplinary content and subject nature	➔	Disciplinary frame

2.2.2 Contextual Factors

Design is often initiated by a particular *design situation* (Paton & Dorst, 2011; Schon, 1983), which requires examining the *need* for design in the first place, and the *context* within which the design is carried out. Identifying the needs and contexts of faculty as they engage in design work contributes to the "why" of design, eliciting the rationale and sense-making in faculty design practices. Multiple researchers have alluded to the importance of context in design, particularly because contextual factors serve as intrinsic filters influencing the decisions in faculty design practices (Bennett et al., 2008, 2011, 2015; Goodyear et al., 2010; Goodyear & Markauskaite, 2009; Markauskaite &

Goodyear, 2014; Masterman, 2013; Masterman & Manton, 2011; Prosser & Trigwell, 1997; Stark, 2000, 2002). Markauskaite & Goodyear (2014) mapped reasoning from faculty interviews and descriptions of teaching decisions to identify emergent knowledge frames.

The six knowledge frames and their influencing contextual factors are described in detail in the next subsections. Following this, a summary of knowledge frames and contextual factors is provided in Table 1 and a literature map is provided in Table 2.

2.2.3 Student Frame

Design involves understanding the learners and what they need, applying learning principles and theories relevant to the users, and designing solutions that will best meet the learners (Beetham & Sharpe, 2013). When designing courses, faculty are strongly influenced by their perceived characteristics of students, particularly their needs, preferences, previous and expected knowledge, motivations, experiences, and fears (Bennett et al., 2008, 2011, 2015, 2017, 2018; Kali, Markauskaite, et al., 2011; Markauskaite & Goodyear, 2014; Masterman, 2013; Stark, 2000; Young, 2010). Faculty tend to reflect and anticipate the needs of future cohorts and characteristics of students based on previous experience of the types of students who enrolled (Bennett et al., 2015; Martin, Ritzhaupt, et al., 2019). For example, faculty may need to consider different instructional approaches or course goals if the anticipated students enrolled are taking the course as an elective rather than a core discipline. Laurillard (2012) suggests considering whether students are enrolled full-time or part-time. This is particularly important in online or blended course design. Faculty shared that they also take into consideration students' busy schedules when designing courses (Martin, Budhrani, et al., 2019).

Common among STEM faculty is the need to cater to a diverse range of students entering first year courses, many of whom are not prepared or lack strong prior background in science or mathematics; this poses additional requirements for faculty to provide both remedial and extension materials to better cater to the diverse needs of students (Bennett et al., 2008). Culture, gender, and ethnicity pose additional considerations for course design (Masterman, 2013). Faculty also consider the characteristics of students, including their motivations and attitudes (Young, 2010).

2.2.4 Teacher Frame

Course design is highly influenced by the knowledge, beliefs, preferences, feelings, and motivations faculty possess about themselves as a teacher (Entwistle & Peterson, 2004; Markauskaite & Goodyear, 2014), specifically on their: educational aims, purposes, and values (Kali, Markauskaite, et al., 2011); approaches and preferences to teaching (Bennett et al., 2008, 2015, 2018; Laurillard, 2012; Markauskaite & Goodyear, 2014); expertise on the subject matter (Bennett et al., 2015); knowledge of learning theory (Bennett et al., 2015; Masterman, 2013); knowledge of teaching methods and strategies (Bibi & Khan, 2017); and personal beliefs and knowledge about technology (Khlaif et al., 2019; Koehler & Mishra, 2009; Markauskaite et al., 2011). From these examples, it can be seen that course design knowledge stems from intrinsic factors and personal proclivity where a faculty may have a predisposed tendency or approach when making design choices (Khlaif et al., 2019; Masterman, 2013).

Faculty interviewed in Bennett et al. (2015, 2008) explained their personal beliefs about learning and approaches to teaching influenced their course design. Some faculty believed that learning was more effective when it is fun and when students enjoy the journey but also when students take responsibility for their own work (Bennett et al., 2015). Another faculty described her approach to teaching as one that is "critiquing and challenging," recognizing that learning should not be too easy because students need challenge (Bennett et al. 2015, p. 3). Faculty who had experience working in industry designed learning activities and assessments with "industry eyes" (Bennett et al., 2015, p. 215). Such faculty place importance on students linking theory to real world practice and thinking critically rather than just learning facts (Bennett et al., 2008). However, other researchers oppose this and state that design practices are a product of beliefs and behaviors formed in response to adapting to demands from a particular context, rather than being a characteristic intrinsic to an individual (Bennett et al., 2008, 2015; Norton et al., 2005). "The same teacher might adopt an information-transmission approach when teaching first-year undergraduate students but a learning-facilitation approach when teaching postgraduate students" (Norton et al., 2005, p. 563).

Research by Bennett et al. (2015) revealed that some faculty described their course design thinking as being underpinned by knowledge of learning theories. This finding is not unique to just faculty-designers, but also common to designers in general, who are known to draw from "first principles," the theoretical underpinnings that guide a designer to generate good or creative design (Cross, 2006, 2011; French, 1994). Instructional designers draw from seminal theoretical approaches to learning (e.g., behaviorism, cognitivism, constructivism, socio-constructivism, experiential learning) and theories of instructional design and technology (Reigeluth, 1999; Reigeluth et al., 2017; Reigeluth & Carr-Chelman, 2009). These form the pedagogical core of how people learn and how faculty teach, all of which inform course design knowledge and practice.

As faculty take on the role of designers, they are likely to draw from the same theoretical base.

Faculty believe training is important for developing teaching expertise or pedagogical knowledge (Bennett et al., 2015; Masterman, 2013). Pedagogical knowledge encompasses knowledge of learning theory; knowledge of course goals, content, objectives, teaching methods and strategies; pedagogical considerations for teaching different kinds of knowledge and skills to diverse groups of students; and planning for various teaching activities to support students (e.g., such as gaining attention, recalling previous knowledge, reviewing assignments) (Bibi & Khan, 2017; Markauskaite et al., 2011; Markauskaite & Goodyear, 2014). Laurillard (2012) explains that when faculty take a theoretical perspective, it can influence their design ideas. While faculty prefer constructivism as a theoretical approach where students build knowledge and ideas themselves, they do not lock themselves to believe there is one correct theory; theories are woven into the faculty's general worldview and adapted based on how students learn best (Bennett et al., 2015; Markauskaite & Goodyear, 2009, 2014; Masterman, 2013).

Whether designing for a lesson or a course, faculty design learning tasks, activities, resources, materials, and tools based on a pedagogical intention or context (Beetham & Sharpe, 2013). More importantly, Masterman (2013) found that even faculty who use theories extensively admit that they need to be pragmatic.

2.2.5 Course Frame

When considering the course context in course design, faculty revisit information known about the course such as the course description, course goals/objectives, pre-requisites, topic coverage, course credits, hours of study, the type of course (e.g., didactic, laboratory, clinical), course schedule (e.g., 15-week semester vs. 5-week summer course), and teaching modality (e.g., face-to-face, blended, or online) (Bennett et al., 2015, 2018; Entwistle & Peterson, 2004; Laurillard, 2012; Markauskaite & Goodyear, 2014; Sims, 2014). But research has found that in practice, faculty go beyond such information and think deeply about the progression of the course as it is positioned within the broader curriculum sequence (Bennett et al., 2008, 2017; Kali, Markauskaite, et al., 2011; Laurillard, 2012; Martin, Ritzhaupt, et al., 2019). Some faculty hold a strong knowledge of the curriculum and may consider course pre- and post-requisites in their course design. Additionally, faculty consider their workload, specifically whether they would teach subsequent iterations of the course in the future or on the amount of work required to make revisions on an existing course that they had not taught before (Bennett et al., 2017).

The course context goes beyond information about a course and into how faculty design courses. Faculty typically design courses following a top-down sequence, with either: (1) identifying course goals, or what students are expected to know and do within the context of the curriculum and the profession/discipline (Bennett et al., 2015; Entwistle & Peterson, 2004; Markauskaite & Goodyear, 2014; Sims, 2014); or (2) identifying the content coverage (Bennett et al., 2017; Stark, 2000, 2002). Once course goals and topics are defined, faculty work their way down to identifying activities, materials, and assessments (Bennett et al., 2017). Course goals vary in how they are identified by a faculty: (1) they are defined in compliance to disciplinary accreditation or validating bodies (Laurillard, 2012); (2) they are defined by the program curriculum and coverage (Masterman & Manton, 2011); (3) they are decided based on the faculty's individual motivations, interests, or ambitions for how they want their students to learn (Laurillard, 2012); (4) they are lifted or aligned to main textbooks in for the course; (5) they are reused from existing course syllabi; (5) they are tempered based on multiple contextual factors related to the teacher (e.g., beliefs, expertise, and familiarity with the course content and course goals), the course (e.g., course description, course pre-requisites, topic coverage, course credits, hours of study, type of course, course timetable), the students (e.g., learner entry level skills, learner characteristics), and the learning environment (e.g., class size, availability of physical resources, technological resources, teaching assistants) (Bennett et al., 2015, 2017, 2008, 2018, 2011; Bibi & Khan, 2017; Bibi et al., 2012; Entwistle & Peterson, 2004; Kali, Markauskaite, et al., 2011; Khlaif et al., 2019; Laurillard, 2012; Markauskaite & Goodyear, 2014; Stark, 2000, 2002; Young, 2010).

2.2.6 Learning Environment Frame

Environmental factors like time, class size, and their experience with using technology or ICT in teaching rose up as primary factors in practice (Khlaif et al., 2019; Masterman, 2013). Designing with the learning environment in mind requires faculty to think beyond the curriculum and pedagogical approaches, and consider pragmatic factors related to the course such as number of credit hours, teaching modality, technological resources, instructional resources, physical space, and class size for course design (Bennett et al., 2008, 2015; Bibi & Khan, 2017; Kali, Goodyear, et al., 2011; Khlaif et al., 2019; Laurillard, 2012; Markauskaite et al., 2011; Markauskaite & Goodyear, 2014; Masterman, 2013). These factors are either affordances or constraints due to their reachability, availability (or lack thereof), and affordability (Bennett et al., 2017; Bibi & Khan, 2017; Khlaif et al., 2019; Markauskaite & Goodyear, 2014).

Markauskaite et al. (2011) found that faculty who are sensitive to student's access to technology understand the type of technological resources students currently have, which resources need to be provided, and how the access to such resources can be assured to be available at the institution. Faculty also need to understand the features, characteristics, and affordances of technology and tools before they can plan how they can be effective for teaching and learning (Bibi & Khan, 2017; Espiritu & Budhrani, 2019; Koehler & Mishra, 2009). Instructional resources (e.g., textbooks, web tools) are highly dependent on access, availability, and cost. More faculty are opting to design courses with open-access resources for easier and cheaper access (Bennett et al., 2015).

A frequently cited constraint related to course design is the mention of class size (Bennett et al., 2008, 2015; Laurillard, 2012; Masterman, 2013). Number of students is a significant factor in determining instructional strategies, how learning activities might be designed, and how students can interact with each other as pairs or groups (Bennett et al., 2015). Other faculty express frustration that even if they want to be innovative by moving away from lecture-based classes, they have to be pragmatic and consider the reality of the learning environment they are situated in.

2.2.7 Institutional Frame

The institutional home of the faculty has underlying factors that affect their design practices, such as: institutional politics, culture, and strategy; institutional policies, rules, and requirements (Bennett et al., 2008, 2011, 2015, 2018); departmental practices, requirements, and culture (Entwistle & Peterson, 2004); faculty development support

(Lee, 2010); and incentives or reward structures (Herman, 2013b; Varma-Nelson & Tarr, 2012). However, these vary for each faculty and by institution.

It is common to have policies, strategies, conventions, procedures, guidelines and norms formulated by different groups in the institution that concern curriculum planning, timetabling (e.g., length of the semester), assessment policies, software purchasing policies, and technology policies; on a broader plane, such policies may extend to state-level or national policies (Bennett et al., 2011; Masterman, 2013). Some higher education institutions have curricular requirements set by the department, requiring that faculty maintain a level of consistency in their course delivery or for courses to align to a specific curriculum standard. Some faculty find such requirements limiting for tailoring lessons to specific student needs (Bennett et al., 2008). Departments that have multiple faculty teaching a course tend to develop shared curriculum and common assessments, while departments with one faculty teaching a course often provide greater academic freedom (Bennett et al., 2008).

Attention to effective course design has been noted by higher education institutions as a key strategy for improving the quality of teaching (Goodyear, 2015; Laurillard, 2012). With this, faculty development programs have become increasingly prevalent with the establishment of centers of teaching and learning (CTLs) (Herman, 2013a). These institutional support centers serve as centers of the pedagogical universe (Lieberman, 2018) whose mission is to support design work, advance teaching excellence, foster innovation, and translate educational research to practice. Faculty development programs vary by institution and are delivered using multiple approaches and modalities. Most institutions apply the traditional model of professional development, offering a wide selection of short, individual, training options such as workshops, seminars, webinars, teaching guides, and one-to-one consultations with instructional designers (Lee, 2010). Other strategies include establishing communities of practice (Baran & Correia, 2014; Bond & Lockee, 2018) and peer mentoring (Lunsford et al., 2018; Wasserstein et al., 2007). Faculty have expressed the need to have their teaching and course design efforts recognized or rewarded by the institution, requesting for grants related to course and curricular innovation, faculty release time to enhance their teaching, and graduate student assistants to provide support for teaching (Bennett et al., 2008; Herman, 2013b; Varma-Nelson & Tarr, 2012).

2.2.8 Disciplinary Frame

Distinctive pedagogies of teaching and learning in each discipline have their roots in traditions that built up over time (Entwistle & Peterson, 2004). Factors such as faculty views on the nature of the discipline, disciplinary norms, dominant research methodology, and compliance to disciplinary accreditation or validating bodies influences their goals and beliefs about education, which in turn, influences how they plan and design courses—from selecting learning outcomes, content, strategies, activities, and assessments, defining what skills and values their students should carry into the profession, and to deciding how course content is selected, organized, presented and assessed (Bennett et al., 2017, 2008, 2018; Bibi, Markauskaite, & Ashe, 2012; Cameron, 2017; Entwistle & Peterson, 2004; Goodyear, 2005; Markauskaite & Goodyear, 2014; Masterman, 2013; Stark, 2000, 2002; Young, 2010).

Stark (2002) found differences in how faculty view their discipline and define learning goals for students. For example, faculty in biology, mathematics, nursing, and psychology view their discipline as an organized body of knowledge, with an interrelated set of principles, theories, concepts, and skills that need to be transmitted to students; faculty in history, literature, psychology, and sociology view their students as individuals who can explore and explain phenomena through various modes of inquiry; faculty in English composition, mathematics, nursing, and romance languages view skill acquisition and application as important and more frequently emphasize values or personal enrichment in students. Other researchers found that faculty expect students to demonstrate non-discipline-specific, rather generic or universal skills (Bennett et al., 2008; Young, 2010). Young's (2010) communication with a senior veterinary lecturer revealed that the skills expected from students were not discipline-specific, but targeted high cognitive and transferable skills such as problem-solving, research, analysis of data, presentation of information in written form, oral presentation, working with others, action planning, and time management. Similarly, in Bennett et al. (2008), a faculty wanted his students to "think like a chemist" (p. 4) but also needed them to develop writing, communication, and critical thinking skills. However, the faculty explained that student's development of critical thinking could not happen immediately in their first year, but in later years, after gaining a strong foundational understanding of chemistry content.

The multidisciplinary nature of some disciplines creates concerns on the selection of course content and instructional strategies. Disciplinary knowledge closely linked to professions influences the selection of instructional strategies that are more fitting to preparing students for professional practice (Young, 2010). For example, law faculty typically adopt a very formal and technical approach when teaching so as to model the formality required in professional practice. But when teaching law to social work, medical, or engineering students, the technical knowledge of law must be contextualized and combined with explanations of its professional purpose and application to professional practice (Braye et al., 2003). Similarly, faculty from the business school believe that students who are business majors must gain a more in-depth mathematical knowledge compared to students from education who need application level knowledge (Goodyear & Markauskaite, 2009).

Faculty also consider students' career paths. They refer to requirements of the industry or profession when deciding on course content with the intent of developing graduates fit for the workplace (Bennett et al., 2015; Laurillard, 2012; Martin, Ritzhaupt, et al., 2019; Masterman, 2013). Others seek industry input to make courses and programs relevant to students before for employment and try to infuse rigor required to build students' ability to do certain jobs or tasks that employers expect them to do (Bennett et al., 2015).

Table 1

Summary of Knowledge Frames and their Contextual Factors

Knowledge Frames	Contextual Factors
Student frame	• Perceived characteristics of students • Student needs, preferences, motivations, fears • Student experiences • Student expected knowledge/readiness
Teacher frame	• Knowledge, beliefs, feelings, motivations • Educational aims, purpose, values • Approaches and preferences to teaching • Knowledge of learning theory • Knowledge of teaching methods and strategies • Personal beliefs and knowledge about technology
Course frame	• Course description • Course goals/objectives • Pre-requisites • Topic coverage • Credit hours • Workload • Course design • Course schedules • Teaching modality • Curriculum sequence and progression
Learning environment frame	• Technological resources • Instructional resources • Physical space • Class size
Institutional frame	• Institutional politics, culture, and strategy • Institutional policies, rules, and requirements • Departmental practices, requirements, and culture • Faculty development support • Incentives and reward structures
Disciplinary frame	• Nature of the discipline • Disciplinary norms and/or goals • Dominant research methodology • Disciplinary accreditation bodies • Career paths

Table 2
Literature Map on Design Knowledge

Research	Knowledge Frames					
	SF	TF	CF	LEF	IF	DF
Agostinho, S., Lockyer, L., & Bennett, S. (2018)	♦		♦			
Bennett, S., Agostinho, S., & Lockyer, L. (2015)	♦	♦	♦	♦	♦	
Bennett, S., Agostinho, S., & Lockyer, L. (2017)	♦		♦			♦
Bennett, S., Agostinho, S., Lockyer, L., Kosta, L., Jones, J., & Harper, B. (2008)	♦	♦	♦	♦	♦	♦
Bennett, S., Lockyer, L., & Agostinho, S. (2018)	♦	♦			♦	♦
Bennett, S., Thomas, L., Agostinho, S., Lockyer, L., Jones, J., & Harper, B. (2011)	♦				♦	
Bibi, S., & Khan, S. H. (2017)		♦		♦		
Bibi, S., Markauskaite, L., & Ashe, D. (2012)						♦
Cameron, L. (2017)						♦
Entwistle, N. J., & Peterson, E. R. (2004)		♦	♦		♦	♦
Goodyear, P. (2005)						♦
Goodyear, P., & Markauskaite, L. (2009)		♦				♦
Kali, Y., Markauskaite, L., Goodyear, P., & Ward, M.-H. (2011)	♦	♦	♦			
Khlaif, Z., Gok, F., & Kouraïchi, B. (2019)		♦		♦		
Laurillard (2012)	♦	♦	♦	♦		
Markauskaite, L., Bachfischer, A., Kali, Y., & Goodyear, P. (2011)		♦		♦		
Markauskaite, L., & Goodyear, P. (2014)	♦	♦	♦	♦	♦	♦
Masterman, E. (2013)	♦	♦		♦	♦	♦
Norton, L., Richardson, T., Hartley, J., Newstead, S., & Mayes, J. (2005)		♦				
Stark, J. S. (2000)	♦		♦			♦
Stark, J. S. (2002)			♦			♦
Young, P. (2010)	♦					

2.3 Design Practice

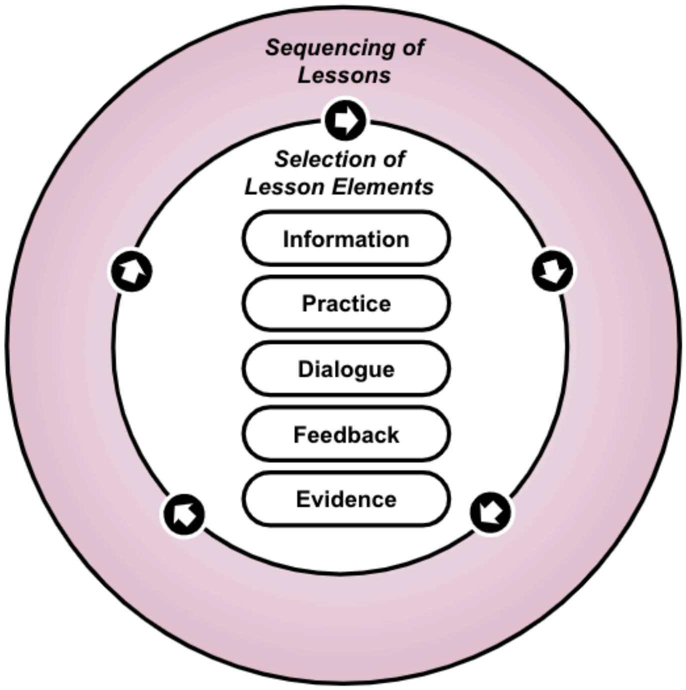
Attention is being given to improving the design of undergraduate gateway courses (i.e., entry-level, introductory) in the fields of science, technology, engineering, and mathematics (STEM) (Auerbach & Andrews, 2018; Beach et al., 2012; Dass, 2015; Freeman et al., 2011, 2014; Henderson et al., 2011; Koproske, 2017; Leibovich et al., 2017; Weaver et al., 2015). Universities have ignited course redesign efforts to incorporate more relevant pedagogical approaches to increase student success in STEM gateway courses. High attrition, low motivation, and low enrolment continue to be big challenges for STEM higher education (Sithole et al., 2017). Improving how STEM introductory courses are designed is seen as a strategy to reduce attrition among undergraduate students (Mervis, 2010).

Compared to traditional lecturing, undergraduate students perform better in courses that use active, collaborative, cooperative, and problem-based teaching approaches (Auerbach & Andrews, 2018; Beetham, 2013; Blanchard et al., 2010; Chen et al., 2018; Dehbozorgi et al., 2018; Freeman et al., 2014; Knight & Wood, 2005; Prince, 2004; Prince & Felder, 2006). A meta-analysis of 310 peer-reviewed journal studies showed that undergraduate course innovations in STEM courses including technology, conceptually oriented tasks, collaborative learning, and inquiry-based projects had a positive effect on student learning (Ruiz-Primo et al., 2011). It has been suggested that to promote active learning, institutions must take a more active role in promoting change in faculty practice and faculty beliefs on design (Antunes et al., 2021).

Prior research has examined teaching practices in STEM to build up a substantial knowledge base about effective pedagogies and interventions (Prince & Felder, 2006; Smith et al., 2013). However, limited research has examined *design practices* of STEM faculty. Design work of faculty is challenging and complex (Goodyear, 2015) and should be supported with instructional resources, tools, materials, and/or equipment to ensure faculty are successful in this task (Beetham & Sharpe, 2013; Goodyear & Carvalho, 2013). This research study examines how faculty design knowledge influences their design practice. The conceptual framework on design practice (see Figure 6) is examined as the design tasks that faculty-designers partake in during lesson design, specifically: selection of lesson elements and sequencing of lessons. Each task is elaborated in the next subsections.

Figure 6

Conceptual Framework on Design Practice



2.3.1 Selecting Lesson Elements

There are multiple elements that faculty need to consider in lesson design. When designing lessons, faculty imagine what students will know, think, feel, talk about, make, or say from the learning experience (Goodyear & Carvalho, 2016). They consider what students will do, where students will do activities, what tools or resources students will need, how long each activity should be, and who they will do activities with. Faculty-designers need to pay attention to selecting elements for several reasons. First, lesson elements influence student engagement. Less-challenging activities include listening to a presentation or reviewing a past lecture; more challenging activities involve critical thinking and problem solving with varied examples and difficulty, and group discussions (Glennie et al., 2017). Second, knowing the lesson elements used in courses can characterize how students and instructors are spending their time in undergraduate STEM classrooms (Glennie et al., 2017; Smith et al., 2013). Smith et al. (2013) found that faculty did not have a good sense of how much time they spend on different activities during class. The Learning Environment Modeling Language (LEML) from the Learning Environment Modeling toolkit denotes lesson elements as five core building blocks which can be configured to represent lesson sequences: Information (I), Dialogue (D), Feedback (F), Practice (P), and Evidence (E) (iLED, 2017) (See Table 3).

Table 3

LEM Lesson Elements as Building Blocks

LEM element	Description	Sample activity types
Information (I)	A building block that presents information to the learner in a lesson	• Lectures • Textbooks • Images • Articles • Presentations • Websites • Videos • Video conference
Practice (P)	A building block that provides opportunities to rehearse and practice skills in a learning environment, often used to represent formative assessment opportunities	• Application activities • Problem sets • Tabletop group exercises • Individual assignments • Practice quizzes
Dialogue (D)	A building block that describes communication, reflection, or collaboration elements in a lesson	• Classroom discussions • Peer debate • Group discussion • Reflections
Feedback (F)	A building block that represents opportunities for instructors to comment or critique students work to enhance performance and application of knowledge or skills	• Diagnostic questionnaires • Instructor feedback • Peer feedback

Evidence (E)	A building block that represents opportunities to capture evidence of learning, frequently associated to a learning outcome or a summative assessment	• Individual or group presentations • Individual or group projects • Examinations

Note: The information in the table is adapted from iLED (2017)

2.3.2 Sequencing Lessons

The structure of a course begins to crystalize as faculty attempt to break the duration of the semester into specific lessons. Lesson sequences start with identifying what should be learned first, next and thereafter. It is common for faculty to create a schedule, matrix, or timeline to aid their planning of course sequences (Bibi & Khan, 2017), where they begin to conceptualize the broad order of lessons into weekly or hourly schedules of instruction, activities, deliverables, and deadlines.

Courses are structurally complex to design because they contain a wide range of elements (i.e. objectives, content, resources, activities, assessments, materials, learning environment, and supports) (Churchill, 2007, 2017; Goodyear & Carvalho, 2013, 2016) that can be arranged in various sequences (Quintana et al., 2018; Seaton, 2016). Faculty between switch between high-level pedagogical theory (macro) to low-level details of each course element (micro) (Goodyear, 2005; Jones, 2007) while considering the order and timing (when), duration (how long), and pacing (how fast, slow, or how often). Faculty also consider the overall consistency and distribution of course elements, as well as the scaffolding of resources and activities. Course design requires faculty to find balance and maintain cognitive flexibility as they juggle through course elements and contextual constraints (Pozzi & Persico, 2013), conceptualizing, reflecting, and iterating to construct the best design solutions.

There has been a long tradition of researchers that support the notion that learning occurs in stages, as a process, within in a sequence, and may iterate through a *learning cycle* (Atkin & Karplus, 1962; Bybee et al., 2006; Herbart, 1901; Pedaste et al., 2015). A learning cycle serves as a *mediating artifact* (Conole, 2009; Svendsen, 2015) to scaffold the design process for faculty, suggesting that lessons must have a coherent structure or sequence. Learning cycles provide the "how-to" guide for designing learning sequences. The connections between phases provide a logical progression in lesson design. Learning cycles are flexible for course design in that it can be the organizing pattern of a sequence of daily lessons, individual units, or yearly plans (Bybee et al., 2006). Learning cycle models are also flexible in that they do not suggest specific activities, but rather can accommodate individual faculty design ideas. Bybee et al. (2006) traced the origins of learning cycles since the 1900s that guide faculty when designing inquiry-based lessons in STEM fields (see Table 4) and the 5E learning cycle is popular in recent STEM literature.

Table 4

Comparison of Learning Cycles in STEM

Herbart (1901)	**Dewey (1938)**	**Heiss, Obourn, and Hoffman (1950)**	**Atkin and Karplus (1960)**	**Bybee et al. (2006)**
Preparation Presentation Generalization Application	Sensing perplexing situations Clarifying the problem Formulating a tentative hypothesis Testing the hypothesis Revising rigorous tests Acting on the solution	Exploring the unit Experience getting Organization of learning Application of learning	Exploration Invention Discovery	Engagement Exploration Explanation Elaboration Evaluation

Learning cycles have also been developed in the instructional design field that have blended with the literature such as Gagne's nine events of instruction, Keller's

ARCS Model of Motivational Design, Kolb's Experiential Learning Cycle, and Huitt's Transactional Model of Direct Instruction (see Table 5).

Table 5

Comparison of Learning Cycles in Instructional Design

Gagne (1985)	Keller (1988)	Kolb (1984)	Huitt (1996)
Gain attention	Attention	Concrete experience	Presentation
Provide a learning objective	Relevance	Reflective observation	Practice
Stimulate recall of prior knowledge	Confidence	Abstract conceptualization	Assessment & Evaluation
Present the material	Satisfaction	Active experimentation	Monitoring and Feedback
Provide guidance for learning			
Elicit performance			
Provide feedback			
Assess performance			
Enhance retention and transfer			

Learning cycles have been noted to be one of the most powerful strategies in STEM instruction (Duran et al., 2011). The 5E learning cycle, for example, has been used by faculty to reflect or assess their existing practice and lesson sequences (Svendsen, 2015). It has been effective for developing conceptual understanding and reasoning, and resulted in improving learning compared to traditional lecture-based instruction in STEM courses (Almuntasheri et al., 2016; Bybee et al., 2006; Ceylan & Geban, 2009; Cigdemoglu & Geban, 2015; Tuna & Kacar, 2013). The cycle is also useful for courses that include both theory and practice (Bybee et al., 2006; Ceylan & Geban, 2009). Jun et al. (2013) found that the 5E learning cycle combined with problem-based learning is an effective way to help freshmen students understand content and apply scientific nursing principles/concepts to authentic clinical situations. The researchers found that students had increased the self-efficacy, critical thinking, learning attitude, and learning satisfaction among nursing students. The phases in the learning cycle provide structure and order to cognitively engage students in activities that mimic problem-solving (Dass, 2015; Withers, 2016).

The concept of a learning cycle has been criticized indicating that learners may not necessarily engage in phases sequentially, or some phases may happen simultaneously, or that learners may not engage in some phases at all (Lindsey & Berger, 2009). Svendsen (2015) found that faculty differ in how they use learning cycles when designing lessons such that each one fits the model to their own needs and environment based on how they order, prioritize, and define roles for each phase. Duran et al. (2011) modified the 5E to create a more inclusive model by adding the "Express" phase to assess and ensure all students are progressing through the phases in the cycle. Other researchers have added an "E-Search" phase to infuse technology in each phase (Orgill & Thomas, 2007). In a systematic review (Pedaste et al., 2015), researchers found that learning cycles are not a prescribed, linear process; faculty are flexible in their lesson designs, following either a linear, non-linear, or cyclical pathway between steps. Some faculty might even place greater priority or emphasis to some phases over others (Pedaste et al., 2015).

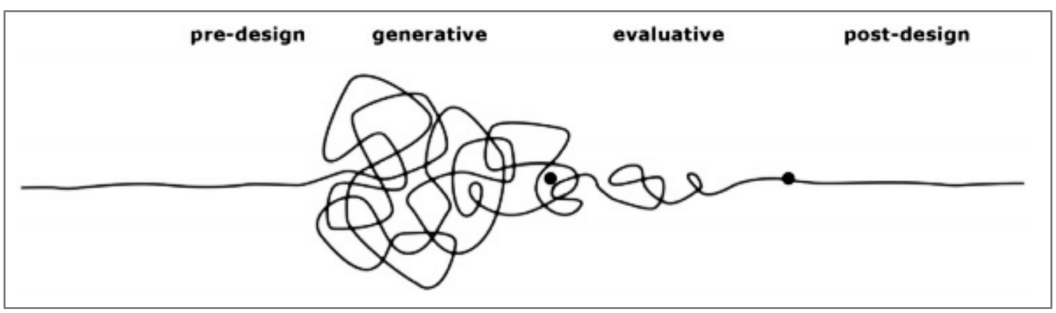
Another criticism of learning cycles is that it is left to the faculty to determine which activities will involve the students or which activities will be led by the faculty. The Inquiry and the National Science Education Standards (National Research Council, 2000) provides a table to guide faculty towards finding a balance between the amount of faculty direction and student self-direction (p. 29). Additionally, Bybee et al. (2006) has developed two charts to explicitly show how the 5E learning cycle can support "what the student does" (p. 33) and "what the teacher does" (p. 34). Evidently, while learning cycles might seem prescriptive, they are not adhered to as is in practice. As the utilization of learning cycles vary by faculty depending on their context (Svendsen, 2015), further research is needed to understand how faculty can benefit from and improve their lesson design using learning cycles.

2.4 Modeling Lessons with Visual Blueprints

For many faculty and administrators in higher education, reference to the role of faculty as designers is still unfamiliar. Faculty "do not know how to design" (Conole, 2013, p. 102) and rely on prior experiences and practices when designing lessons (Conole, 2013; Markauskaite & Goodyear, 2014). For most faculty, not only those who are new to teaching, course design is a fuzzy, generative, problem-solving process because of its ambiguous nature of working with multiple layers of course elements and multiple possibilities of course sequences (Sanders, 2008). Researchers refer to this as the "fuzzy front-end" (Sanders & Stappers, 2014, p. 10) of the design process (Sanders, 2008; Sanders & Stappers, 2008, 2014) (see Figure 7).

Figure 7

Fuzzy Front-End of the Design Process



It can also be difficult to imagine courses from the student point of view. While course design requires constant iteration and problem solving, it lives purely in the mind of the faculty (Falconer & Littlejohn, 2009). It is an internal, siloed process that starts and ends with the faculty themselves. Any design decisions made throughout the process are *invisible* and left as *tacit* design experiences (Carvalho & Goodyear, 2014; Dodd, 2016; Dodd & Gillmore, 2018).

Under the larger umbrella of the field of learning design, the area on *learning design representations and tools* have attracted renewed attention, placing a focus on how to best support faculty in their course design work to help make the invisible, now visible and tacit knowledge more explicit (Nguyen & Bower, 2018).The common thread in the area of research on learning design representations is on creating a *visual blueprint* (Dodd, 2016, 2018, 2019; Dodd & Gillmore, 2018; iLED, 2017), a design artifact that represents a designer's thinking about their course, in effect, externalizing current pedagogical ideas, reflections, experiences, and intentions, and later serving as a reference for future assessment or improvement of their course design (Dodd, 2018; Persico & Pozzi, 2015). The role of a visual blueprint is to "capture pedagogy" (Dalziel et al., 2016, p. ix), essentially to represent and codify faculty pedagogical plans visually so that it can be documented, communicated, shared, revised, or reused (Britain, 2006; Falconer & Littlejohn, 2009; Persico & Pozzi, 2015). This visualization process aids the course designer to focus on the sequence of learning activities (Conole & Wills, 2013). Blueprints are central to design work for professional designers to develop high levels of modeling skills such as problem framing, ideation, modeling and manipulation, communication, planning and organizing, testing and evaluation (Shepard, 2017). With visual lesson blueprints, designers can first *imagine*, and then *see* their imagined ideas become concrete, movable, and tangible blocks that can be tested, prototyped, and experimented with.

At its core, the essential language of design representation is through *modeling* (Archer, 1979; Cross, 2006; Shepard, 2017). "A model is a representation of something" (Archer, 1979, p. 20). Modeling design ideas in numbers, language, and symbol systems are important visual elements that help represent design ideas (Norman & Baynes, 2017). Modeling is motivated by the constructionist approach (Papert, 1990) where *constructing* or *making things* is an effective medium for knowledge construction. This approach favors hands-on activities oriented towards the design and discovery process (Conole et al., 2004). Modeling helps make ideas visible and concrete, which enables further cognitive processes to take place such as *construction* and *evaluation* (Casaday, 1996; Sanders & Stappers, 2014). Modeling with visual lesson blueprints helps designers articulate design ideas to others and get feedback. Modeling also helps externalize and offload ideas that lie within the imagination of the designer.

When designers engage in modeling, they spark mental connections while making and thinking (Harrison, 1978) and while making and doing (Archer, 1979). Designers use *making* to give shape to the future (Sanders & Stappers, 2014). Schon (1983) describes the design process as a *kind of making* where the designer *reflects-in-action*, "having a reflective conversation with the situation" (p. 76), internalizing the design problem, their design process, and decisions up to that point, and the contextual factors that have implicitly influenced the designer's ideas. Schon explains that the design situation then "talks back," (p. 79) which in turn, may produce unintended changes or allow the designer to gain a new way of "seeing" to reframe the design problem or solution.

Designers who reflect-in-action think about what they are designing while designing. Cowan (2006) and Cross (2006, 2011) describe reflection-in-action as productive thinking which can illuminate surprises and aha-moments, leading the designer to question, add to, or modify the original structure of their design, keeping the *construction* and *evaluation* loop going. In effect, modeling serves as a visual "intelligence amplifier" (Cross, 2006, p. 38) to help the designer think, explore, and resolve their thoughts, just as explaining is a verbal intelligence amplifier, and writing is a text-based intelligence amplifier. Hansen (2000) states

> Visual representations, on the other hand, can render phenomena, relationships and ideas visible, allowing patterns to emerge from apparent disorder to become detectable and available to our senses and intellect (p. 194).

2.5 Modeling Tools

Recent interest in course modeling tools to support faculty in designing for teaching is based on the premise that such support will improve the quality of teaching and ultimately improve the quality of student learning outcomes (Bennett et al., 2011). Modeling tools facilitate the production of blueprints, which assist faculty to be more intentional in selecting lesson elements and sequencing lessons. Course modeling tools can be classified in two formats: digital or analog (Dodd & Gillmore, 2018). Each is elaborated in the next sections.

2.5.1 Digital tools. Early tools were developed as specialized planning software to help the teacher reflect on pedagogical decisions like the LdShake tool (Hernández-Leo et al., 2011), ScenEdit tool (Emin et al., 2009), the Learning Designer (Laurillard & Ljubojevic, 2011), Web Collage (Villasclaras-Fernández et al., 2011), CompendiumLD (Laurillard & Ljubojevic, 2011), and CADMOS (Katsamani & Retalis, 2011). While some are still active, many have ceased activity. Newer web-based tools such as

Coursetune.com have evolved to meet the same goal of course planning and design. Other researchers have used a make-shift diagramming or concept mapping tool. For example, Seaton (2016) attempted to use the web interactive graphing tool Plot.ly to simulate course structures of MOOCs. Powers (2015) used dendrograms (i.e., tree-structure relationships) to show hierarchical clusters and color coding of course structures. Baaki and Luo (2019) selected Cacoo as a cloud-based concept mapping tool for collaboration and iteration through external representations of design diagrams.

The advantages of software tools for modeling include storage and reuse, switching among views, and learner analytics (Persico & Pozzi, 2015). However, researchers have found that these tools are too complex for non-technical users and takes a long time to learn (Botturi & Stubbs, 2008; Emin et al., 2009; Walmsley, 2012). Such tools require a *bridge person* to assist to encode pedagogical details. Additionally, these tools give too many choices and options that make it difficult for faculty (who are subject specialists, not necessarily pedagogy experts) to select appropriate activities, structures, and sequences. Thus, software tools in fact serve more as a barrier than an aid.

2.5.2 Analog tools. Analog tools are freeform, movable tools that use physical craft materials that involve colored paper, sticky notes, whiteboards, markers, drawings, and sketches (Dodd & Gillmore, 2018; Sanders, 2000). These tools enable thinking, remembering, mapping, visioning, feeling, or storytelling, allowing people to express themselves, their thinking, their visions, and their dreams (Sanders, 2000). Conole (2010) has found that paper-based tools are effective when faculty are designing courses. However, bridging the gap between analog and digital tools remains to be explored (Conole, 2010).

Analog tools are being used in teaching and learning centers for faculty development workshops on course modeling to support faculty in their course design or redesign efforts. Dr. Bucky Dodd from the LxStudio (https://lxstudio.com/) from the University of Central Oklahoma has developed the Learning Environment Modeling (LEM) toolkit as a visual language system to facilitate the design of lesson blueprints using custom sticky notes (Dodd, 2016, 2018, 2019; Dodd & Gillmore, 2018; iLED, 2017). The LEM Toolkit supports analog models (Figure 9) but also offers an online editor using Draw.IO to convert analog models to digital models for archiving, reuse, and sharing (Figure 10).

Figure 8

Analog Lesson Blueprint Created with the LEM Toolkit

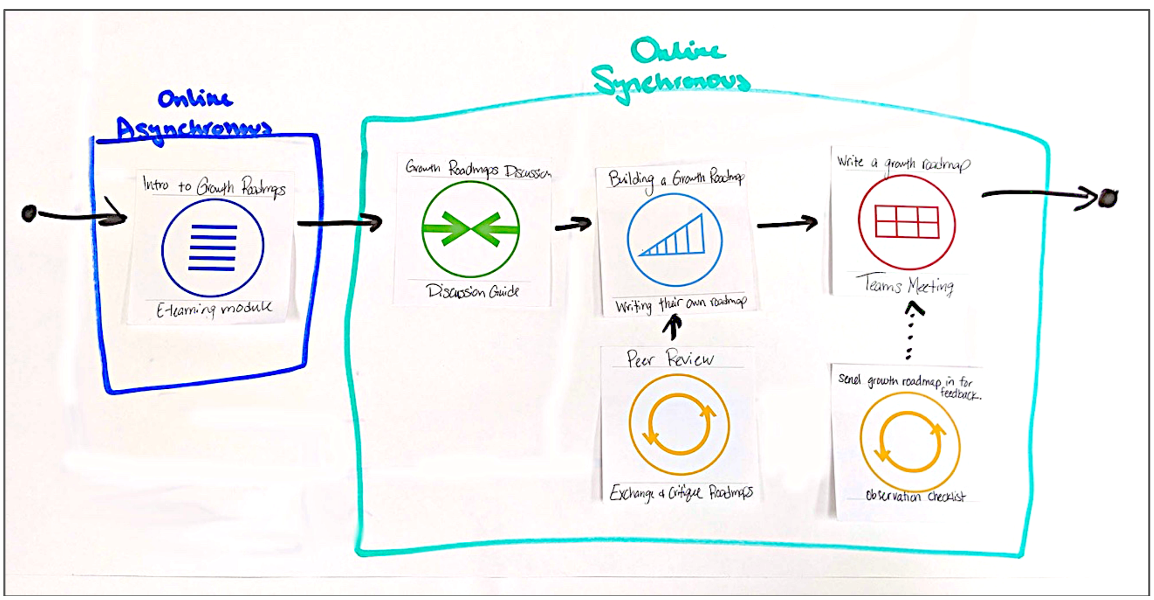
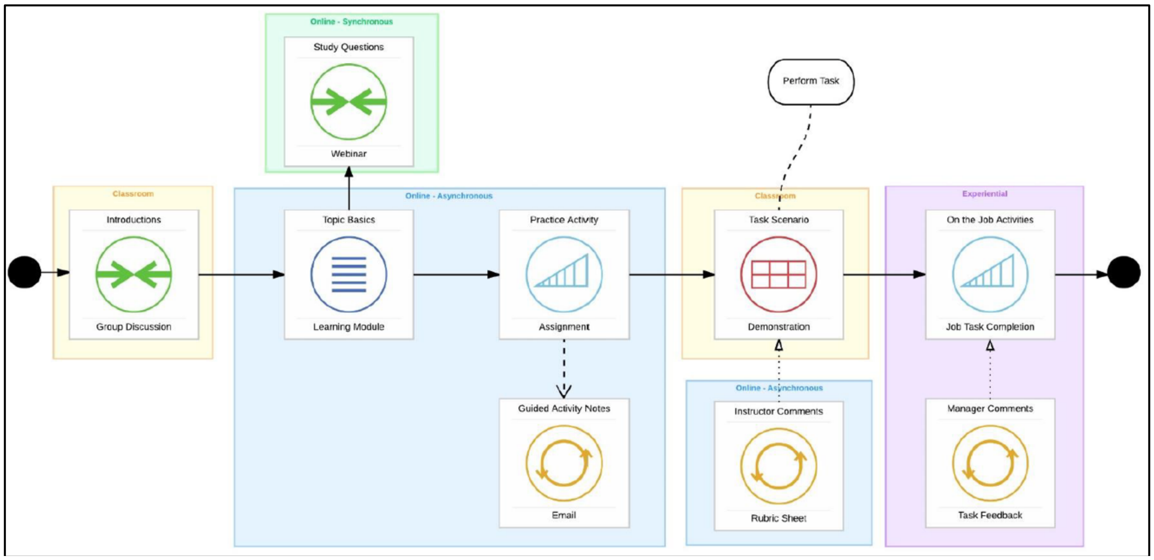


Figure 9

Digital Lesson Blueprint Created with The LEM Online Editor



In Australia, the Carpe Diem program (Salmon, n.d.) has helped faculty plan and design courses using post-its and flip charts to create course blueprints and prototypes. Sticky notes and flip charts have also been used by Quintana (2018) from Academic Innovation at the University of Michigan as a mediating tool during design conversations between faculty and instructional designers for curriculum design. Quintana et al. (2018) attempted to use craft beads to creatively envision course structures as bracelets.

The complex task of design in the higher education environment might be improved with good guidance, inspiring examples, and supportive tools (Cameron, 2011). However, it is important to consider that design tools are highly dependent on faculty design knowledge and practice in the setting where they are used (Masterman, 2013). Researchers have examined various design representation formats and their pedagogical intent. Conole (2010) and Falconer and Littlejohn (2009) summarized textual and visual representation formats. More recent research suggests the use of infographics to communicate ideas on course design (Barac, 2015). But as Stubbs and Gibbons (2008, p. 46) points out

> As important as drawing may be to the design process, it rarely stands alone. Design representations are nearly always accompanied by narrative, which supplements and adds meaning.

2.6 Summary

This chapter described the empirical evidence on faculty design knowledge and practice. Multiple researchers have systematically investigated faculty as designers, examining their design knowledge and design practice in higher education—looking into how faculty go about designing lessons, why they make certain design decisions in their courses, and what informs their design thinking. In practice, faculty engage in design tasks such as selecting lesson elements and sequencing lessons. To support faculty, design representations and tools have surfaced in recent years.

Prior studies have utilized various research methods for faculty-designers to represent or articulate their design knowledge and practices, some of which are through retrospection studies where faculty consciously reflect and explain past design activities (Agostinho et al., 2018; Bennett et al., 2008, 2011, 2016, 2017); think aloud sessions while faculty plan and design courses (Goodyear & Markauskaite, 2009; Markauskaite & Goodyear, 2014) observations and interaction with faculty in their routine or natural settings (Jones, 2015); content analysis of design artifacts or written ideas (Kali, Goodyear, et al., 2011); interviews with faculty (Brogt, 2009); or teacher logs (Glennie et al., 2017). There is minimal research that examines faculty design knowledge and practice as they model lessons using visual lesson blueprints. Such research warrants scholarship because "good" design has been linked to high quality courses and improved learning outcomes (Beetham & Sharpe, 2013; Bennett et al., 2008). The next chapter presents the methodology.

CHAPTER 3: METHODOLOGY

This chapter details the research design, research questions, research procedures, research instruments, selection of participants, data collection methods, and data analysis methods. The chapter ends with a description of quality measures, and the role of the researcher.

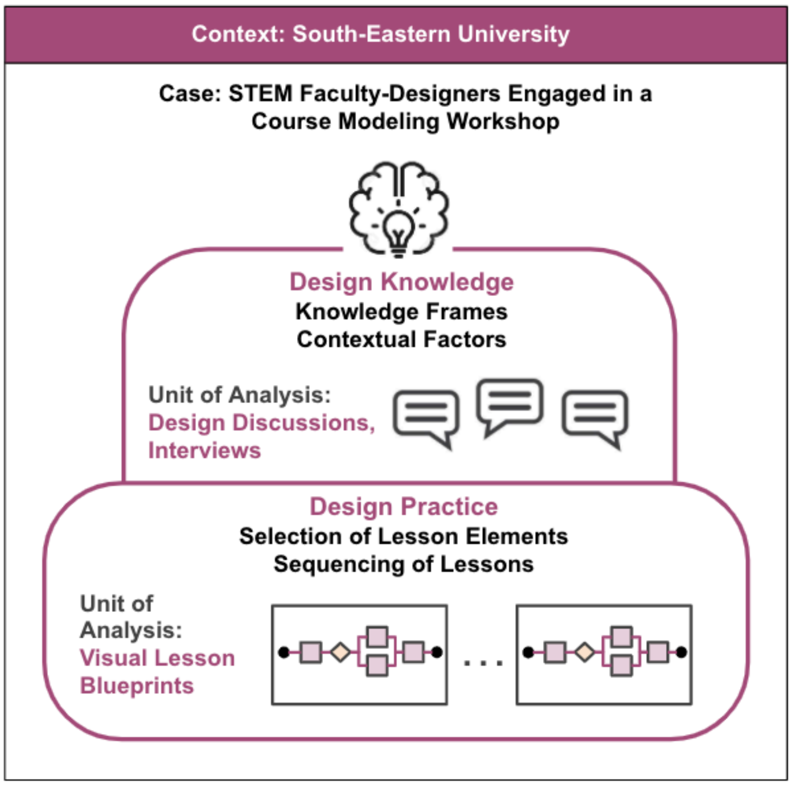
3.1 Research Design

This qualitative research applies an embedded case study design (Yin, 2014) to examine how design knowledge influences design practice among STEM faculty-designers within the context of a south-eastern university (see Figure 10). Yin (2014) indicates that the distinctive need for case study research is to focus on drawing real-world perspectives on small group behavior. The "case" in this study is denoted by university faculty who were engaged in a course modeling workshop to redesign STEM gateway courses.

As an embedded case, this study included three participants with multiple sets of data. There were two primary units of analysis: The first unit of analysis references the 13 visual lesson blueprints that three faculty-designers produced from participating in a course modeling workshop. Faculty-designers utilized the Learning Environment Modeling (LEM) toolkit as a visual language system to create lesson blueprints that represent their lesson ideas. Inductive analysis was applied to examine design practices in lesson blueprints, which resulted in identifying six patterns of practice evident in lesson blueprints. The second unit of analysis references the design discussions and semi-structured interviews conducted during the course modeling workshop. Deductive analysis was applied to examine design knowledge, which led to identification of contextual factors and knowledge frames that influence faculty-designers as they engage in design practice.

Figure 10

Embedded Case Study Design



3.2 Research Questions

The purpose of this study is to examine how design knowledge influences design practice among STEM faculty-designers. Design practice is defined as the design tasks that faculty-designers engage in during lesson design, specifically the selection of lesson elements and sequencing of lessons. Design knowledge is defined as the pieces of knowledge that are mentally activated during a design process, specifically contextual factors and knowledge frames. In line with this, the following research questions are posed:

1. Design Practice: How do STEM faculty-designers select lesson elements and sequence lessons in visual lesson blueprints?
2. Design Knowledge: How do knowledge frames and contextual factors influence STEM faculty-designers as they engage in lessons design?

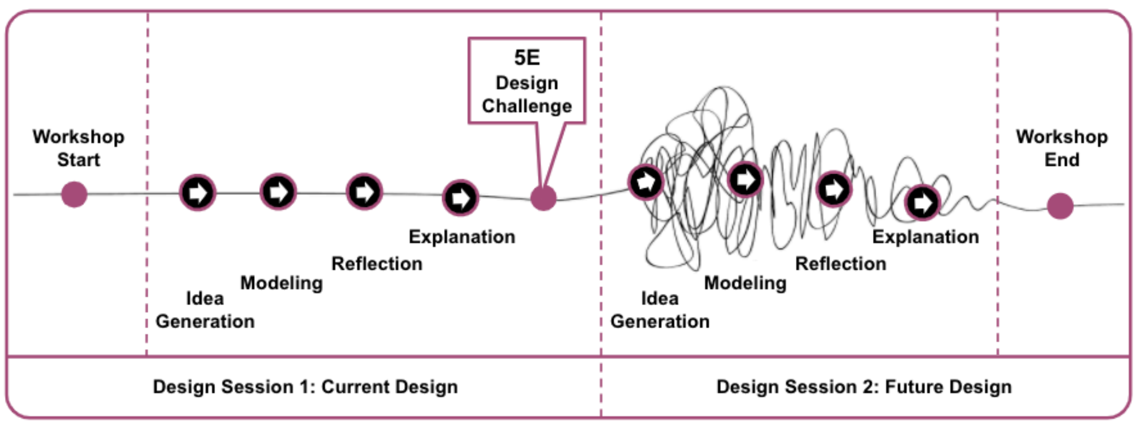
3.3 Research Procedure

3.3.1 Workshop Design

This research employs a workshop format, requiring faculty-designers to participate in a *course modeling workshop* with two design sessions (see Figure 11).

Figure 11

Course Modeling Workshop Design



The course modeling workshop had two goals: The first goal was that the workshop was a professional development program for faculty to engage in design work towards improving their lessons. For most faculty, design is a fuzzy problem-solving process because of its ambiguous nature of working with multiple layers of course elements and multiple possibilities of course sequences (Sanders, 2008). There was a need to provide a design process to facilitate an iterative and systematic design process (Sanders & Stappers, 2014; Shepard, 2017). With this in mind, the researcher prescribed each design session to follow a 4-step design process of idea generation, modeling, reflection, and explanation. These steps allow for deep design discussions to incur between the faculty-designer and the researcher (who also served as the workshop facilitator).

The second goal was that the workshop served as a medium for research. The workshop allowed for the researcher to be situated in multiple, authentic, live, interactive design discussions with faculty. This afforded the researcher to study design discussions that took place first-hand, while faculty were engaged in actual design work, as opposed to gathering data in retrospection of past design work (Agostinho et al., 2018; Bennett et al., 2008, 2011, 2016, 2017). While the 4-step design was meant to facilitate a systematic workshop for faculty-designers, it also allowed for systematic process of data collection for the researcher.

Design session 1 (3 hours) began with an orientation and consultative pre-interview to build rapport between the researcher and faculty-designer and to gain a deeper understanding of the faculty design experience, teaching experience, and the course selected for redesign. The pre-interview was followed by the four steps of the design process, requiring the faculty-designer to focus on modeling a "current lesson design." Design session 2 (3 hours) was scheduled on a second day and required the faculty to apply the 5E learning cycle as a design challenge to modify or improve their lessons towards a "future lesson design." Interviews were conducted as a culmination activity of design session 2. Table 6 provides a breakdown of the phases and activities of the course modeling workshop.

Table 6

Course Modeling Workshop Phases and Activities

	Phases	Description of Activities
Design session 1 (120 min)	Workshop start (45 min)	The researcher began with a workshop orientation and consultative pre-interview with each faculty-designer to build rapport, gain a deeper understanding of the faculty design experience, teaching experience, and the course selected for redesign. The researcher also provided a tutorial on how to use the LEM modeling toolkit for creating visual lesson blueprints.
	Idea generation (15 min)	The faculty-designer was asked to select a lesson for re-design and draft a brief lesson plan with learning objectives.
	Modeling (30 min)	The faculty-designer was asked to map lesson elements and sequences to create lesson blueprints of a current lesson. This phase was a codesign experience between the faculty-designer and the researcher to support the faculty through their first-time using the LEM toolkit.
	Reflection (30 min)	The faculty-designer was asked to review the lesson blueprint/s created. The researcher guided reflection with prompts to encourage the faculty-designer to talk aloud their reflections and what they were thinking in the moment.
	Explanation (45 min)	The faculty-designer was asked to explain their visual blueprint/s, describing their selection of lesson elements, lesson sequencing, rationale for making decisions, and factors or considerations that guided their decisions.
	5E design challenge homework (15 min)	In preparation for design session 2, the researcher briefed the faculty-designer on their design challenge and homework on the 5E learning cycle.
Design session 2 (120 min)	Review of design session 1 (optional)	The researcher recapped the activities and reviewed the lesson blueprints generated from design session 1 with faculty-designer.
	Idea generation (15 min)	The faculty-designer and researcher brainstormed design ideas about the 5E learning cycle, including whether it was feasible to apply it to the course. During this phase, the faculty-designer and researcher discussed possible approaches to redesign lessons based on the thoughts brought forward by the faculty-designer.
	Modeling (30 min)	The faculty-designer was asked to map lesson elements and sequences to create lesson blueprints for a reimagined, future lesson. This phase was a codesign experience between the faculty-designer and the researcher to support the faculty through their use of the LEM toolkit.

Reflection (30 min)	The faculty-designer was asked to review the new lesson blueprint/s created. The researcher guided reflection with prompts to encourage the faculty-designer to talk aloud their reflections and what they were thinking in the moment.
Explanation (45 min)	The faculty-designer was asked to explain their visual blueprint/s, describing their selection of lesson elements, lesson sequencing, rationale for making decisions, and factors or considerations that guided their decisions.
Interview (60 min)	The researcher ended the workshop with an interview with the faculty-designer to gain a deeper understanding of their overall course design knowledge and practice using visual lesson blueprints.

3.3.2 Selection of Participants

In order to get a real-world account of design knowledge and practice, it was necessary to select faculty who planned to or were already partaking in a course redesign process. Given this, a purposive sampling (Creswell, 2013) was used to recruit faculty who had pre-allocated time for design and had a design need. These faculty would be more willing to participate in a series of workshops that can help improve their course design. This is relevant because design work requires extensive time and most faculty often express they lack time for design (Bennett et al., 2008).

After receiving IRB approval, a letter of invitation was sent to select STEM faculty teaching gateway courses at a south-eastern university, requesting their participation. The selection criteria included faculty who:

(1) Were planning to or were already partaking in a course redesign process for a STEM gateway course at their university;

(2) Had taught the course to be redesigned at least once; and

(3) Were willing to participate in all phases of the course modeling workshop.

Three faculty-designers (see Table 7) participated in the study from varied STEM disciplines. All three had between seven to ten years teaching experience with large class sizes ranging from 60 to 80 students.

Table 7

Participant Demographics

	Reema	Ella	Jared
Course Taught	Statistics	General Biology	Organic Chemistry
Teaching Experience	7 years	10 years	9 years
Class Size	60-90 students	70-80 students	70-80 students

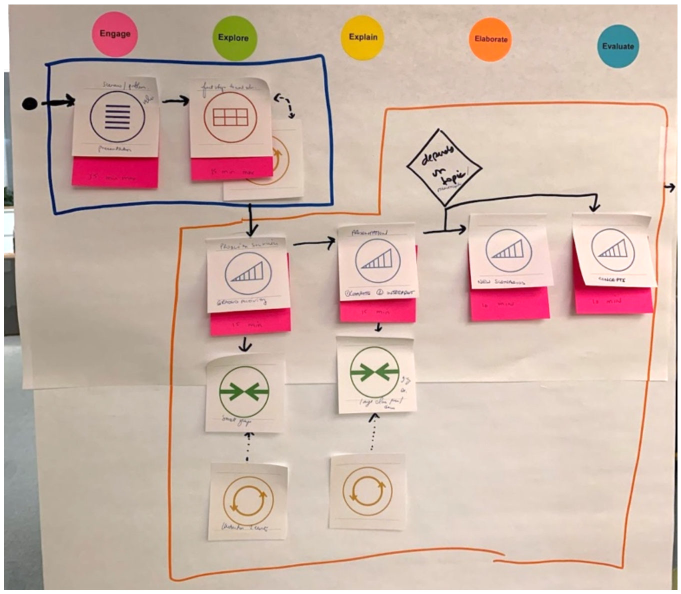
3.3.3 Research Instruments

This study utilized two research instruments: the LEM modeling toolkit and an interview protocol.

3.3.3.1 LEM modeling toolkit. Faculty-designers used the Learning Environment Modeling (LEM) course modeling toolkit (Dodd, 2016, 2018, 2019; Dodd & Gillmore, 2018; iLED, 2017) to create visual lesson blueprints. Dr. Bucky Dodd from the LxStudio (https://lxstudio.com/) at the University of Central Oklahoma granted permission to use the proprietary LEM modeling toolkit for this research. The toolkit includes five custom sticky notepads (i.e., post-it notes) with color-coded symbols that reference five course elements: Information (I), Dialogue (D), Feedback (F), Practice (P), and Evidence (E) (see Figure 13). Course elements are sequenced using predefined arrow and box notations that represent learning activities, environments, and interactions. Additional materials such the LEM design guide, flipcharts and markers were provided to assist faculty-designers in creating lesson blueprints. The LEM visual language is explained in the next section.

Figure 12

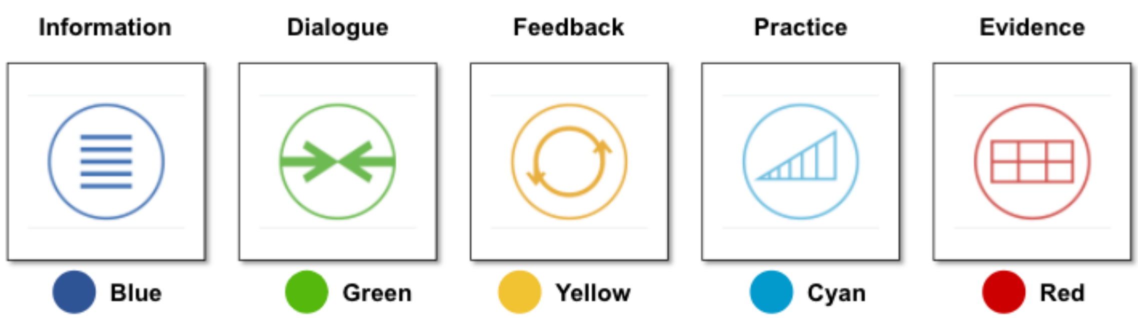
Sample Lesson Blueprint (BP2)



There are two parts to a LEM lesson blueprint (see Figure 12): lesson elements and lesson sequences. LEM lesson elements have a common notation system for representing five common course activities (see Figure 13). Each element is color coded and tagged with a unique symbol on a custom sticky post-it note.

Figure 13

LEM Lesson Elements



During the design process, faculty-designers selected multiple lesson elements and filled three required parameters per lesson element: (1) an activity description, (2) an activity type; and (3) a time-code indicating the duration of the activity (see Figure 14). Note that the original LEM system did not include the time-code parameter; the researcher added this as a third parameter for the purpose of this study.

Figure 14

LEM Parameters for Lesson Elements

Each lesson blueprint has multiple lesson elements that are prescribed to follow a sequence using directional arrows (see Figure 12). The entire lesson has a start and end point. Lesson-sequences are framed in color-coded border notations to describe the spaces where the learning experience is intended to take place (see Figure 15).

Figure 15

LEM Parameters for Learning Spaces

3.3.3.2 Interview protocol. The research utilized a semi-structured interview protocol for participant interviews as the workshop culminated. When developing the protocol, the researcher benchmarked on existing protocols that were developed by two research teams in Australia who conducted similar research to this study (Bennett et al., 2006; Goodyear & Markauskaite, 2008). The research teams each emailed their protocols for review. The researcher examined the two protocols and determined the scope of questions from the prior research did not align specifically to the scope of this study. Given this, the researcher could not use the existing protocols as is, but was guided by their protocol design. The researcher then prepared an interview protocol unique for this study.

3.4 Data Collection

The “Say-Do-Make” framework suggests that there are three perspectives from which we can gather information from people: from what people say, from what people do, and from what people make. Traditional data collection methods were focused primarily on *what people say* (through interviews, explanations, and questionnaires) and *what people do* (through observations). Listening to or reading *what people say* tells us what they are thinking, expressed in words as explicit knowledge; watching *what people do* shows us their actions and behaviors, expressed as observable knowledge (Sanders, 1999). “Make tools” (through design artifacts, drawings, and toolkits) (Sanders 1999, p. 5; Sanders 2001, p. 4) enables us to see *what people make*, accessing their tacit and latent knowledge related to: (1) deeper levels of expression; (2) unspoken or difficult-to-express thoughts, feelings, ideas, imaginations, or dreams; and (3) discoveries of unknown or undefined needs (Sanders, 1999, 2001, 2002). However, *making* cannot stand alone and requires the designer to tell their story to supplement and add meaning to design artifacts (Sanders, 1999, 2001; Sanders & Stappers, 2014; Stubbs & Gibbons, 2008).

This research applies the "Say-Do-Make" framework (Sanders, 1999, 2001, 2002), generating multiple sources of data from each faculty-designer in textual, verbal, and visual forms. These provide the researcher with a deep and rich contextual understanding underlying the thinking and experiences of faculty-designers. Table 8 details the data sources gathered for this study.

Table 8

Data Sources

"Say-Do-Make" framework	Data sources
Say	• Design discussions • Semi-structured interviews
Do	• Design process: Idea generation, modeling, reflection, explanation
Make	• Lesson blueprints

3.4.1 Lesson Blueprints

Textual and visual data were collected from faculty-designer's lesson blueprints in two design sessions during the workshop. Faculty-designers utilized the LEM modeling toolkit, which provided a common visual design language to map ideas as well as to enhance the communication and understanding between the faculty-designer and researcher (Agostinho, 2009; Waters & Gibbons, 2004). Multiple design sessions allowed the faculty-designer to iterate and document the evolution of their lesson sequences. Visual lesson blueprints served as a common design artifact on-hand, which the faculty-designer and the researcher could refer to during the reflection and explanation phases of the workshop. A total of 13 lesson blueprints were generated from the course modeling workshop among three faculty (see Table 9) and analyzed for this study. Each lesson blueprint was mapped to one class session. Reema mapped three lesson blueprints that spanned between 50 to 61 minutes of class time. Ella mapped three lesson blueprints that spanned between 55 minutes to 79 minutes of class time. Jared mapped seven lesson blueprints that spanned between 35 minutes to 60 minutes of class time.

Table 9

Summary of Lesson Blueprints Generated from the Workshop

Faculty participant	Design session	Lesson blueprint identifier	Lesson blueprint name	Lesson duration
Reema	Session 1	BP1	BP1-REEMA-DS1-01	61 min
	Session 2	BP2	BP2-REEMA-DS2-01	50 min
		BP3	BP3-REEMA-DS2-02	50 min
Ella	Session 1	BP4	BP4-ELLA-DS1-01	55 min
		BP5	BP5-ELLA-DS1-02	79 min
	Session 2	BP6	BP6-ELLA-DS2-01	75 min
Jared	Session 1	BP7	BP7-JARED-DS1-01	51 min
		BP8	BP8-JARED-DS1-02	39 min
		BP9	BP9-JARED-DS1-03	40 min
	Session 2	BP10	BP10-JARED-DS2-01	50 min
		BP11	BP11-JARED-DS2-02	50 min
		BP12	BP12-JARED-DS2-03	35 min
		BP13	BP13-JARED-DS2-04	60 min

3.4.2 Design Discussions and Interviews

The course modeling workshop had two design sessions that integrated a 4-step design process (idea generation, modeling, reflection, and explanation) to help facilitate a systematic process for the faculty-designer and the researcher to engage in deep design discussions. Each design session was scheduled as a 3-hour session, however this varied during implementation, often exceeding the three hours scheduled per session. Each faculty spent between six to seven hours with the researcher on brainstorming, designing, and talking about their disciplines of Biology, Statistics, and Organic Chemistry. For the purpose of the research, only design discussions held during the reflection and explanation steps were used for data analysis because it was in these steps where faculty-designers reflected and explained their visual blueprint/s, describing their selection of lesson elements, lesson sequencing, rationale for making decisions, and factors or considerations that guided their decisions.

Table 10

Design Discussions and Interviews Included in the Data Analysis

Faculty participant	Design discussions from the reflection and explanation phases in design session 1	Design discussions from the reflection and explanation phases in design session 2	Semi-structured interview	Total time
Reema	101 min	144 min	26 min	271 min (4 hrs. and 31 min)
Ella	97 min	30 min	46 min	173 min (2 hrs. and 53 min)
Jared	154 min	105 min	35 min	294 min (4 hrs. and 54 min)
Total				738 min (12 hrs. and 18 min)

Design discussions were video-recorded to capture both verbal explanation and visual data of faculty referencing their visual blueprints. The semi-structured interview conducted with each faculty-designer at the end of design session 2 was audio-recorded using Audacity. Table 10 summarizes the amount of data collected from design discussions and faculty interviews. Reema's conversation time included in the data analysis was approximately 4.5 hours in duration; Ella's conversation time included in the data analysis was approximately 3 hours in duration; and Jared's conversation time included in the data analysis was approximately 5 hours in duration. In total, over 12 hours of audio-visual data was analyzed for the study.

3.5 Data Preparation and Analysis

This study utilizes a two-phased hybrid inductive-deductive analysis approach which combines inductive and deductive methods (see Figure 16) (Fereday & Muir-Cochrane, 2006; MacCarthy, 2021). During the first phase, inductive analysis was conducted to examine how STEM faculty-designers select lesson elements and sequence lessons in visual lesson blueprints. The six "design patterns of practice" derived from Phase 1 were used as a priori codes to guide the deductive analysis process in Phase 2, which led to emergent themes describing the contextual factors and the knowledge frames activated during design practice.

Figure 16

Two-Phased Hybrid Inductive-Deductive Approach

	Phase 1 **Inductive Analysis of Lesson Blueprints**	**Phase 2** **Deductive Analysis of Design Discussions and Interviews**
Data Collection	**Step 1:** Modeling lesson blueprints	**Step 1:** Conducting interviews and design discussions
Data Preparation	**Step 2:** Digitizing blueprints	**Step 2:** Transcribing and reviewing interviews and design discussions
Data Analysis	**Step 3:** Flowcharting blueprints **Step 4:** Schematizing blueprints **Step 5:** Timelining blueprints **Step 6:** Abstracting blueprints **Step 7:** Defining design patterns of practice	**Step 3:** Initial deductive coding **Step 4:** Identifying themes **Step 5:** Reviewing themes **Step 6:** Defining contextual factors and mapping knowledge frames

To meet the analytic needs of research, Saldana (2016) encourages researchers to develop new and hybrid methods. The hybrid approach in this research study complements the research purpose which requires that the outcomes of design practice be derived first before arriving at the outcomes of design knowledge. Detailed descriptions of each phase and the subsequent steps are explained in the next sections.

3.5.1 Phase 1: Inductive Analysis of Lesson Blueprints

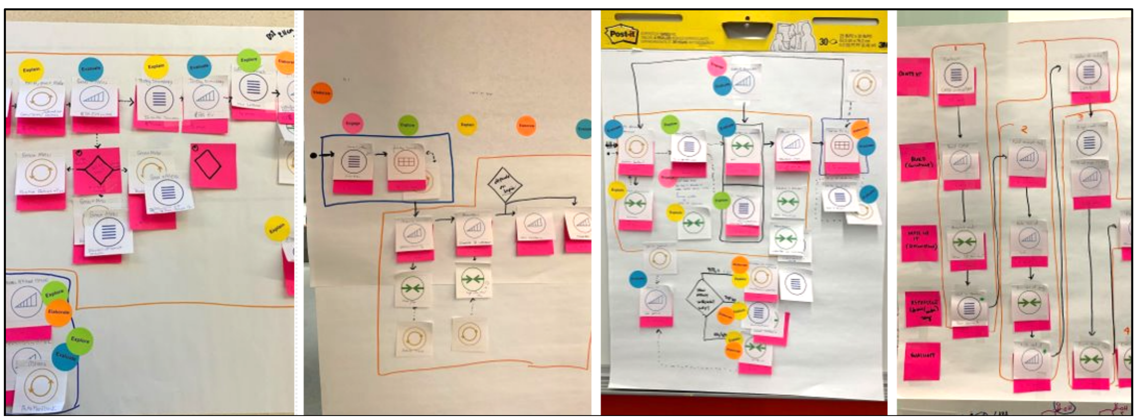
The construct of design practice was examined by referencing the 13 visual lesson blueprints produced from the course modeling workshop. As a design artifact, a lesson blueprint can be categorized as a type of visual data or design document (Saldana, 2016) which served two audiences in this study. For the faculty-designer, lesson blueprints enabled the expression of tacit knowledge on lesson design and provided a concrete visual tool to codify lesson design elements and represent lesson sequences (Pain, 2012). For the researcher, lesson blueprints helped develop shared meaning of design ideas with participants, build rapport between the researcher and the participant, and facilitated verbal discussion and reflection among participants (Pain, 2012).

Visual data warrants the use of visual methodologies to understand and interpret images and enhance the richness of the overall data (Glaw et al., 2017; Pain, 2012). Visual methods are new and novel to qualitative research that adds another dimension to traditional data collection methods by capturing more details and multidimensional data than verbal and written methods alone (Glaw et al., 2017). Pain (2012), however, cautions that visual methods can bring forth additional challenges in analysis and presenting results. Tools for accurate analysis of visual data are also lacking (Mey & Dietrich, 2017).

Early stages of the analysis process brought about challenges in preparing and coding visual data. In its original form, lesson blueprints were collected as paper-based blueprints that were on flip-charts with LEM sticky notes and drawing notations representing lesson sequences (see Figure 17). These blueprints could be rolled and stored but faced risks of being damaged, altered, or lost. By characteristic, paper-based blueprints are generative drawings, which means they were uniquely hand-made and each one contained an original lesson design representation (Fiorella & Mayer, 2016; Sanders & Stappers, 2014). Markauskaite and Goodyear (2014) recommends paying attention to such generative features because they capture intuitive pedagogical knowledge from participants. The challenge in this research study was that generative drawings were messy, unorganized, and essentially, not ready for coding and analysis.

Figure 17

Sample LEM Lesson Blueprints in Paper-Based Format



This challenge motivated the researcher to develop a seven-step method for collecting, preparing and analyzing visual data to elicit new knowledge models and derive deeper understanding from lesson blueprints (see Table 11). The process began at the initial step of modeling blueprints, digitizing blueprints, flowcharting blueprints, schematizing blueprints, timelining blueprints, abstracting blueprints, and defining "design patterns of practice." Inductive analysis was conducted to examine how STEM faculty-designers select lesson elements and sequence lessons in visual lesson blueprints beginning at step 3. Each step is explained in the next section. Sample graphics are provided to show the LEM blueprints in their different formats.

Table 11

Steps to Collecting, Preparing, and Analyzing Visual Data from Lesson Blueprints

Process	Step	Tool used	Visual format produced
Data Collection	Step 1: Modeling lesson blueprints	LEM Modeling Toolkit	LEM Paper-Based Blueprint
Data Preparation	Step 2: Digitizing blueprints	Digital Phone Camera	LEM Digitized Blueprint (see Appendix A)
Data Analysis	Step 3: Flowcharting blueprints	Draw.IO Online Diagram Software	LEM Flowchart (see Appendix B)
	Step 4: Schematizing blueprints	MAXQDA	Text-Based Lesson Blueprint (see Appendix C)
	Step 5: Timelining blueprints	MAXQDA Codeline and Document Comparison Functions	Time-Based Lesson Blueprint (see Appendix D)
	Step 6: Abstracting blueprints	Powerpoint Diagramming Software	Abstracted Lesson Blueprint (see Appendix E)
	Step 7: Defining design patterns of practice	--	--

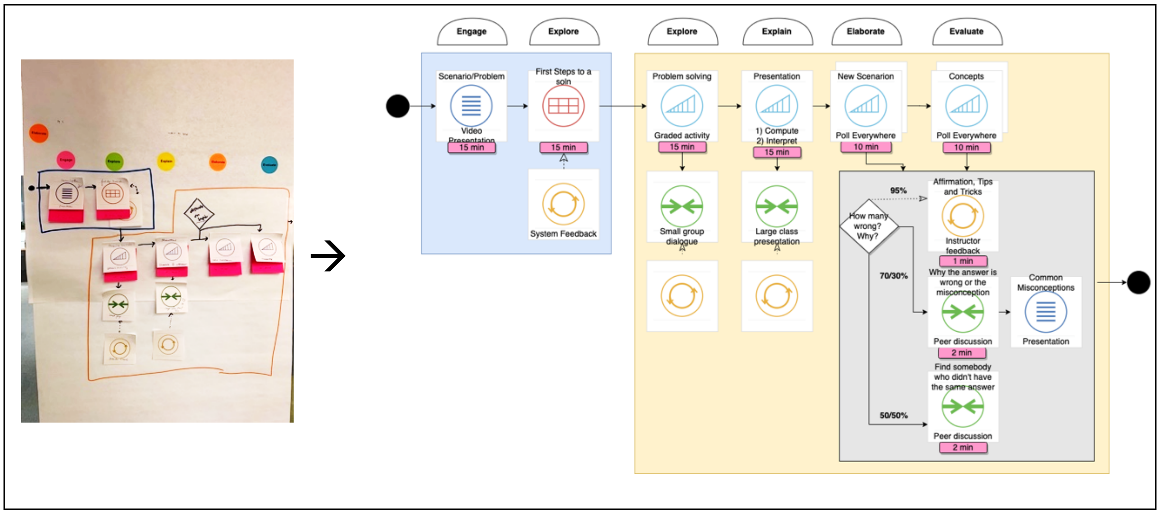
3.5.1.1 Step 1: Modeling lesson blueprints. This step involved the faculty-designer and the researcher, both engaged in a design process. Faculty-designers used the LEM modeling toolkit to create paper-based lesson blueprints that represented lesson elements and lesson sequences (see Figure 16). Additional materials such the LEM design guide, flipcharts and markers were provided to assist in drawing directional arrows denoting lesson sequences and color-coded borders to describe the spaces where the learning experience is intended to take place (see Figure 15). Faculty-designers were also required to handwrite the three required parameters for each lesson element: (1) an activity description, (2) an activity type; and (3) a time-code indicating the duration of the activity (see Figure 14). The researcher assisted by organizing the layout of the LEM sticky notes and securing them with sticky tape.

3.5.1.2 Step 2: Digitizing blueprints. In its original form, lesson blueprints were collected as paper-based blueprints that were modeled on flipcharts. Immediately after a design session, the researcher used a digital phone camera to take pictures of all lesson blueprints for the purpose of digitizing the paper-based blueprint into a digital blueprint graphic. Delays may risk lesson blueprints being damaged, torn, or altered from sticky notes falling out, compromising data for the research. This step ensured that visual data from lesson blueprints were preserved in its original form for data integrity, accuracy, completeness. At the end of step 2, the researcher shifted into the multiple steps of coding and analysis.

3.5.1.3 Step 3: Flowcharting blueprints. In this step, the researcher refurbished the LEM blueprint into a LEM flowchart using the Draw.IO Online Diagram Software (see Figure 18). LxStudio provided the researcher with a LEM digital graphic library that could be installed into Draw.IO to facilitate this process. The researcher extracted all handwritten text from the LEM post-its and redrew all each building block, arrow, and border to present a cleaner, more standardized view of the lesson blueprint. At this step, the blueprint still strongly applied LEM notations to preserve the original ideas of the faculty-designer. The goal of this step is to enhance the legibility, accuracy, and conformity of the visual data to aid succeeding steps that require coding and analysis. It was necessary to convert paper-based blueprints into a digital format readable by qualitative data analysis programs like MAXQDA which could support and enable the systematic coding and analysis of lesson elements and sequences. At this step, the researcher conducted a scan of all blueprints and initial codes were identified on common activity types per lesson element and sequence patterns.

Figure 18

Converting LEM Paper-Based Blueprints to Flowcharts (BP2)



3.5.1.4 Step 4: Schematizing blueprints. In this step, the researcher focused the analysis on understanding how faculty-designers selected lesson elements. All digital blueprint graphics created in step 2 were imported into MAXQDA for coding. The researcher began the coding process by using the traditional coding methods of visual data such as highlighting sections of a visual graphic and assigning codes for each lesson element and its parameters across all 13 maps. This process quickly fell short and posed limitations; multiple code labels began to make the visual data illegible and difficult to analyze (see Figure 19). One option at this point was to resort to paper-based coding by printing each flowchart but this strategy posed data integrity risks.

The researcher then explored an alternate method to efficiently process the visual data from flowcharts. The researcher explored the idea of reverse engineering lesson blueprints from visual data into textual data which could then be coded and analyzed as text documents in MAXQDA. To do this, the researcher developed a coding schema that outlined every parameter of a LEM lesson element, then built a syntax to define the coding logic to ensure every element would be encoded consistently.

Figure 19

Challenges of Traditional Coding Methods for Visual Data in MAXQDA

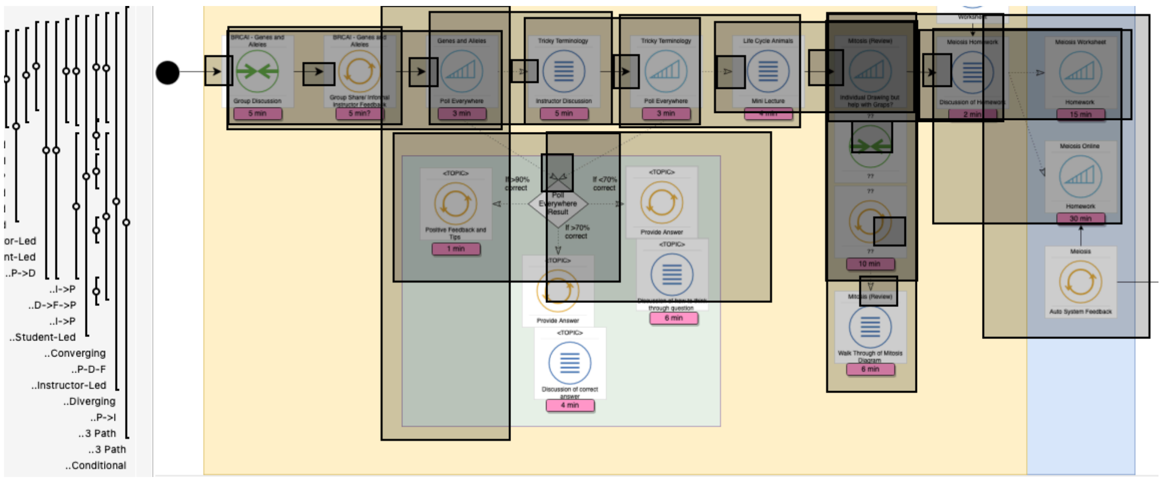


Figure 20

LEM Elements Coding Schema

Coding Syntax:

`[Element Type] – [How] – [What] [Time-Code]`

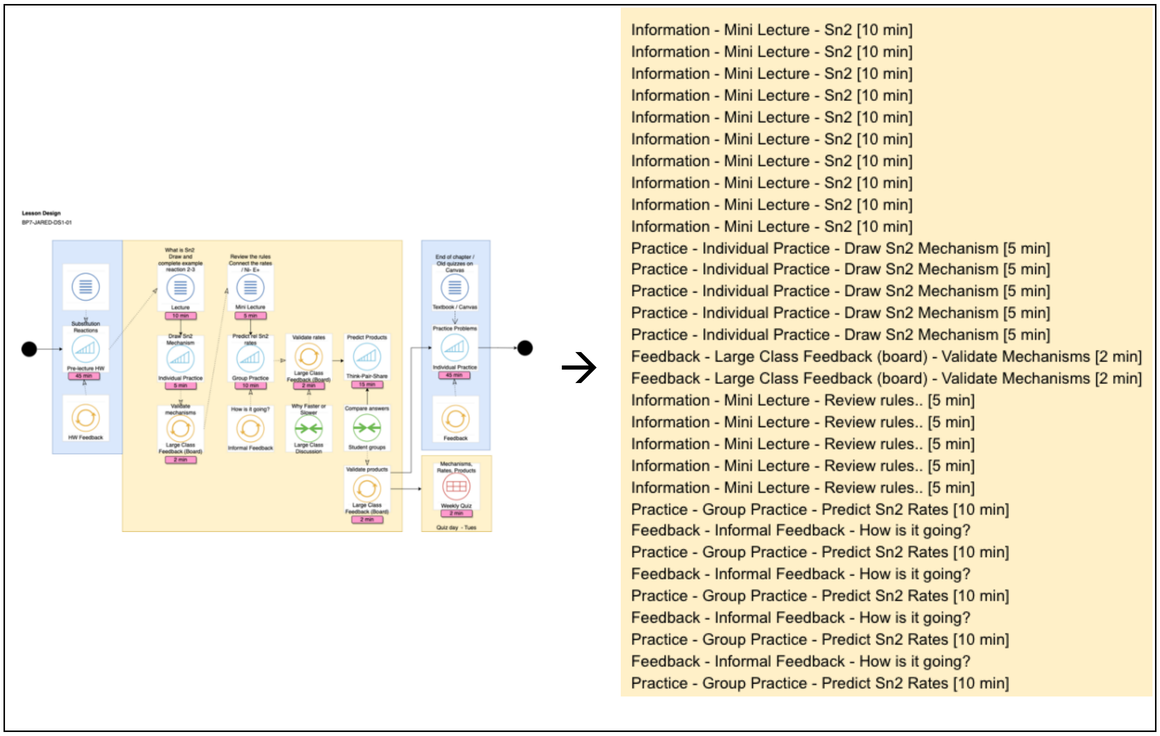
Sample textual data:

`Information — Mini Lecture — Sn2 [10 min]`

Figure 20 illustrates a sample of how a LEM element was encoded into textual data using the coding syntax. Applying the schema, the researcher documented a time-series for each blueprint and proceeded to assign codes for each lesson element and its parameters across all 13 maps (Figure 21). Initial codes were identified from common activity types per lesson element and sequence patterns.

Figure 21

Sample Time-Series for Visualizing Lesson Sequences (BP7)



3.5.1.5 Step 5: Timelining blueprints. In this step, the researcher focused the analysis on understanding how faculty-designers selected lesson elements and sequenced lessons. Leveraging the schema for text-based blueprints in step 4, the researcher generated timelines for each blueprint using the Codeline and Document Comparison visualization functions in MAXQDA. Codeline is a “visual function that displays a sequential view of a document’s coded segments” while the Document Comparison function shows a visual comparison of coded text (MAXQDA, 2020, p. 395). These functions were instrumental during the data analysis process because it allowed the researcher to treat the LEM elements as variables that could be isolated or grouped together for comparison purposes.

Based on the color-coded coding system defined by the researcher, MAXQDA timelines show meaningful data about the frequency, duration, order and positioning of lesson elements in visual lesson blueprints. The researcher analyzed the timelines as visual images to draw comparisons, interpretations, insights, or patterns in several iterations: for a single lesson element (see Figure 22), for multiple lesson elements within a single lesson blueprint (see Figure 23), or for multiple elements across multiple lesson blueprints (see Figure 24). Initial codes were tested, reviewed, and collapsed into themes.

Figure 22

Sample Timeline View of an Isolated Lesson Element (Practice)

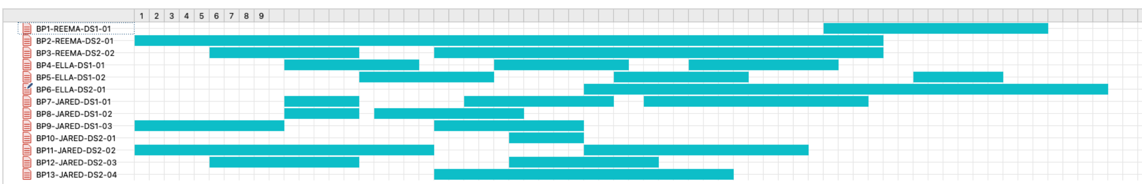


Figure 23

Sample Timeline View of Multiple Lesson Elements in a Single Lesson Blueprint (BP3)

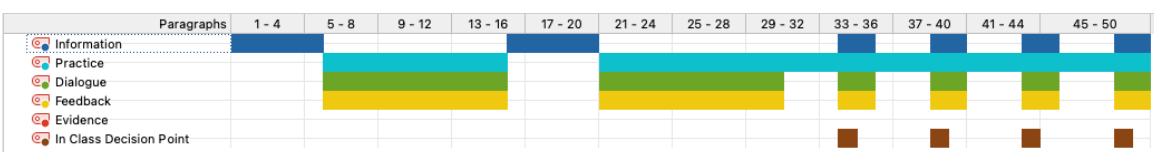
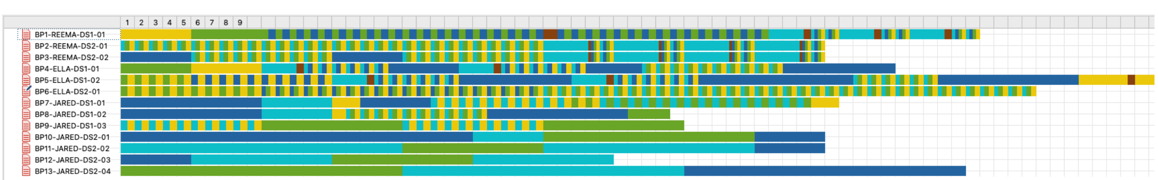


Figure 24

Sample Timeline View of Multiple Lesson Elements Across Multiple Blueprints



3.5.1.6 Step 6: Abstracting blueprints. In this step, the researcher focused the analysis on understanding how faculty-designers sequenced lesson elements. The researcher attempted to remodel the LEM blueprint into an abstracted, scaled-down representation to efficiently review and check for themes specific to lesson sequencing (see Figure 25). With a scaled-down view, the researcher could compare all 13 lesson blueprints side by side for patterns. The abstracted view helped solve the researcher's challenge of losing sight of patterns within multiple and large pieces of visual data by reducing the amount of detail from the original blueprints. This helped the researcher focus on analyzing sequences and deducing patterns of similarities, differences, and complexity among blueprints.

To create an abstracted, scaled-down LEM representation, the researcher had to first draw miniatures on paper and revise them until they were accurate. Then the researcher engaged in on-going analysis to check and refine the specifics of each design pattern and begin to generate clearer names for each. At the end of the process, the researcher digitized all abstracted LEM blueprints using Powerpoint diagramming tools for a future reporting purpose.

3.5.1.7 Step 7: Defining design patterns of practice. In this step, the researcher finalized the themes emergent from lesson blueprints as six "design patterns of practice" It was determined that lesson blueprints revealed two design perspectives: (1) narrow activity sequences that span across short segments of class time, and (2) broader lesson sequences that span across a full class time, possibly across multiple lessons. Activity sequences were described to have three design patterns: (1) prerequisite activity sequence, (2) parallel activity sequence, and (3) conditional activity sequence. Lesson sequences were described to have three design patterns: (1) repeating lesson design, (2) linked lesson design, and (3) structured lesson design.

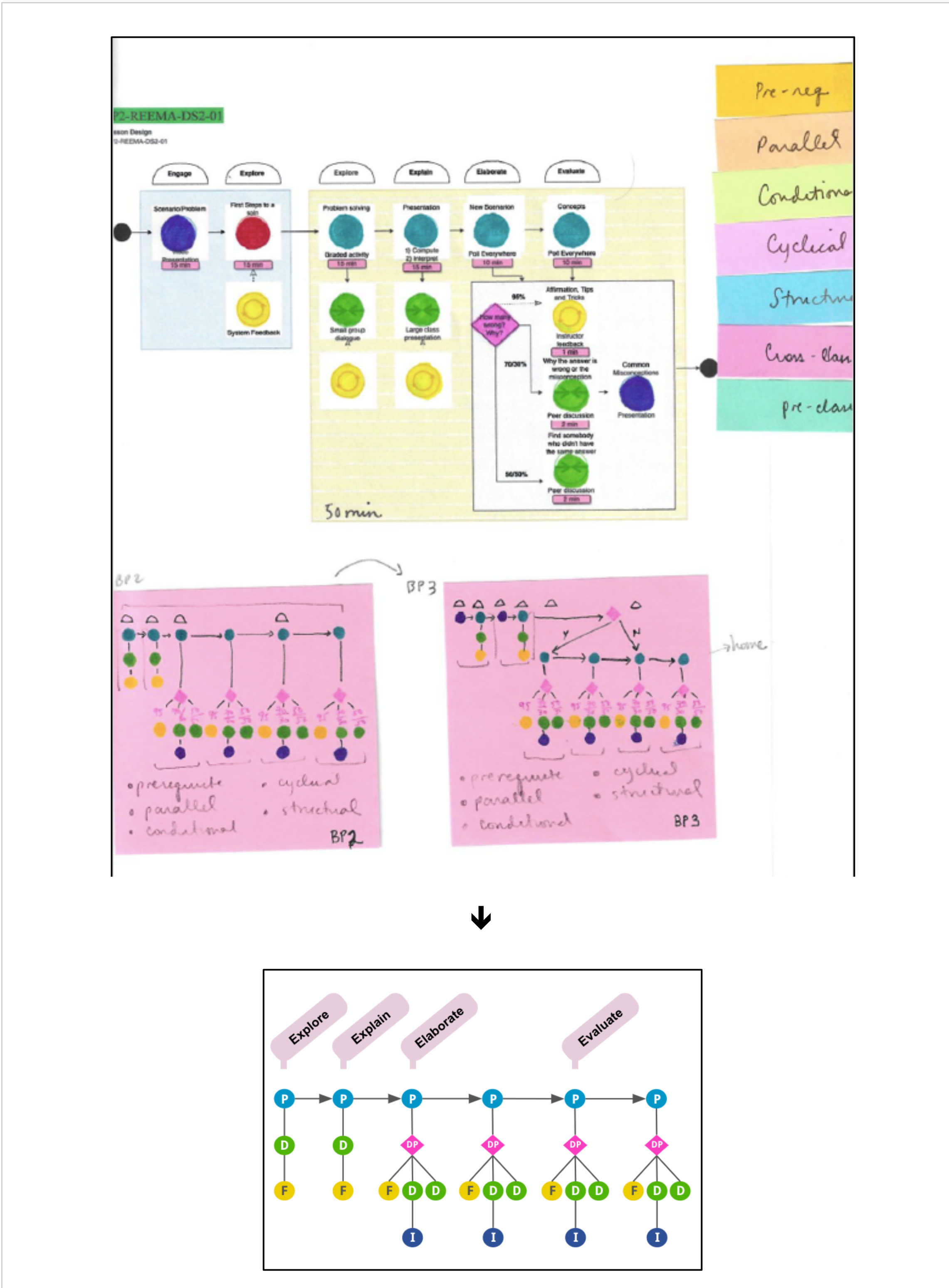
3.5.2 Phase 2: Deductive Analysis of Design Discussions and Interviews

In phase 2, the researcher utilized a six-step deductive analysis process. Each step is described in the next sections.

3.5.2.1 Step 1: Conducting interviews and design discussions. This research gathered data through a course modeling workshop which required faculty participants to take part in two design sessions that integrated a 4-step design process (idea generation, modeling, reflection, and explanation). For the purpose of the research, only design discussions held during the reflection and explanation steps were used for data analysis because it was in these steps where faculty-designers reflected and explained their visual blueprint/s, describing their selection of lesson elements, lesson sequencing, rationale for making decisions, and factors or considerations that guided their decisions. Design discussions were video-recorded to capture both verbal explanation and visual data from the faculty referencing the visual blueprint. The semi-structured interview conducted with each faculty-designer at the end of design session 2 was audio-recorded using Audacity. The interviews followed a semi-structured protocol (see Appendix) that covered a series of questions about selecting lesson elements (i.e., information, practice, dialogue, feedback, evidence) and lesson sequencing. Table 9 summarizes the amount of data collected from design discussions and faculty interviews.

Figure 25

Developing Abstracted LEM Blueprints (BP2)



3.5.2.2 Step 2: Transcribing and reviewing interviews and design discussions. Design discussions and interviews were transcribed and imported into MAXQDA for coding and analysis. The researcher ensured that each transcript was formatted similarly, segmenting conversations into sections that align to each phase of the course modeling workshop (i.e., idea generation, modeling, reflection, explanation, post-interview). The researcher began by reading the transcript accompanied with the audio/video recording playback of each faculty participant. The researcher reviewed the data several times per faculty to gain familiarity before attempting the initial coding to gain a holistic understanding of faculty reflections, explanations, and interviews. This was a demanding process because each faculty-designer had lengthy transcripts from their long hours engaged in the workshop (see Table 9). While reading and listening, the researcher kept a printed copy of the lesson blueprints on hand for reference, which was especially useful when the faculty would reference a specific topic within their subject area.

3.5.2.3 Step 3: Initial deductive coding. A first round of coding was applied to all design discussion transcripts followed by interview transcripts to code significant phrases and statements that conveyed similar meanings. The six “design patterns of practice” derived from Phase 1 were used as a priori code categories. Some codes were also noted in vivo while other codes were noted by their meaning or concept. While reading the transcript and listening to the audio-video recordings, the researcher noted specific keywords, meanings, or concepts that describe the key characteristics related to each design pattern. This facilitated data reduction to focus the analysis.

3.5.2.4 Step 4: Identifying themes. The researcher conducted a second round of coding on the design discussions for each blueprint to dig deeper and revisit faculty thoughts specific to their lesson blueprints. It was also at this step where the researcher referenced printed copies of lesson blueprints on hand for reference, which was especially useful when the faculty would describe their thoughts about a specific type of activity or lesson sequence. The researcher then validated existing codes, sorted and grouped similar codes into broader themes (i.e., contextual factors), and identified emergent or supporting codes. An initial draft of a thematic map was developed to map design patterns of practice to themes on contextual factors.

3.5.2.5 Step 5: Reviewing themes. In this step, the research continued to review the themes across transcripts and blueprints to check if codes fit each category. Themes which did not have enough data to support or did not align to reasoning on design patterns were discarded from the analysis. With few participants, the researcher prioritized codes that were common to at least two of the three participants. The thematic map was revised based on changes.

3.5.2.6 Step 6: Defining contextual factors and mapping knowledge frames. In this step, the researcher finalized theme names and referenced them as the contextual factors, which indicated the reasons or rationale that drove a design decision for a design pattern in the blueprint. At this point, the researcher had to review the transcripts once again to examine the knowledge frames (Markauskaite & Goodyear, 2014) referenced by faculty participants. This meant reading closely on which contextual frames were faculty thinking about or referencing during their interviews and design discussions. The researcher coded statements as either the student context (SF), teacher context (TF), course context (CF), learning environment context (LEF), institutional context (IF), or disciplinary context (DF). The thematic map was finalized to include knowledge frames and their alignment to contextual factors and design patterns.

3.6 Strategies for Quality

This research employed multiple strategies to maintain validity and dependability (Creswell, 2013; Yin, 2014):

1. Robustness: as a single case study with multiple sources of data collection (i.e., design discussions, interviews, lesson blueprints) in different forms (textual, verbal, and visual) and formats (audio recording, design documents, video recordings) to strengthen findings.
2. Prolonged engagement and persistent observation: the researcher had prolonged interactions with participants through a course modeling workshop that required six hours of interaction with each participant.
3. Peer review or debriefing: the researcher discussed findings and results with the research adviser and research methodologist.
4. Clarification of researcher bias: the researcher described any possible biases and clarified the role of the researcher in the research document.
5. Rich, thick descriptions: the researcher compiled a detailed transcript and descriptions of participants.
6. Member checking: after converting paper-based blueprints to a digital format, the researcher created a website for each participant to compile and access all lesson blueprints and to further check them for accuracy and validation. Any errors encountered were informally discussed and corrected.

3.7 Role of the Researcher

As an instructional design professional for over 15 years, coupled with experience as a faculty and administrator in higher education, the researcher is well-qualified to facilitate a design workshop using modeling toolkits such as sticky notes and flip charts. The researcher has also been certified as a Learning Environment Architect by the LxStudio at the University of Central Oklahoma on designing lesson blueprints using the LEM toolkit and facilitating design conversations.

As a trained instructional designer, the researcher recognizes that she had to go beyond her personally founded design knowledge and practices to engage in authentic research on faculty design knowledge and practice. It was important, not only to capture faculty design ideas, thinking, and blueprint sequences, but to get the details of their subject matter accurately represented. The researcher had to shift into the world of the faculty, examine how their courses manifest in practice, and inhibit their frames of thought. While lengthy, a design workshop format was necessary for these purposes. A workshop format also offered prolonged and dedicated time for systematic design discussions. Each faculty spent between six to seven hours with the researcher brainstorming, designing, and talking about their disciplines of Biology, Statistics, and Organic Chemistry. The more that the researcher listened to the faculty talk about their subject matter, their design problems, and their design ideas, the easier it was to remain in the role as a researcher.

The daily work of an instructional design professional is to help faculty solve learning problems and identify course design solutions. The researcher recognized this natural tendency early and tried very hard to remain objective throughout the research. It is reasonable, and expected, that faculty would ask questions or feedback about their lesson designs during the workshop. It was very difficult for the researcher to "not give the answer," especially if the answer would influence the results of the study. When the researcher sensed the faculty was asking for direct answers, there was an intentional effort to redirect the discussion so that faculty would make their own design decisions. The researcher constantly reminded herself that in that moment, she was a researcher and not an instructional designer. This ensured results were authentic to the discipline and authentic to the way design knowledge and practices are represented – through the lens of the faculty-designer and not the lens of an instructional designer. The researcher followed the planned research process and used the protocols that were in place to help guide the research study.

The researcher also expected that faculty may need help creating their visual lesson blueprints at the beginning of the design process and may have to play a more active role as an instructional designer to support faculty through the workshop activities. Naturally, new design work was challenging for faculty. There were two instances where faculty got stuck in the workshop. The first instance was when faculty had to organize their thoughts and map out LEM elements into lesson blueprint sequences. The LEM toolkit had a learning curve at the start because it was new, but this was expected. The researcher helped the faculty in the laying out post-its and reviewing the arrow notations, but did not influence the selection of elements or sequencing decisions of the blueprint.

The second instance was when faculty were prompted to use the 5E learning cycle. Two of the three faculty wanted to make their own learning cycle. At that moment, the researcher had to make a decision whether to help the faculty organize their ideas into a cycle or not. Because the workshop was a real faculty development program, the researcher chose to switch into the role of an instructional designer to codesign new learning cycles that faculty wanted to try out for their "future lesson design." Extra support during this ideation phase was necessary to push the workshop process forward so that faculty could engage in succeeding phases of modeling, reflection and explanation, which were key points of data gathering for the study.

3.8 Summary

This research study utilized an innovative method for data collection, preparation, and analysis referencing the "say-do-make" framework (Sanders, 1999, 2001, 2002) to generate multiple sources of data in textual, verbal, and visual forms. Design artifacts in the form of lesson blueprints captured textual and visual data, while design discussions and interviews captured verbal data. The two-phased hybrid inductive-deductive approach developed for this study offers a new method for inductive analysis on visual data and deductive analysis of design discussions and interviews. Phase 1 outlined a seven-step inductive analysis process of lesson blueprints which begins at modeling lesson blueprints, to digitizing blueprints, flowcharting blueprints, schematizing blueprints, timelining blueprints, abstracting blueprints, to defining design patterns of practice. Phase 2 outlined a six-step deductive analysis process which begins with conducting interviews and design discussions, transcribing and reviewing data, initial coding, identifying themes, reviewing themes, and defining contextual factors and mapping knowledge frames. The next chapter presents the results of the study.

CHAPTER 4: RESULTS

This chapter details the results from the study. The first section presents results on design practice, specifically on faculty selection of lesson elements and lesson sequences in visual lesson blueprints. The second section presents results on design knowledge, specifically on the contextual factors and knowledge frames that influence STEM faculty-designers as they engage in lesson design.

4.1 Examining Design Practice

This section provides results to the first research question: How do STEM faculty-designers select lesson elements and sequence lessons in visual lesson blueprints? Visual data from 13 lesson blueprints was analyzed to answer this question.

4.1.1 Selection of Lesson Elements

4.1.1.1 Variety of activity types in lesson blueprints. Lesson elements are the individual building blocks that make up a lesson blueprint. Each lesson blueprint denotes a single class session. Five types of elements were analyzed across the 13 lesson blueprints: Information (I), Dialogue (D), Feedback (F), Practice (P), and Evidence (E). For each element selected, faculty filled out a LEM custom sticky note with three required parameters: (1) an activity description, (2) an activity type; and (3) a time-code indicating the duration of the activity. A total of 150 element blocks were collected and coded from the 13 lesson blueprints.

Results show that STEM faculty have a variety of activity types selected in their lesson blueprints. These activity types reflect the variety of instructional strategies that STEM faculty are using in the classroom. Table 12 references the list of activity types identified per type of lesson element.

Table 12

Variety of Classroom Activities by Lesson Element

Lesson element	Activity type
Information (I)	Mini-lectures (<=15 min) Lectures (>15 min) Answer explanations Lesson summaries
Practice (P)	Hands-on manipulatives Written questions Problem-solving exercises Poll quizzes Case studies
Dialogue (D)	Large-class discussions Project discussions Small-group discussions Pair dialogue Student Q&A
Feedback (F)	Large class feedback Individual student feedback Peer review and feedback Group feedback Informal instructor feedback
Evidence (E)	Group project

Note: Activity types are limited to classroom activities; online or homework activities were excluded from the study.

4.1.1.2 Frequency of lesson elements in lesson blueprints. The 13 lesson blueprints showed that faculty utilized a combination of elements in each class session, with at least three of the five types of elements selected per blueprint (Table 13). The dialogue (D) and practice (P) elements were dominant across all lesson blueprints. The information (I) element was seen in all blueprints but one. The feedback (F) element was seen in 9 of 13 (70%) blueprints. The least selected element was evidence (E), seen in only one blueprint.

Table 13

Frequency of Lesson Elements by Participant

Participant	Lesson Blueprint	Information (I)	Practice (P)	Dialogue (D)	Feedback (F)	Evidence (E)
Reema	BP1	●	●	●	●	
	BP2	●	●	●	●	
	BP3	●	●	●	●	
Ella	BP4	●	●	●	●	
	BP5	●	●	●	●	
	BP6	●	●	●	●	●
Jared	BP7	●	●	●	●	
	BP8	●	●	●	●	
	BP9		●	●	●	
	BP10	●	●	●		
	BP11	●	●	●		
	BP12	●	●	●		
	BP13	●	●	●		

4.1.1.3 Distribution of lesson elements in lesson blueprints. Time-based lesson blueprints were examined for the distribution of lesson elements across blueprints. These results provide comparative insight on how faculty are making use of class time. To be noted is that in this analysis, the element of evidence (E) was excluded since it did not have enough data to make comparisons.

Comparing individual elements and their distribution across blueprints in Figure 26, 27, 28, and 29, the following trends were observed:

First, there is a wide spread of how faculty distribute elements in lesson blueprints. There was no common element preferred for the beginning of class, middle of the class, or towards the end of the class. A class could begin with either an information (I), practice (P), dialogue (D) or feedback (F) element.

Figure 26

Timeline View of the Lesson Element on Information

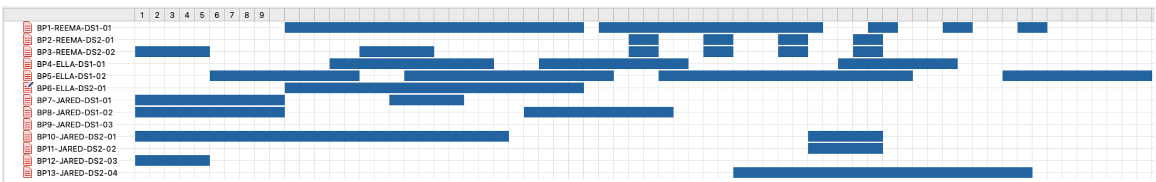


Figure 27

Timeline View of the Lesson Element on Practice

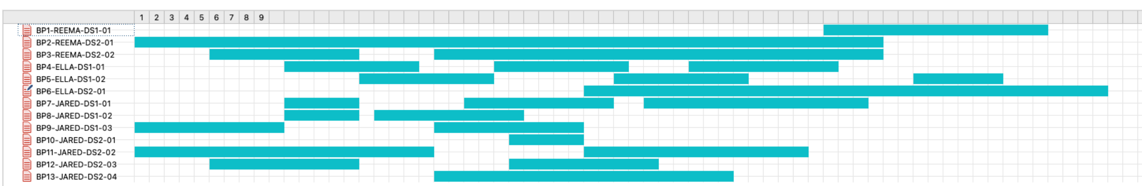


Figure 28

Timeline View of the Lesson Element on Dialogue

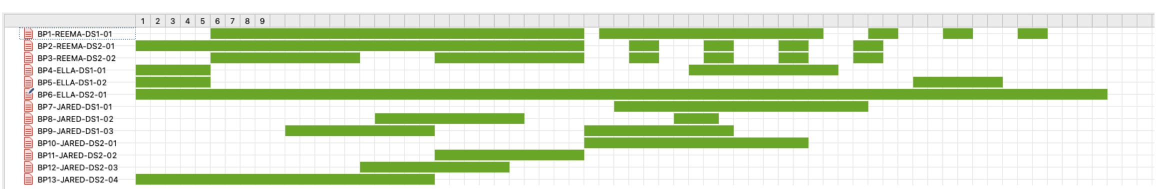
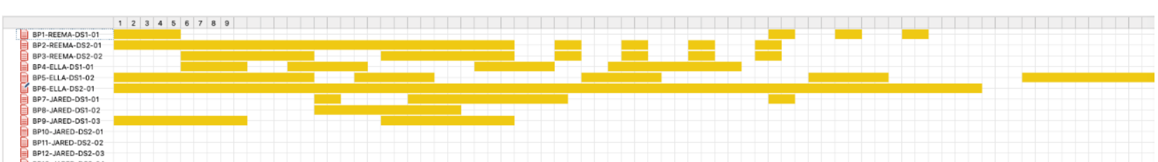


Figure 29

Timeline View of the Lesson Element on Feedback



Second, elements vary in duration, ranging anywhere from as short as 5 minutes to 25 minutes. Duration of elements are displayed on the x-axis in minutes. No element was scheduled to take place for more than 25 minutes. Breaking down the 150 elements from all blueprints, 31% of elements spanned 1 to 5 minutes, 46% of elements spanned 6 to 10 minutes; 10% of elements spanned 11 to 15 minutes; and 13% of elements spanned 20 to 25 minutes.

To recall, lesson blueprints created in DS1 reflected a "current lesson," while lesson blueprints created in DS2 reflected a "future lesson" that faculty were just beginning to reimagine. When comparing lesson blueprints between the two design sessions, there was a notable difference in how faculty selected lesson elements during design session 1 (DS1) and design session 2 (DS2):

First, comparing the number of lesson elements selected, Jared and Ella had similar trends (see Figures 31 and 32). They had more elements selected in each lesson blueprint from DS1 than in DS2. Second, comparing the number of lesson segments, there were shorter lesson segments observed in lesson blueprints from DS1 than in DS2 (see Table 14). DS2 showed longer lesson segments. Note that a lesson segment is a chunk of time allocated to one or more lesson elements. Reema had a different trend where the number of elements and segments were not noticeably different between DS1 and DS2 (see Figure 30).

What was common to all three faculty was that lesson blueprints from DS1 showed more specific and granular time estimates per element, emphasizing minute-level details compared to DS2. Examples of specific and granular estimates would be like "2 minutes," "6 minutes," or "8 minutes." Lesson blueprints from DS2 showed larger time estimates that did not emphasize minute-level details like “10 minutes,” “15 minutes,” “20 minutes” but rather included time buffers.

Table 14

Comparison of Lesson Blueprints from DS1 and DS2

Faculty participant	Design session	Lesson blueprint identifier	Lesson blueprint name	Lesson duration	No. of lesson elements selected	No. of lesson segments
Reema	Session 1	BP1	BP1-REEMA-DS1-01	61 min	18	8
	Session 2	BP2	BP2-REEMA-DS2-01	50 min	22	6
		BP3	BP3-REEMA-DS2-02	50 min	24	8
Ella	Session 1	BP4	BP4-ELLA-DS1-01	55 min	15	8
		BP5	BP5-ELLA-DS1-02	79 min	18	11
	Session 2	BP6	BP6-ELLA-DS2-01	75 min	12	5
Jared	Session 1	BP7	BP7-JARED-DS1-01	51 min	11	8
		BP8	BP8-JARED-DS1-02	39 min	9	6
		BP9	BP9-JARED-DS1-03	40 min	6	4
	Session 2	BP10	BP10-JARED-DS2-01	50 min	4	4
		BP11	BP11-JARED-DS2-02	50 min	4	4
		BP12	BP12-JARED-DS2-03	35 min	4	4
		BP13	BP13-JARED-DS2-04	60 min	3	3

4.1.2 Lesson Sequences

The 13 lesson blueprints were analyzed to examine how faculty-designers sequence lessons. When analyzing sequences, the researcher attempted to detect patterns in how elements were arranged, ordered, positioned, or grouped over one or more class sessions. Two prominent design strategies surfaced that describe how faculty sequence lessons:

Figure 30

Segmented View of Reema's Blueprints

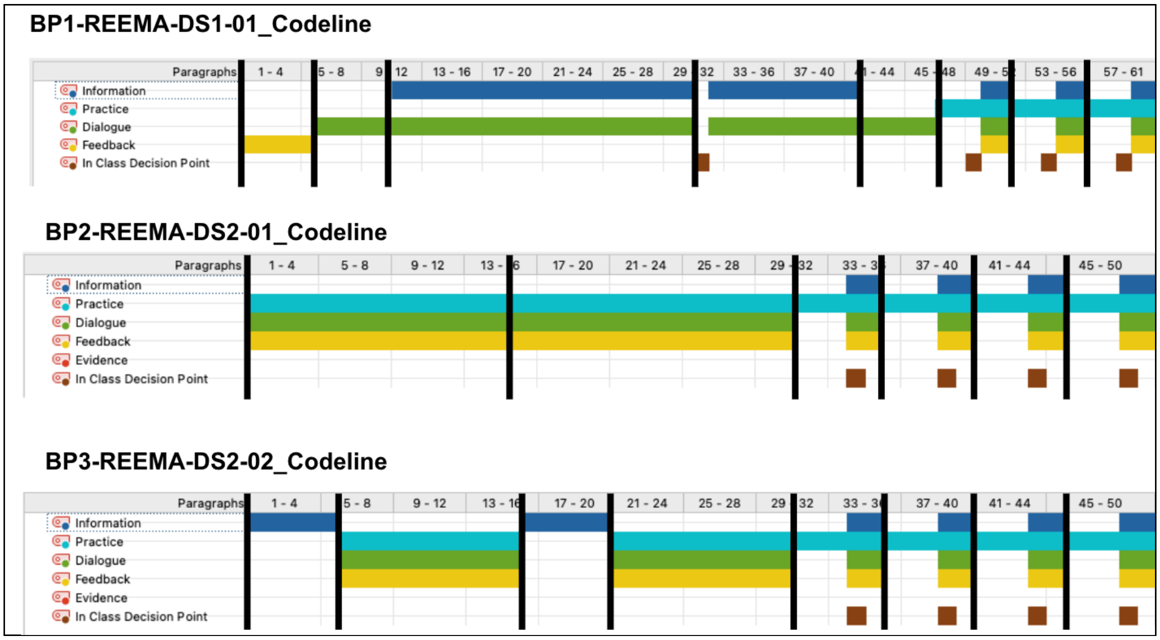


Figure 31

Segmented View of Ella's Blueprints

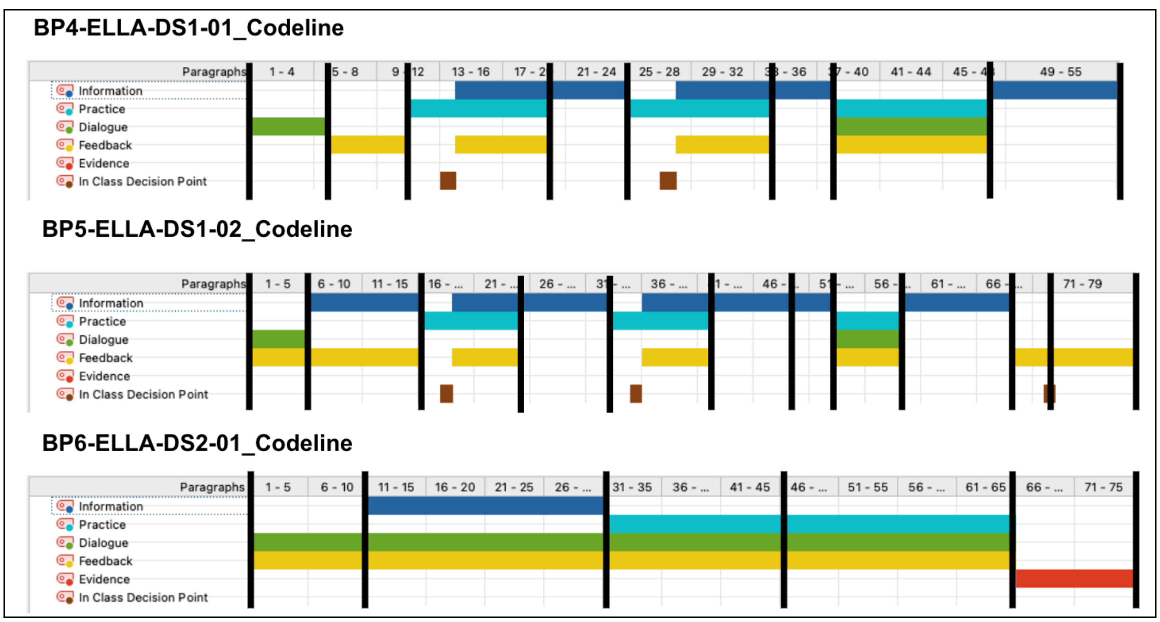
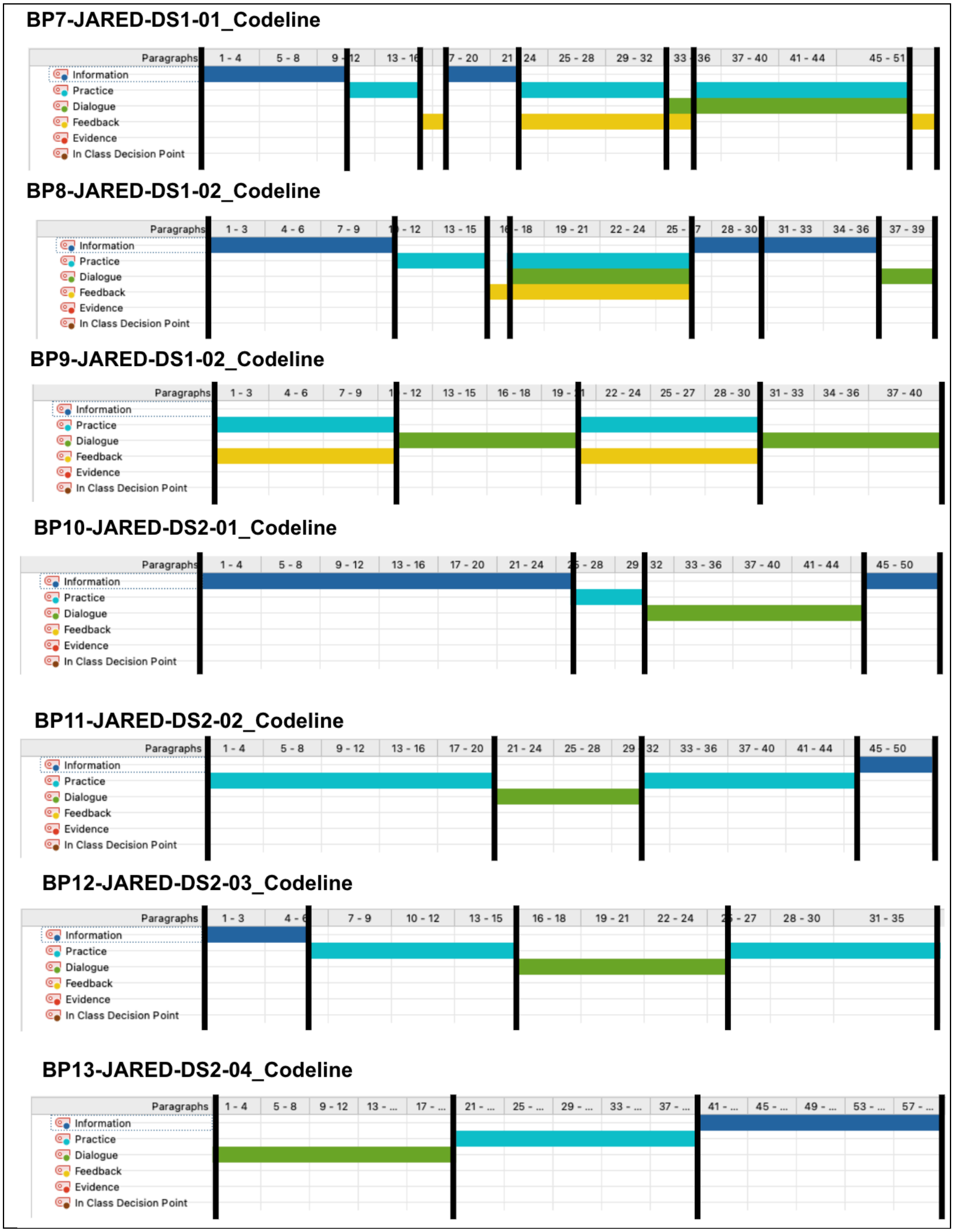


Figure 32

Segmented View of Jared's Blueprints



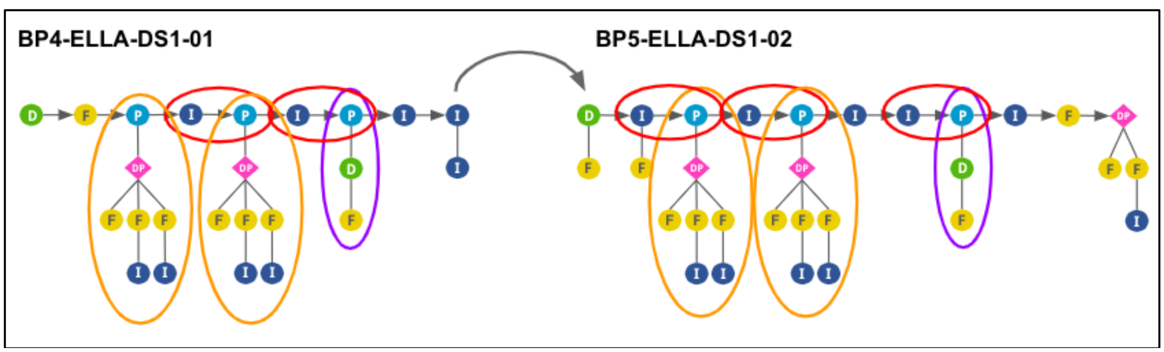
The first strategy showed that faculty-designers were designing *activity sequences*, which was a strategy to select and arrange lesson elements into short activity segments that execute within a class session. Three design patterns were identified among activity sequences: (1) prerequisite activity sequence, (2) parallel activity sequence, and (3) conditional activity sequence.

The second strategy was that faculty-designers were designing *lesson sequences*, which was a strategy to arrange multiple activity sequences into one or more lessons. Three design patterns were identified among lesson sequences: (1) repeating lesson sequence, (2) linked lesson sequence, and (3) structured lesson sequence.

The six design patterns among activity sequences and lesson sequences contribute to the distinct *design patterns of practice* emergent among STEM faculty from this study. Each design pattern of practice is described in more detail in the next sections.

Figure 33

Example Lesson Blueprints with Highlighted Activity and Lesson Sequences



4.1.2.1 Prerequisite activity sequence. This sequence describes an activity sequence with two or more elements that execute in succession. In Figure 33, for example, BP4 and BP5 show elements encircled in red that illustrate the prerequisite logic DO (I), THEN (P). This representation means that within a lesson, faculty are likely to execute an information (I) activity followed by a practice (P) activity. This is just one of the five prerequisite activity sequences, and the most frequently used, among the 13 lesson blueprints (see Table 15). In this activity sequence the order of elements matter, such that the preceding element is the primary activity that leads the sequence.

Table 15

Identified Prerequisite Activity Sequences

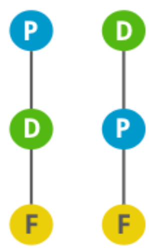
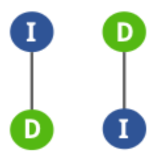
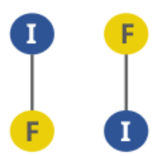
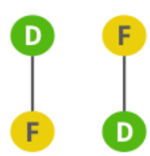
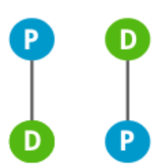
Representation	Logic	Lesson blueprint
I → P	DO (I), THEN (P)	BP3, BP4, BP5, BP7, BP8, BP10, BP12, BP13
I → D	DO (I), THEN (D)	BP6, BP8, BP9
P → D	DO (P), THEN (D)	BP10, BP11, BP12, BP13
P → F	DO (P), THEN (F)	BP7, BP8
D → P	DO (D), THEN (P)	BP11, BP12

Note: Sequences with only one occurrence in the analysis were omitted.

4.1.2.2 Parallel activity sequence. This sequence describes an activity sequence with two or more elements that execute concurrently. In Figure 33, for example, BP4 and BP5 show elements encircled in violet that illustrate the parallel logic DO (P) AND (D) AND (F). This representation means that within a lesson, faculty are likely to execute a practice (P) activity with a concurrent dialogue (D) activity and feedback (F) activity. This is an example of the triad parallel sequence, also the most frequently used, among the five parallel activity sequences identified among the 13 lesson blueprints (see Table 16). Four of the five parallel activity sequences are parallel dyad sequences or sequences with two concurrent elements. While this activity sequence has elements that execute concurrently, the first element in the sequence is denoted as the primary element that triggers the parallel activity sequence to execute. While mapping, some faculty indicated DO (D) AND (F) in their lesson blueprints, while others indicated the reverse, to DO (F) AND (D); both were captured to represent the same logic.

Table 16

Identified Parallel Activity Sequences

Activity sequence	Representation	Logic	Lesson blueprint
Triad parallel		DO (P) AND (D) AND (F) DO (D) AND (P) AND (F)	BP2, BP3, BP4, BP5, BP6, BP8
Dyad parallel		DO (I) AND (D) DO (D) AND (I)	BP1, BP10
		DO (I) AND (F) DO (F) AND (I)	BP5, BP9
		DO (D) AND (F) DO (F) AND (D)	BP5, BP7
		DO (P) AND (D) DO (D) AND (P)	BP6, BP7

Note: Sequences with only one occurrence in the analysis were omitted.

4.1.2.3 Conditional activity sequence. This sequence describes an activity sequence that is initially held by a condition and executes based on the outcome of a decision point by the faculty. This type of sequence was evident in lesson blueprints with decision points (i.e., pink diamond symbols) (see Table 17). There were two common conditional activity sequences identified among the lesson blueprints. In Figure 33, for example, BP4 and BP5 show elements encircled in orange that illustrate the conditional logic which is to DO (P), THEN HOLD at DECISION POINT (DP). The sequence is dependent on the decision point of the faculty based on the CONDITION posed. The faculty will determine at that point of lesson which pathway to proceed into among the three pathways identified:

IF CONDITION A IS MET, DO (F)

ELSE IF CONDITION B IS MET, DO (F) AND (I)

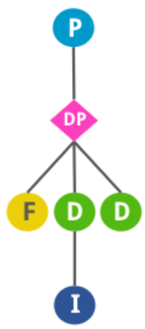
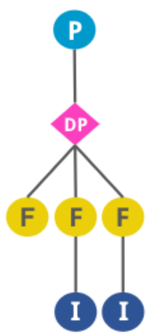
ELSE IF CONDITION C IS MET, DO (F) AND (I)

Table 17 shows two commonly identified conditional activity sequences among the 13 lesson blueprints.

4.1.2.4 Repeating lesson sequence. This sequence describes two or more identical activity sequences that execute in succession. In Figure 33, for example, BP4 and BP5 show elements encircled in red and orange that illustrate a repeating sequence. Elements encircled in red are an example of a repeating prerequisite sequence while elements encircled in orange are an example of a repeating conditional sequence. The repeating lesson sequence shows faculty have the intent to reuse the design of their activity sequences throughout a lesson. There was evidence of all three types of activity sequences (prerequisite, parallel, conditional) repeating in lesson blueprints (see Table 18).

Table 17

Identified Conditional Activity Sequences

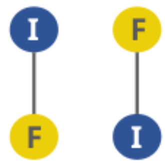
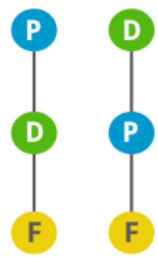
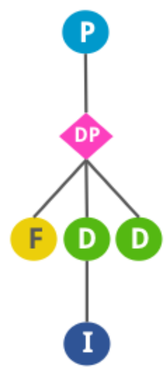
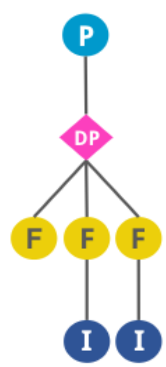
Representation	Logic	Lesson blueprint
	DO (P), THEN HOLD at DECISION POINT (DP): IF CONDITION A IS MET, DO (F) ELSE IF CONDITION B IS MET, DO (D) AND (I) ELSE IF CONDITION C IS MET, DO (D)	BP1, BP2, BP3
	DO (P), THEN HOLD at DECISION POINT (DP): IF CONDITION A IS MET, DO (F) ELSE IF CONDITION B IS MET, DO (F) AND (I) ELSE IF CONDITION C IS MET, DO (F) AND (I)	BP4, BP5

Note: Sequences with only one occurrence in the analysis were omitted.

Table 18

Identified Repeating Lesson Sequences

Activity sequence	Representation	Lesson blueprint
Repeating prerequisite		BP3 (2 repetitions) BP4 (2 repetitions) BP5 (3 repetitions) BP7 (2 repetitions) BP8 (2 repetitions)
		BP9 (2 repetitions)
		BP7 (3 repetitions)

Repeating parallel		BP9 (2 repetitions)
		BP2 (2 repetitions) BP3 (2 repetitions) BP6 (2 repetitions)
Repeating conditional		BP1 (3 repetitions) BP2 (4 repetitions) BP3 (4 repetitions)
		BP4 (2 repetitions) BP5 (2 repetitions)

4.1.2.5 Linked lesson sequence. This sequence is described as two or more lesson sequences linked to execute in succession. All faculty used this design pattern in at least one of their design sessions. The linked lesson sequence shows that faculty have the intent to connect lessons together. Figures 34 to 37 show examples of linked lesson blueprints of each faculty.

Figure 34

BP2 linked to BP3 (Reema)

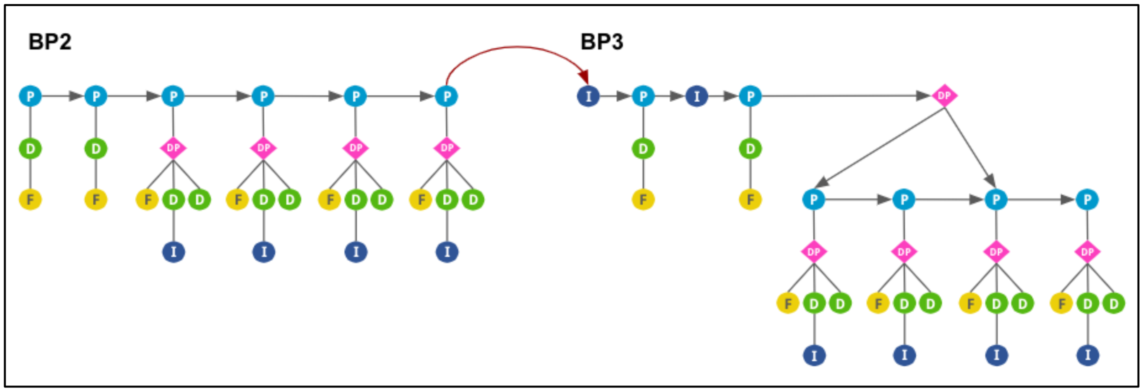


Figure 35

BP4 linked to BP5 (Ella)

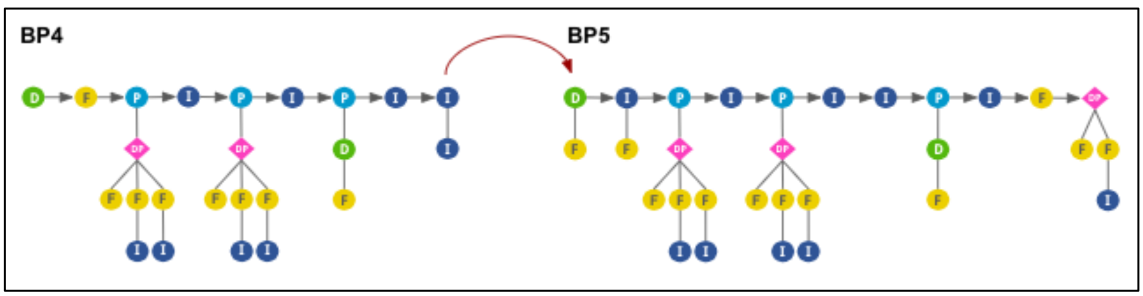


Figure 36

BP8 linked to BP9 (Jared)

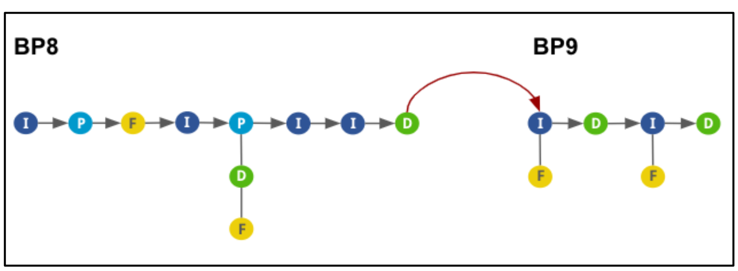
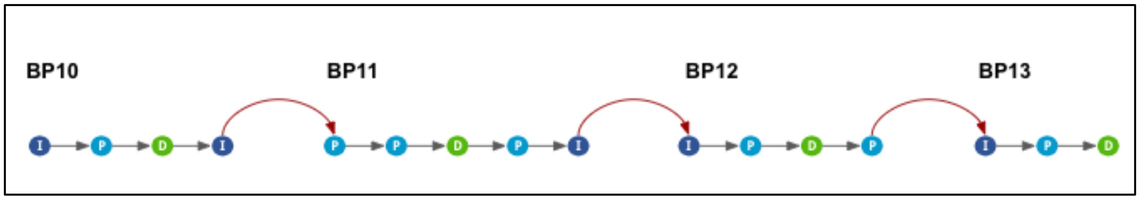


Figure 37

BP10 linked to BP11, BP12, and BP13 (Jared)



4.1.2.6 Structured lesson sequence. This sequence describes a lesson sequence with a predetermined structure that prescribes the order of which activity sequences execute. All faculty used this design pattern during the second design session, after being prompted to use a learning cycle. The learning cycle served as a guiding template to align activity sequences. Ella and Jared designed an original learning cycle for their lesson blueprints (see Figure 38 and 40). Reema applied the 5E learning cycle to her lesson blueprints (see Figure 39).

Figure 38

Structured Lesson Blueprint of Ella

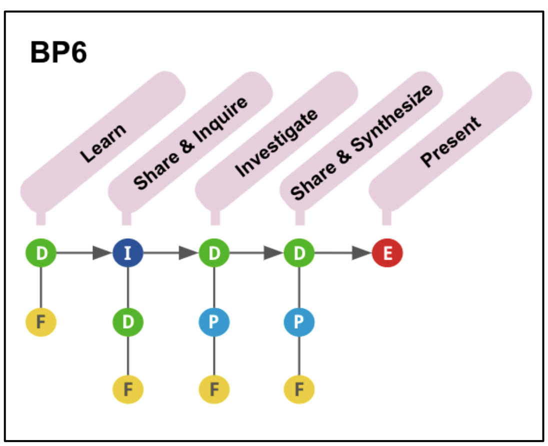


Figure 39

Structured Lesson Blueprints of Reema

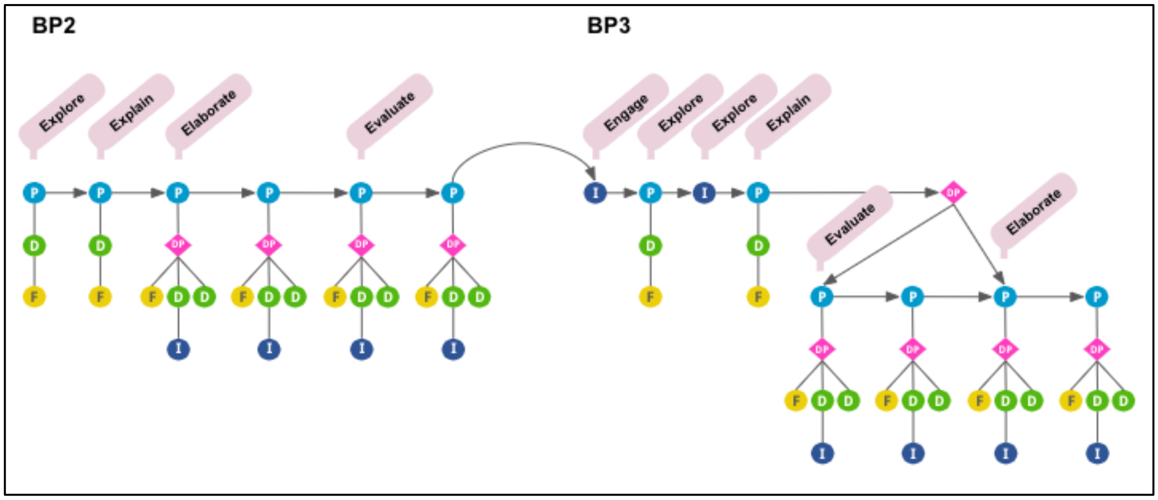
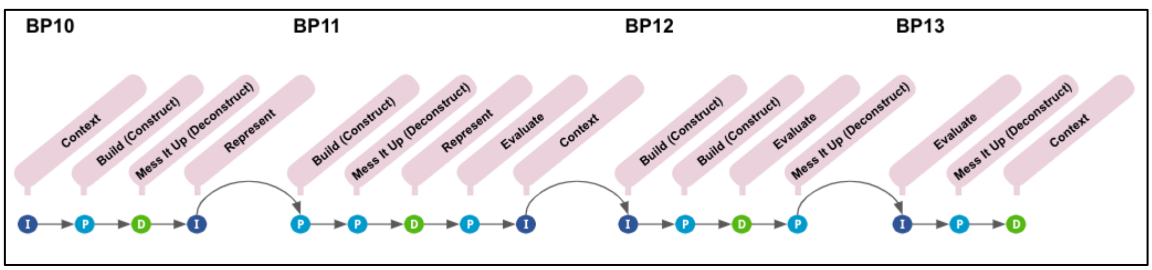


Figure 40

Structured Lesson Blueprints of Jared



To summarize this section, Figure 41 shows the design patterns of practice evident in each lesson blueprint. The perquisite activity sequence, repeating lesson sequence, and linked lesson sequence were the top three sequences used.

Figure 41

Evidence of Design Patterns of Practice in Lesson Blueprints

Participant	Lesson Blueprint	Prerequisite Activity Sequence	Parallel Activity Sequence	Conditional Activity Sequence	Repeating Lesson Sequence	Linked Lesson Sequence	Structured Lesson Sequence
Reema	BP1						
	BP2						
	BP3						

Ella	BP4						
	BP5						
	BP6						
Jared	BP7						
	BP8						
	BP9						
	BP10						
	BP11						
	BP12						
	BP13						

4.2 Examining Design Knowledge

This section provides results to the second research question: How do knowledge frames and contextual factors influence STEM faculty-designers as they engage in lesson design? Faculty design sessions and interviews were analyzed to drive results for this question. The results begin with a discussion of the contextual factors that influenced faculty design decisions for each design pattern of practice (i.e., prerequisite activity sequence, parallel activity sequence, conditional activity sequence, repeating lesson sequence, linked lesson sequence, and structured lesson sequence) followed by a discussion of the knowledge frames that faculty-designers think about or consider when engaged in a design process (e.g., student frame (SF), teacher frame (TF), course frame (CF), learning environment frame (LEF), institutional frame (IF), disciplinary frame (DF)). Selected quotations are included to support research findings related to contextual factors. These quotations are also coded (e.g., [SF], [TF]) to support research findings on knowledge frames in the latter section.

4.2.1 Contextual Factors

4.2.1.1 Prerequisite activity sequence. The prerequisite activity design sequence highlights the need for faculty to constantly check how students are doing while they are in the classroom. Lesson blueprints show that the most dominant prerequisite pattern was for students to engage in practice and dialogue after new information was presented. Interviews revealed three contextual factors that influenced faculty decisions on designing prerequisite activity sequences (see Table 19).

Table 19

Contextual Factors that Influence Prerequisite Activity Sequence Design

Design pattern	Design characteristics	Contextual factors
Prerequisite activity sequence An activity sequence with two or more elements that execute in succession	Beginning stages Prior experiences Preparation Formative assessment	Designing for entry level misconceptions, fears, and anxiety Designing for deliberate practice and accountability Designing for early alerts and feedback

Designing for entry level misconceptions, fears, and anxiety. The prerequisite activity design sequence alludes to faculty's prior knowledge about students from their past teaching experience. All three instructors teaching Organic Chemistry, Biology, Statistics courses anticipated students' fears, anxiety, variety of skill levels, learning gaps, challenges, and misconceptions in the coursework, having taught their courses for several years. They have learned that "a lot of students come into [class] viewing it as a roadblock. They describe students as "scared" and think "this is the dragon that I have to slay."

> It's hard at the beginning of class to kind of get them to settle a little bit [TF]. They come into the class starting so stressed [SF]… it can be hard to get them to engage with the material [TF] because they're, they're scared of it, right [SF]. They are so stressed out very much in their own heads [SF].

Students have more misconceptions at the beginning of the course “because of things that were either left ambiguous… or because they learn the wrong things somewhere else.” [SF] Jared explained that students’ misconceptions, fears, and anxiety stem from the lack of preparation from prior coursework and this feeds into advanced courses: “There's been a lot of research… that talks about [the] wide variety of skill levels of students [SF]. Some are good… other students… don't have any basis to build [their] skills [SF].”

Designing for deliberate practice and accountability. The prerequisite activity design sequence showed that faculty predominantly interweaved class time with practice activities. This was to check if students understood new material, if students can perform the foundational skills, or if they are ready for the next class session. Faculty emphasizes the need for practice after new content has been presented to show that students can “use that content [SF].” “We need to build in checks [TF].” Practice activities are important in that it serves “almost like training wheels [SF]” that develop student mastery and automation. Faculty prefer an active learning environment where they are not just “giving information,” but that students need to “do something” rather than just be passive listeners [TF]. “We have to give them more than lectures [TF].” Faculty want to “get students involved and engaged and thinking” in the classroom because “the more that [students] are working, the better they're learning. [TF]” She contrasted in-class group activities to online or homework assignments

> …they will do better if they talk about something in class [LEF]. I know it's going to be effective because it's going to engage the students… if

> you get students thinking in the classroom [LEF], if you can get them engaged at all, it's a win [SF].

Faculty also shared in frustration that they needed a way to “hold students accountable” or else “they wouldn't necessarily do [the written exercises] [TF].” Reema experienced that her students would “just wait until she tells the answer” and students would avoid any struggle around thinking about solving the problems given in the exercise. Ella and Reema both believed that their lesson design was a contributor to students not engaging in individual written exercises because they were not graded [TF]. With large classes [LEF], they couldn’t manage to grade every exercise student worked on in the classroom. Ella reflected:

> Because I wasn't making them [do it], some would do it but not everyone would [TF]. Converting individual exercises into group projects would hold students more accountable because they're going to have to explain it to their classmates and actually [SF]… turn something in that gets graded… they're going to care more and be more invested [SF].

Designing for early alerts and feedback. With the prerequisite activity design, faculty predominantly interweaved class time with dialogue and feedback activities. This highlights faculty intentions on giving “substantial feedback” [TF] to students after they have been given new information or have engaged in practice activities. Faculty perceived they were the “expert in the room” and it was critical in their role to give students constructive, “good feedback,” [TF] or else they would “not really be doing [their] job” [TF] on addressing student difficulties, answering questions, challenging thoughts and ideas, and correcting mistakes. More importantly, faculty emphasized their need for early alerts, which required identifying struggling students as early as possible and giving them feedback.

> It's like If I go drop you in the jungle and you don't speak the language, you're going to get hit by a snake and die [SF]. You need to know this [SF] and I need to know whether you know it or not as early as possible [TF]. It's also good to be able to give feedback very early... well before the withdrawal date [SF].

Faculty also emphasized the need for positive feedback and incentives so students feel rewarded [SF]. Reema expressed that “it is important for me as the instructor to be on the same side as my students [TF].” Ella expressed that talking or highlighting exceptional students in class would show the whole class that she “cared [TF]” about the work that they did. For this reason, she chose concrete activities like using manipulatives or poster projects to “show off what [students] have learned” among other students [SF].”

4.2.1.2 Parallel activity sequence. The “practice-dialogue-feedback” parallel activity sequence was the most predominant parallel activity sequence in lesson blueprints. Interviews revealed four contextual factors that influenced faculty decisions on designing parallel activity sequences (see table 20).

Table 20

Contextual Factors that Influence Parallel Activity Sequence Design

Design pattern	Design characteristics	Contextual factors
Parallel activity sequence An activity sequence with two or more	Collaboration Interaction Relationships	Designing for group-based dialogical thinking Designing for collaborative peer support Designing for disciplinary fluency

elements that execute concurrently	Designing for timely and personalized feedback

Designing for group-based dialogical thinking. Activities with manipulatives and problem-solving exercises were often designed as group activities for students to work with others in dialogue and receive feedback in class. All faculty believed that it was not enough to give students information [TF]. Dialogical thinking mattered for students to be involved in on-going talk and exchanging viewpoints among classmates [SF]. Reema strongly believed that students experiencing difficulty on topics can benefit from group-based dialogue:

> [It] is rough. I am thinking specifically in terms of the material that gets covered… [the students], in no way, will ever be able to come close to coming up with their own [understanding]... [SF] you need an intervention... a bit of a mini discussion. I think it makes it more interesting [TF] because you can sort of challenge the students to ask questions to each other and they have to go find those answers. [SF]

Ella valued classroom group activities as opportunities for students to think with each other, learn from each other, ask help, practice asking and responding to questions, and engage in “teach back” conversations where students “[become] teachers themselves [SF].” With group exercises, she believes that students “don't have to answer all the questions themselves. They have helpers [SF].”

Designing for collaborative peer support. Faculty also identified group dialogue as opportunities for students to build confidence working in small groups, especially helpful for students who “may be shy” to engage in a large class setting, “who may be distracted,” or “who feel like giving up. [SF]” For example, Ella shared that asking students to participate through "cold calling" or "asking for volunteers" for activities may embarrass students or be inequitable to many others "who will never" participate [SF]. To be more inclusive, group activities and dialogue promote a positive and safe space, free from embarrassment, for students to share and affirm their knowledge.

> This gives them support to feel confident… they are freshmen… if we didn't have [group activities and dialogue] built-in… they're going to feel uncomfortable because they are not sure if they've got the answers right [SF].

There is also a sense among faculty that in-class group activities "are better off" than individual activities because they are meant to "push" students to work [SF]. In some cases, students feel empowered when they feel they are the "expert in the group. [SF]" In other cases, group work helps generate participation among classmates [SF].

Designing for disciplinary fluency. Dialogue with peers helps validate students' self-understanding and verbally refine their disciplinary fluency and show evidence of this while in the classroom. This is a metacognitive process that students engage in to gauge what they think they know against what the other members of the class know. For Reema, dialogue helps students "bridge that gap between thinking they understand and understanding well enough to explain it to somebody else [SF]." Jared aptly describes that "students should be able to talk and discuss and say what they're thinking. If they can't use the words, it becomes pretty clear to them quickly that they don't know how to articulate it. [SF]" For Ella, frequent dialogue can help students develop the fluency to write answers to questions on exams. "Students practice articulating keywords and how they're thinking… that I don't just get a word salad on exams. [SF]"

All faculty also believe that students' career success requires the skill to converse fluently in the discipline, think critically, and explain ideas logically; these are equally important to passing board exams. Classroom dialogue helps because of the large amount of terminology that students must be familiar with in the STEM courses.

> I just want them to stay on task… try to use scientific and logical thoughts… a focused dialogue than fragmented…[SF][DF]
>
> When [encounter] a new scenario in their job [DF], they've got those pathways built for solving this kind of problem or looking at this kind of problem [SF]…
>
> It is just like learning a language; the best way to do it is to force yourself to actually speak the language… students have to be familiar with [terminology]... not only to understand, but then to communicate it back [SF].
>
> It is super important in all fields of Math... to be able to justify your logic and explain why you're coming to decisions and not just say, "Well, I don't know, I followed a formula." [DF]
>
> This is a really key part, especially for engineers… to work with other people… to come to solutions... to be able to explain your logic…[DF]

Designing for timely and personalized feedback. As seen in lesson blueprints, faculty plan time for feedback in parallel with practice or dialogue activities. They use this time to walk around classrooms, interact with students, and informally "sense" how students are doing [TF]. Ella shared her experience: "While I'm walking around, our preceptor is walking around, checking in to see if we need to make any corrections or help [prompt students]. [TF]" However, while critically important, there is a sense of being sneaky to overhear if students are "spreading the wrong information" or to check if they are "not taking [the activity] seriously. [TF]"

During the times allocated for dialogue and feedback in class, faculty believe they are able to get to know their students and build relationships to personalize feedback [TF]. This is exceptionally important to do in class because class sizes are very large and it would be impossible to get to know all students individually [LEF]. Faculty like Jared who has strong empathy for his students "feels so bad" for students who are "on the border" to fail [SF]:

> It is so stressful for me to proctor exams. I can tell they feel so bad [SF]. I don't like to be the bad guy [TF]…The grade is so important for them because they want to pass... [SF]. But now people come to my office and they say what I would want them to say [TF], which is I don't understand what I'm doing wrong. Help me, help me figure out how to, how to do this problem [SF].

4.2.1.3 Conditional activity sequence. The frequent use of poll quizzes drove the design of conditional activity sequences in lesson blueprints. Interviews revealed two contextual factors that influence faculty decisions on designing conditional activity sequences (see Table 21).

Table 21

Contextual Factors that Influence Conditional Activity Sequence Design

Design pattern	Design characteristics	Contextual factors
Conditional activity sequence An activity sequence that is initially held by a condition and executes based on the outcome of a decision point by the faculty	Evidence Data/metrics Decision points Non-linear Multi-pathway	Designing for data-informed teaching and learning Designing for multi-pathway lesson remediation

Designing for data-informed teaching and learning. Faculty value the time they have with students in class to "see what students are doing [TF]" because homework does not provide much information about students' performance. Because of large class sizes, faculty are not able to grade or review all homework assigned to students [LEF]. For Ella, her students are working on online homework programs or adaptive learning systems but "homework is worth very little points [LEF]" There is an assumption that homework is "meant to help them get better, not to penalize…[SF] or fail the class because of homework [SF]" but this assumption is coupled with doubts that students do not like homework or worse, may cheat and "google the answers. [TF]"

> Outside of class, I don't know if they're using Chegg to do their homework… I can't tell what they're doing [TF]. Whereas in class I can see what they're doing… I like that." [TF]
>
> I tend to do everything in class…[TF] [students] do not want homework…[SF] and want to have [most of their work] done in class…[SF] If they are cheating or whatever… I don't like it… but it will show up on the test [TF].

> You will know even if they hide it [SF]. [If they] got a 100 on [their] homework but... failed the test, well "who is doing your homework?" [TF]

With homework seemingly not useful, faculty go one step further than "walking around" during group activities and informal observations to measure students' levels of understanding in the classroom through their use of poll quiz data to gain a "more accurate [TF]" sense of students' performance, especially for large classes.

> If I had maybe a class of ten, I would know better how each of them understand the material… [LEF]
>
> Polls are pretty effective in terms of me being able to see where the class is and people being able to know quickly if they're doing it right [TF].
>
> Me and my preceptor walk around and provide them with all sorts of feedback before we move on. [TF]

Poll quizzes also "force" students to be accountable in class and provide "a better use of class time" [LEF] to focus on formative practice, remediation, and feedback. Faculty explained that polls provide opportunities for instant feedback to identify struggling students early, however warned on its limitations to assess technical, procedural type of learning [TF].

While poll quizzes are helpful for faculty to measure how students are performing, they also believe that poll data is "low stakes [SF]" but largely helps students measure their individual level of competency with instant feedback. Jared shared, "It is very different from the students [view] to see that, oh, I got that question wrong. I actually don't know how to do this. [SF]" All faculty acknowledge that polls also serve multiple purposes: (1) as important checkpoints for students, (2) to stand out concepts or terminology that are important, and (3) to review questions that will likely appear in quizzes or exams [SF].

> I do believe very strongly in a growth mindset that students can come from whatever background and can strongly improve their understanding and their ability in any subject. [SF]
>
> If we get [pass] this even a little bit and they're not completely able to [understand]... then they've got no hope of succeeding in the course at all. [SF]

Designing for multi-pathway lesson remediation. Lesson blueprints with decision points show that faculty are innately flexible and have multiple lesson pathways planned in their mind, ready to adapt their lesson depending on how students are performing in class [SF]. As faculty design with multi-pathways in mind, they evidently position their role as “a policeman, [TF]” one who is in control of the lesson sequence (i.e., moving forward and back) and pace (i.e., moving faster or slowing down). They control moving forward or backward. Ella explains: “I think because I can, I can control what happens in class… We'll do a [poll quiz] to see, did they get it?... test them on what I just talked about… [TF].”

Designing conditional checks for students was predominant in lesson blueprints of Reema and Ella. Two examples of multi-path sequences are shown below:

Example 1: Multi-path decision points of Reema (see BP1, BP2, BP3)

Condition A: If a great majority of students score high (>95%)

Condition B: If majority of students score high (>75%)

Condition C: If approximate half of students score high (>50%)

Example 2: Multi-path decision points of Ella (see BP4, BP5)

Condition A: If a great majority of students score high (>95%)

Condition B: If majority of students score high (>75%)

Condition C: If majority of students score low (<75%)

In cases where decision points were planned for poll activities, both leveraged on the frequency of students who scored high and low [SF] to guide their lesson sequence toward multiple pathways: either to move on to the next lesson or provide remediation through additional feedback or lesson tutorials.

> We do a [poll quiz] to check…75 students… to see did they get it?... [TF] Depending on how they do [SF]… either if they didn't… I tell them… the right answer… we can move forward [TF]. If they have questions, they can ask [SF]. If they don't do as well… only 70% got it, then I do a discussion of the correct answer. And if they do pretty poorly, less than 70% get it correct, then I walk through every one of the answers and I talk about... [the right and wrong aspects] [TF]. So, we really pick it apart [TF].

4.2.1.4 Repeating lesson sequence. It was evident that faculty designed repeating activity sequences throughout their lessons. Common repeating patterns were seen in the use of prerequisite sequences (i.e., information followed by practice), parallel sequences (i.e., group dialogue and feedback), or conditional sequences (i.e., poll questions). Interviews revealed three contextual factors that guided faculty decisions on designing repeating activity sequences (see Table 22).

Table 22

Contextual Factors that Influence Repeating Lesson Sequence Design

Design pattern	Design characteristics	Contextual factors
Repeating lesson sequence Two or more identical activity sequences that execute in succession	Competency Repetition Elaboration Extension Chunking	Designing for scaffolding, mastery, and intuition Designing for critical thinking outcomes Designing for visual representational competencies

Designing for scaffolding, mastery, and intuition. All faculty intended to design scaffolding for students to develop mastery and intuition in conceptual, procedural, and problem-based knowledge. Common strategies to engage students include using multiple iterations of the same type of activity (e.g., repeated polls, repeated discussions), adding variety with additional examples or scenarios, or adding complexing through increasing the level of difficulty of examples.

Reema, for example, designed all her lessons to scaffold through multiple, repeating polls questions to test knowledge of terminology, test conceptual understanding, and test new problem scenarios with increasing difficulty (see BP1, BP3, and BP3) [CF]. She further explained "after the simpler examples… there's a set of more meaty, more complex pieces for them to do. [CF]" However, she confessed that students might "hate this [SF], but I will love it [TF]."

Ella also designed multiple, repeating poll questions to also test students' knowledge of terminology in several of her lesson blueprints (see BP4 and BP5). She intentionally designs questions to have "layers" of content, context, or increased difficulty [CF][TF] so that students develop mastery [SF]. Ella's lesson (see BP6) showed her design intentions for multiple group discussion activities that execute in succession to allow students to repeatedly investigate, share, and synthesize new information [SF]. Her lesson sequence encompassed multiple jigsaw-type discussions where students rotate through different groups, but eventually land back in their original group to collaborate and answer questions and discuss ideas.

Jared's lesson design (see BP10 to BP13) showed broader design thinking through multiple lessons, throughout the middle of the course, and even considering the post-requisite course [CF]. He planned to engage students in multiple problem-solving iterations of building and deconstructing molecular representations so that they develop spatial thinking and mastery in Organic Chemistry 1, which prepares them strongly for the next class in Organic Chemistry II. He explains:

> Students need to think intuitively in translating between the two dimensional and three-dimensional representations [SF]; this is really important for later in the class… even through Organic II [IF]. By the time they get to the middle part of the course [CF], they won't need the model kit anymore because they will build enough models and draw enough of these two-dimensional representations…[SF] to have some sort of intuitive understanding of the connection between the two [SF][CF]. When they can do the basic work mentally, almost intuitively, they can apply [their knowledge] in a new context [SF]… This large-skill needs to… be accessed very quickly and reliably without too much extra thought. [SF]

With repetition, students receive consistent and formative assessment which helps them determine readiness for exams.

> The more they are thinking and doing, they are building those pathways in their brain that are necessary for when they sit down to take a test in my class…[SF]

Designing for critical thinking outcomes. From experience, all three faculty could anticipate areas in the course where students typically would have trouble [SF]. They could also anticipate both the rare and common mistakes that students would make throughout the course. However, it was not enough to "just… give them the corrections. [SF]" Faculty believed in the power of making mistakes and learning from mistakes; this guided them to intentionally design opportunities for learning from mistakes into lessons.

Jared, for example, shared his idea "to show students… the wrong way to do it and the wrong way we've conventionally been thinking about it. [SF]" He also designs lessons where he asks questions, but "twists [them] again [SF]" to see if students can understand it better the second time. He deepened understanding of conceptual knowledge by evaluating "the wrong and right" way to "see which is better or worse." This type of repetitive lesson design would allow students to engage in critical thinking.

Similarly, All three faculty strongly prioritized designing for critical thinking skills in the classroom over memorization.

> I'm not interested in seeing if people can memorize a bunch of stuff [TF]. Who cares if you can memorize, if you don't understand anything [DF]? This is the course where we help them… understand it, use it, and apply it [TF]. I also think the material is quite fascinating [TF]. If you really understand it - it is super interesting [TF].

Ellen admitted, “students often think they should already know all the answers. But we are supposed to ask questions and they are not supposed to know the answer.” Reema was adamant that her lesson design should be “tapping into how they think? [CF]” She conceded that she was the one who was really married to the idea of solely testing students but this has changed as she reframed her lessons from tests to scenario-based problem solving.

> “That's part of my culture coming up [TF] through the Math programs and that's how we do things in the Math department [IF]. It's really hard to get a feeling of [individual students] [TF]. I'm doing my best to evaluate their understanding as an individual [TF]. But this has been a different way for me to look at [lesson design] [CF].”

All three faculty members highlighted their frustrations with their departments at their university on content inclusion and exclusion. They believe that there is unnecessary focus on “too much content” rather than broadly designing for those essential skills that “students should get out of a college degree, [DF]” which is to think critically and apply information to new situations.

> … an argument that I’ve made with some of [my colleagues] over the years [IF]. we don't need to teach them [too much content] [TF][CF]. It doesn't serve any goal to have them memorize…[TF] It does not help students learn a skill [SF]. This is not what I think the point of the class should be [TF].

> It no longer matters if you [memorize] everything, because who cares [DF]? What [jobs] care about… can you actually use… assimilate… and apply [information] DF].

Designing for visual representational competencies. Another design strategy that resonated among faculty lesson blueprints is the use of class time to help students engage in repeated practice using crafty manipulatives, commercial model kits, and computational modeling software to develop visual representational competencies. This was predominant in the lesson blueprints of Ella and Jared.

Ellen explained that she was looking for tools to “teach the material well” [LEF] and so that she could “demonstrate [TF]” difficult, tricky topics. She selected crafty manipulatives because they were simple enough to build herself [TF] at a low-budget (e.g., paper cutouts, foam pool noodles) [LEF] and could effectively help students visualize Biology concepts in 2D and 3D, and then draw illustrations from their understanding [SF].

> I have giant chromosomes that I bring into the class made of foam pool noodles…[TF] [LEF] And I have little paper models of proteins…[TF][LEF]. [Students] have to see how they fit together like a puzzle… [SF]. It is better because it is a 3D model as opposed to a picture [LEF][CF]. It helps us model [the concept] [CF][TF].

Jared on the other hand was interested in helping students visualize and represent Chemistry concepts with commercial model toolkits in class and provided extended practice at home through computational experiments with modeling software.

> There's a lot of graphic elements involved…[CF] it is very hard to [just learn from] a written block of text [SF][LEF]. I've always told my students having the model kit is important…[TF][LEF] to be able to visualize and manipulate a three-dimensional object and understand the two-dimensional representation as a three-dimensional object [CF].

Both faculty believed that shifting between 2D and 3D spatial thinking is an "unusual skill" and is not within every student's comfort zone. "Students have a lot of problems with this skill, [SF]" however, such skill is fundamental to meeting course goals. Faculty strongly distinguished that "there's a difference between saying it to the students, and letting them experience it [CF]." Students needed repeated practice with some type of manipulation tools to "experience," "visualize," "build," "look at," and "feel with [their] hands" to succeed in the course and in their later careers [SF][DF].

4.2.1.5 Linked lesson sequence. As faculty designed lesson blueprints, they were aware and intentional in designing links across content, activities, and lessons. Interviews revealed three contextual factors that influence faculty design decisions on designing linked lesson sequences (see Table 23).

Table 23

Contextual Factors that Influence Linked Lesson Sequence Design

Design pattern	Design characteristics	Contextual factors
Linked lesson sequence Two or more lesson sequences linked to execute in succession	Connections Progression Order Time elements (i.e., past, present, future) Before and after comparisons	Designing for order across course topics Designing for bridges across activities and lesson Designing for time buffers across lessons

Designing for order across course topics. The three instructors from Organic Chemistry, Biology, Statistics courses recognize that "the material is very connected." [CF] The faculty presented an analogy to how textbooks and other courses are sequenced:

> You sort of continuously get more advanced with each piece until you reach the end of the unit. [CF]
>
> For every course… everything is building up… the structure is how something is represented… [CF] many [topics] in the world are taught like this, right? It's not just [this course], business courses have the same idea. [CF]

The sequence of course topics were described as "building blocks" [CF] that connect to each other in some "logical sequence" [CF] and essentially serve as prerequisites to each other (e.g., Jared: two-dimensional to three-dimensional objects; Reema: one-sample hypothesis testing to two-sample hypothesis testing). Ellen explained her thinking around course topics sequenced from a "narrow to broad" view:

> It is in the way you design it [CF]… we go in the order of the textbook [CF], which is pretty logical [TF]. I think of it as [units] [CF]. The first unit is macro molecules, like what macro-organisms are made of [CF]. The second unit is cellular processes, like how energy is transformed and used [CF]. The last one is how information is stored and passed on in cells [CF]. It's definitely not by skills, it is by topic… starts narrow and gets broader [CF].

The goal in lessons is to "work on these topics… and show students how everything is connected [SF]." Faculty believe that the natural order of topics prescribed in textbooks can develop foundational, prerequisite knowledge towards students in the current course [SF], and over the progression of multiple courses in their program of study [IF].

Designing for bridges across activities and lessons. Knowing that course topics follow a prerequisite order, faculty evidently designed activity sequences that execute in a specific order to help students learn through each topic. With reference to their completed lesson blueprints, faculty could point out and explain the order of activity sequences and lesson sequences during the design discussions and interviews.

Jared noticed “a train of things” [CF] planned among his activity sequences that repeated for example, in BP7 and BP8:

> I sort of wrote this out in terms of how I thought the flow would work in class [TF]. Because there's a progression of topics here [CF]. There's a lecture, some exploration and student practice, and then a bit of self-evaluation based on what we show on the board for correct answers (refer to BP7) [CF].

Ella also noticed an order in her activity sequences mapped in BP4 and BP5:

> We start here… the first thing we do… they bring [in the homework from last class] ... they compare with their neighbors [CF]. Myself and my preceptor, walk around the room and we provide them some informal feedback, ask them questions, that sort of thing [TF]. I will then introduce a new topic… [TF] We'll do a poll everywhere to kinda see… test them on what I just talked about [TF]. Then they get a little mini lecture... because they're going to do a case study with it (refer to BP5) [SF].

However, the three faculty were able to not only design links across multiple activity sequences, but also thought about the broader connections (i.e., zooming out) bridging across multiple lessons:

Reema was able to demonstrate this as she linked two lesson sequences in succession during her second design session (BP2 and BP3).

> I'll go over it in the next class but also [CF], I will also post a written key so they will have feedback on why they missed certain questions [SF], they can go back and figure out what they are doing wrong [SF].
>
> Thinking about what we're going to be doing next class, my [topic] has two parts [CF]. We're going to take what we did in this class and tweak it for the next class [CF].

Ella linked two lesson sequences in succession during her first design session (BP4 and BP5).

> The online homework has automatic feedback on it, so they immediately know what they got wrong and it actually gives them hints and stuff to help them with this, they won't get feedback until they come to the next class [CF][SF].
>
> They bring it back with them and we'll continue with the second part of the lesson [CF][SF].
>
> I'll probably spend some time next class reviewing what topic it is that they were struggling the most with [CF][SF].

Jared linked two lesson sequences in succession during his first design session (BP8 and BP9) and linked four lesson sequences in succession during his second design session (BP10 to BP13).

> It looks a little more complicated because it is split over two classes [CF]. It's basically the same sort of pattern over here for this lesson and the [second lesson] [CF]. [However, in lesson two], there are more difficult concepts than the first one. [CF].
>
> So, this would be the end of that class where we introduce the [new topic] ... similar to the [old topic] ... And then the next class we'd start by discussing the [new topic] [CF].
>
> The context was presented not only at the beginning…but linked… out for the four weeks [CF].
>
> They have had practice in previous classes…[SF][CF] So that would be one class period there. The next time we would start off [with a different topic] so that we can see them from a new perspective…[SF][CF].

In examining the lesson blueprints, several patterns emerged that describe the types of bridges that faculty were thinking about when sequencing lessons. First, faculty believed that there is a need to sequentially "chunk content" into lessons such that content and activities are interwoven into the "different pieces." [CF] One faculty described this design process as "how [they] plan for instruction [to] become [more] organized." Chunking activities and lessons sequence helps frame the course week by week [TF].

> So, the idea there is to give [students] one little piece… at a time, and... do the same thing [now familiar to them] ... things are connected to each other [SF].

Second, faculty believe there needs to be a sense of order in building up the level of difficulty or complexity of topics across lessons [CF]. This ties back to STEM courses that by nature have a progressive sequence like "building blocks." Among the 13 lesson blueprints, faculty lessons would often begin with either one of these design sequences: (1) A presentation of a new topic with a higher level of difficulty or complexity in class; (2) An elaboration or extension of the same topic with deeper dialogue or extended practice in class; or (3) A review of topics from a homework or the prior class.

Designing for time buffers across lessons. From interviews and the design sessions, it was apparent that faculty struggled to accurately time the duration of activity sequences. A common reason was the fact that the university where all three faculty were employed offers their course in both 50 minute and 75-minute schedules. This meant that the faculty might be required to teach with a 50-minute schedule (i.e., meeting students three times a week) on one semester, and a 75-minute schedule on another semester (i.e., meeting students twice a week); this institutional constraint, coupled with the challenging nature of course topics and students' lack of preparation, negatively impacts the planning of courses and lessons. Ella felt balancing class time was "stressful" and "finding that balance… is really, really difficult." [TF][LEF] Jacob felt the same: "I know in every class, no matter how much I will prepare, I feel very rushed…" [TF] "Because it's a large class, I still struggle putting activities in." [TF][LEF]

The shorter class schedule offers “little time for review [CF]” and limitations on doing multiple practice examples in class. All three faculty have “moved away from long lectures” and preferred the longer time block to carry out activity sequences that offer students active learning with opportunities to practice, engage in dialogue, and get feedback.

> The nice thing about a 75-minute block…[LEF] I'm going to set up… an easy example…[CF] [then] work on an intermediate example like in a group… [SF][CF] [then] give a challenging one at the end to kind of ramp it up…[SF][CF]

While constructing lesson blueprints for this study, faculty were asked to break down every block of time for each lesson element. It was observed that faculty would make their best guess when asked, but also quickly recognize that their response was loaded with ambiguity or doubt. Jacob and Ella, for example, showed uncertainty in statements such as: “I think it could be doable in 50-minute blocks…,” “it seems about right…,” “that would probably take…” or “it’s pretty close…” [LEF]

When asked to sum up the time for one entire lesson blueprint, faculty would either go over their allocated class time or fall short. None of the faculty accurately got their timing right the first time. Faculty were battling several considerations as they were timing out their lessons. The first consideration was on the purpose of the activity: whether the task was for practice or for assessment. For practice purposes, faculty would focus on the students' needs and estimate how much time a novice student would typically spend on a difficult task. For example, one faculty mentioned, “usually, we can get through about half of this, as this requires a whole lot of drawing and it takes [students] a long time [SF][LEF].

For assessment purposes, faculty would focus on standard time expectations, expecting students to perform within a standard time limit. Another faculty mentioned, “These problems shouldn't take more than about 45 minutes [LEF]. That's probably close to the maximum amount of time I want them to spend on it [TF]”

The second consideration was on the actor (who) performing the task: whether the task was being performed by the faculty or by students; or whether the students were working individually or in groups. Ella explained that time was harder to plan for student-led activities. All three faculty also considered whether the activity required some buffer time for feedback or explaining correct answers.

> When I’m talking, I am less worried about the management of time. I know what I need to say [TF]. When I give them time, things take longer than I think they should [LEF].
>
> This [group activity] would be a longer block of time, probably around ten minutes where I and…[LEF] the student assistant… would walk around and give informal feedback to the students…[SF]
>
> You can set a five-minute timer, but it's hard to know that five minutes is the appropriate time to do that. [LEF] With my class size… some groups will be done in five minutes… for other groups, it's going to take a lot longer…[LEF] It's really hard for me to know how long to give them because I want them to have time. [TF][LEF] But then I also don't want them to get bored or like to do other things or to waste time. [TF]

All faculty took several design iterations to balance the number of activity sequences they could fit within the class schedule they were planning for. In order to account for the compounding factors that goes into timing lessons, they applied several flexible techniques:

First to reduce the time, some faculty would offset classroom activities to homework or online activities, generating activity sequences that needed to be completed prior to the lesson as "pre-work." Commonly, faculty removed activities that would "waste time" in class, converting the knowledge terminologies as online readings or lesson introductions as online videos.

> I don't have to spend ten minutes saying, what does it mean when I say nucleophile? Because in a 50-minute block, that is wasted time. [LEF]
>
> It's important for them to do homework outside of class… we have limited time in class and they need to practice. [SF][LEF]

Ella in fact found that online activities were more helpful because of the "automatic feedback" from online homework systems:

> The online homework has automatic feedback on it, so they immediately know what they got wrong and it actually gives them hints and stuff… otherwise, they won't get feedback until they come to the next class. [SF][LEF][CF]

Alternatively, some faculty would plan with flexibility in mind, adding buffer time to activities to ensure the lesson blueprint was foolproof. This meant planning for a 75 minutes schedule, where the extra 15 minutes would serve as a buffer to a 50-minute schedule; extra time could be spent to extend time on practice activities or add elements of dialogue and feedback.

> This [activity will need] a little longer [time] usually at the end, usually about maybe 15 minutes or so… That's my buffer [LEF][SF][TF].

4.2.1.6 Structured activity sequence. This study supported faculty in two design sessions through a course modeling workshop. Design session 1 required the faculty to focus on modeling a "current lesson design," while design session 2 required the faculty to apply a learning cycle to remodel or reimagine a "future lesson design." All three faculty were able to design new lesson blueprints using a learning cycle to guide and structure their lesson sequences. Interviews revealed three contextual factors that influence faculty design decisions on designing structured lesson sequences (see Table 24).

Table 24

Contextual Factors that Influence Structured Lesson Sequence Design

Design pattern	**Design characteristics**	**Contextual factors**
Structured lesson sequence A lesson sequence with a predetermined structure that prescribes the order of which activity sequences execute	Organization Structure Alignment Process	Designing for learning cycles Designing for transparent lesson design Designing for reusable and transferable lesson design

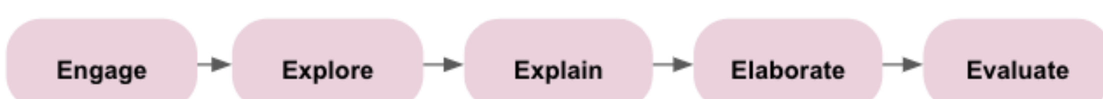
Designing for learning cycles. All faculty generated three different results when prompted to consider the use of learning cycles in their lesson design. As a pre-work to design session 2, faculty were led with the 5E learning cycle to get them to start thinking about how to structure lessons.

Reema's decision on her lesson blueprints was to use the 5E learning cycle to guide her redesign (see Figure 42). When asked why, she explained that her ideation towards a new lesson blueprint started from examining the five phases (i.e., Engage, Explore, Explain, Elaborate, and Evaluate) and whether it aligns to the lesson outcomes [CF] and the topics [CF] that she needed to cover for the lesson. She also considered whether she would be able to identify the lesson elements that she needed to develop or create for each learning phase [CF]. Reema felt that the 5E learning cycle aligned with her redesign goal: to connect Statistics to student personal and disciplinary interests [SF]. The following describes Reema's explanation of the activities that students would engage in for each step of the learning cycle:

- Engage: [Capture students] their attention, something that's interesting to them, something that they can take what they already know…
- Explore: [Present] a scenario… an interesting problem I want them to take what they understand… and apply it…
- Explain: [Give students] information… along the way…
- Elaborate: Take the discussion [and shift it to another situation or problem] ...
- Evaluate: Use [poll quizzes] with concept questions… process how much [did they understand] ... can they generalize... apply it to other situations? That kind of evaluating their more critical thinking than procedural skills.

Figure 42

Learning Cycle applied to BP2 and BP3 (Reema)



Ella did not resonate to the 5E learning cycle, but attempted to ideate on alternative ideas. Ella “liked the idea behind the 5E” but could not clearly determine activities for all phases of the cycle. She compared it to the “Bloom’s Taxonomy” on her wall [CF][TF]; both frameworks intermittently served as a useful guide in her thinking [TF]. She had additional conversations with the instructional designer (also the researcher) to help her “move to something totally new [TF]” that aligned with her redesign goal: to put more accountability and responsibility on students as they engage in group-based case studies in the classroom [TF].

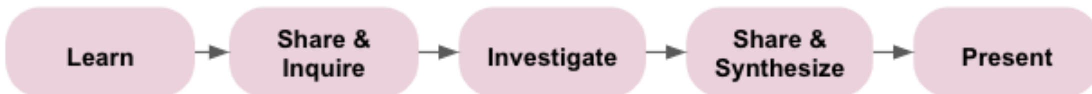
Ella and the instructional designer co-designed an original learning cycle (see Figure 43) that captured Ella’s learning outcomes for the lesson. The following describes Ella’s explanation of the activities that students would engage in for each step of the learning cycle:

- Pre-Work: [Students] will have a pretty significant homework assignment... [to learn about their assigned topic]. They have guided questions… and a practice quiz…
- Learn: [Students] come to class… work in their first group for 10 minutes…learn more about the topic with students who have the same topic...
- Share and Inquire: Students switch tables to a second group to share findings learned from the first group… ask each other questions… type questions on a Google doc
- Investigate: Students switch back to the first group… use their laptops to research and find answers to questions posed by the prior group for 15 minutes…

- Share and Synthesize: Students switch tables again to the second group to share and synthesize ideas towards building a group poster project…
- Present: Students would stay in their second group to present the poster and submit the project for grading and feedback.

Figure 43

Learning Cycle applied to BP6 (Ella)



Like Ella, Jared did not resonate to the 5E learning cycle either but attempted to ideate on alternative ideas. He explained that the learning cycle was useful to his design thinking because “he liked planning things, [TF]” it “matched his philosophy [TF]” and “mirrors” how he prepares for new lessons [TF]. However, “it felt difficult… and less natural to put things into someone else's system. [TF]” He hoped to create his own “pedagogical model and fit his design into it.” [TF]

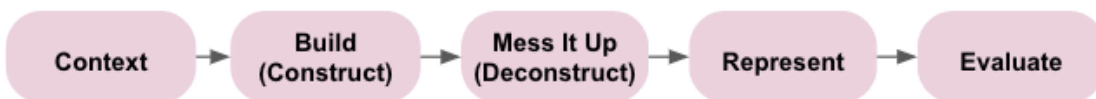
Jared had additional conversations with the instructional designer (also the researcher) to help align with his redesign goal: to add real-life context while students practice with 2D and 3D modeling using commercial toolkits [SF]. Jared and the instructional designer co-designed an original learning cycle (see Figure 44) that captured Jared’s learning outcomes for the lesson. The following describes Jared’s explanation of the activities that students would engage in for each step of the learning cycle:

- Context: Student connects with a real-life context
- Build (Construct): Students build a physical 3D model of the molecule… manipulate it and turn it back into its 2D representation

- Mess It Up (Deconstruct): Students will twist, bend, rotate the 2D model of the molecule
- Represent: Students illustrate and draw visual representations on paper
- Evaluate: Students evaluate visual representations with core concepts, discuss in groups, and connect it back to the context

Figure 44

Learning Cycle applied to BP10, BP11, BP12, and BP13 (Jared)



All faculty demonstrated openness and willingness to reimagine their lessons through the structure of a learning cycle. Comparing across the 13 lesson blueprints produced in design session 1 and 2, only blueprints produced in design session 2 applied a learning cycle. Lesson blueprints from design session 1 showed that topic sequences guided their selection of activity sequences, which built up to a lesson sequence. When given the opportunity to begin the design process with a learning cycle in design session 2, the phases of the learning cycle guided faculty selection of activities in alignment to topics (see Figure 45).

> There was really never a bigger intention to follow a cycle [before this]. Now… I think subconsciously I have a cycle in mind… [TF] it is sort of a bigger project… [with] mini projects [CF].

Figure 45

Shifting Design Mindset Between Design Session 1 and 2

Design Session 1:
Topic sequence → Activity sequences → Lesson Sequence

Design Session 2:
Learning cycle → Lesson Sequence → Activity Sequence → Topic Sequence

Interviews with faculty show their design thinking shifted from focusing on the topic to focusing on the learner, learning outcomes, and the learning process. Jared believes that the learning cycle is an “effective method… to prepare activities. [CF]” He is relieved that he found “a good framework” to integrate in class where he “can cycle between [the steps] [CF]” in his lessons (refer to BP10 to BP13).

Ella also believed that with learning cycles, the “structure is good for [her] [TF]” because her lesson blueprint is “so much bigger” than what she was used to. She claimed she has always “had a hard time” [TF] and never planned for “[lesson sequences] that would take an entire class period with an 80-person class;” this resulted in most of her planning on shorter activity sequences only. She also did not believe she had the confidence prior to attending the workshop for this study. Reema also explained positive insights:

> Learning cycles very much changed the structure of my class… to what the students are going to be doing versus what topics I want to cover. [CF] It's like a backwards design… I'm starting from what I want to [happen] in their brains… and how I can make my class fit with that, instead of how I arrange my class and then [determine later] what will happen in their brains. [CF][TF]

Designing for transparent lesson design. Interviews with faculty revealed that faculty valued having a learning cycle as a structure helps students “see big picture connections” [SF] within the lesson and in effect, the larger course to help. Jacob shared

> It's important for the students…to build this framework of knowledge…[SF] They have a really hard time doing that… step back and see the big picture… see how everything fits. [SF]

Faculty also believe that having a learning cycle as a structure for students helps build a transparent “lesson narrative, [CF]” links a clear sequence between lesson topics and activities, creates alignment between lesson outcomes and activities, and creates a sequential order between activities.

> There should be a beforehand and an overview of how everything is linked and a clear sequence between the topics that you're actually covering. [CF] You are able to pinpoint what types of topics... or concepts fit better. [CF] It follows an order... because there's more of a sequence. [CF] [The lesson blueprint from design session 2] is more process-based… [CF] you can see the process become more evident… [The lesson blueprint from design session 1] is more sort of activity-based…[CF]

A learning cycle, by design, defined a structured learning process for students and instructors. All three faculty strongly resonate to a learning structure as it provides them “a map” to preparing activities in class [TF]; for students, they are guided through a method of learning that aids deeper understanding, retention, and learning support [SF]. Jared referred to the learning cycle as a way to provide “good story… easier to remember. [SF]”

Ella explained that it helps “set up more structure” for students to practice on their own because “they're able to sort of see everything works together... through a process.” A learning cycle forces instructors to design activities for “what [they] want [students] to be able to do.” [SS] It gives assignments purpose as they connect to the steps or phases in the learning cycle. In turn, the steps or phases in the cycle also become “a checklist” for students to predict workload and know where they are headed in the lesson.

For all three faculty, applying a learning cycle was challenging at first. Jared admitted he “never had a good framework in class [TF].” Ella admired other faculty who used something similar to learning cycles, “liked the idea behind it,” and believed that she could create one too. Ella believes the “structure is good for her” because she finds it “hard to manage a big class.” Having a learning cycle provides her “enough structure” for her to “know exactly what students are supposed to be doing” [TF] in the classroom and what she can manage to do in-between those activities. Without structure, she would lose control and feel nervous to make changes to her lesson design. Reema was also very proud of her lesson blueprint as she completed it with a learning cycle; she claimed that now “there was so much inquiry-based learning” [CF] and backwards design. She also believed that a learning cycle helps students “stay on task.” [SF]

Designing for reusable and transferable lesson design. As the faculty completed their lesson blueprints, they recognized that lesson structures developed through a learning cycle could be reusable and serve as a transferable design pattern to other lessons, and more broadly, to other courses that they would teach in the future [CF][IF]. Jared could mentally reimagine and recognize how the learning structure that emerged from his design process could “cycle through different days, [CF]” and see how the steps could be rearranged to align to certain lesson outcomes. He noted that students could work through "a similar process," scaffolding and practicing similar skill sets. [SF]

Similarly reflecting on her lesson design pattern, Ella "was thinking that something similar… might be nice to reuse" [IF] in her 75-student Ecology class after feeling unsatisfied from her first experience teaching it. Given her personal challenges of developing new course materials, the learning cycle offered her a quick starting point for a course redesign.

> I was teaching [the Ecology class] for the first time this semester. I did stuff with [the class], but... I've just been barely keeping up... because it's [my] first semester. [TF] This… general structure… I could possibly use it for that class... [IF] which is nice. I have till next Fall, so there's time to kinda really flesh out the project [LEF].

Narrowing from a broad lesson sequence design to activity sequence design, the lesson blueprints and interviews also showed evidence of faculty finding "ancillary benefits" in reusing formative activities in summative exams. [CF]

> The final is very much summative. It's very much... an integrated, comprehensive exam… I tell the students… The final exam should be the least surprising exam you ever take because you've seen it all before, multiple times. [SF]
>
> I like to have these. In fact, I prefer to have these in class… that's what their tests are going to be more like. [TF]
>
> I would also hope [it] will help them identify where they need to use that type of skill when a quiz comes up. [SF]

All faculty specifically reused poll quizzes and written exercises in their final exams. Jared recognized that in his multiple years teaching Organic Chemistry, "even students who knew the material would do much more poorly [on exams] than I would expect [SF]." The reusability was intentional in their lesson design and this was for several reasons: (1) to improve familiarity with test questions; (2) to improve recall on solving test problems; (3) to reduce test anxiety and stress; and (4) to bring forward important concepts or problems that are key to being successful in current and succeeding courses.

4.2.2 Knowledge Frames

This research study identified six design patterns that are emergent distinct design practices of STEM faculty. These six design patterns are categorized into two major design strategies that faculty utilize when designing lesson blueprints: activity sequences and lesson sequences. Activity sequences are a combination or set of lesson elements arranged into a learning activity that executes within a class session. Three design patterns were identified among activity sequences: (1) prerequisite activity sequence, (2) parallel activity sequence, and (3) conditional activity sequence. Lesson sequences are broader sequences that combine multiple activity sequences into one or more lessons. Three design patterns were identified among lesson sequences: (1) repeating lesson sequence, (2) linked lesson sequence, and (3) structured lesson sequence. The first column in Figure 46 lists the six design patterns.

This research study then examined the contextual factors that influenced design practice, specifically what are the design decisions that underlie the six design patterns in lesson blueprints. The second in Figure 46 lists contextual factors in alignment to each design pattern.

Figure 46

Thematic Map

Design Practice: Designing Activity Sequences		Design Knowledge: Knowledge Frames					
Design Pattern	**Contextual Factors**	**SF**	**TF**	**CF**	**LEF**	**IF**	**DF**
Prerequisite Activity Sequence	Designing for entry level misconceptions, fears, and anxiety	■					
	Designing for deliberate practice and accountability	■	■		■		
	Designing for early alerts and feedback	■	■				
Parallel Activity Sequence	Designing for group-based dialogical thinking	■					
	Designing for collaborative peer support	■					
	Designing for disciplinary fluency	■					■
	Designing for timely and personalized feedback	■	■		■		
Conditional Activity Sequence	Designing for data-informed teaching and learning	■	■		■		
	Designing for multi-pathway lesson remediation	■	■				
Design Practice: Designing Lesson Sequences		**Design Knowledge: Knowledge Frames**					
Design Pattern	**Contextual Factors**	**SF**	**TF**	**CF**	**LEF**	**IF**	**DF**
Repeating Lesson Sequence	Designing for scaffolding, mastery, and intuition	■		■		■	
	Designing for critical thinking outcomes	■	■	■		■	■
	Designing for visual representational competencies	■	■	■	■		■
Linked Lesson Sequence	Designing for order across course topics	■		■		■	
	Designing for bridges across activities and lessons	■	■	■			
	Designing for time buffers across lessons	■	■	■	■	■	
Structured Lesson Sequence	Designing for learning cycles	■	■	■			
	Designing for transparent lesson design	■	■	■			
	Designing for reusable and transferable lesson design	■	■	■		■	

Note: SF: Student frame; TF: Teacher frame; CF: Course frame; LEF: Learning environment frame; IF: Institutional frame; DF: Disciplinary frame

The third column group in Figure 46 shows the knowledge frames "activated" for each contextual factor. When coding design discussions and interviews, the researcher closely analyzed whether the perspective, meanings, or explanation presented by the faculty was referencing the student (SF), the teacher (TF), the course (CF), the learning environment (LEC), the institution / department home of the faculty (IF), or the discipline (DF). Codes can be seen marked up across the discussion in the prior section. Selected quotes were also included in Table 25 for quick reference.

Table 25

Selected Participant Quotes Coded for Knowledge Frames

Participant quote
I just want them to stay on task… try to use scientific and logical thoughts… a focused dialogue than fragmented…[SF]
This [activity will need] a little longer [time] usually at the end [LEF], usually about maybe 15 minutes or so… That's my buffer [TF].
I was teaching [the Ecology class] for the first time this semester. I did stuff with [the class], but... I've just been barely keeping up... because it's [my] first semester. [TF]
This… general structure… I could possibly use it for that class... [IF]
I have till next Fall, so there's time to kinda really flesh out the project [LEF].
It's hard at the beginning of class to kind of get them to settle a little bit. They come into the class starting so stressed [SF]…
Usually, we can get through about half of this, as this requires a whole lot of drawing and it takes [students] a long time [SF][LEF]
…it is important for me as the instructor to be on the same side as my students [TF]
… an overview of how everything is linked and a clear sequence between the topics that you're actually covering [CF]
It is super important in all fields of Math... [DF] to be able to justify your logic and explain why you're coming to decisions and not just say, "Well, I don't know, I followed a formula."

4.2.2.1 Frequency and illumination levels of knowledge frames. The thematic map in Figure 46 summarizes how design knowledge (i.e., knowledge frames and contextual factors) influences design practice (i.e., design patterns of practice). Results show differences between knowledge frames activated for activity sequences and knowledge frames activated for lesson sequences in terms of their frequency and illumination levels.

The frequency of knowledge frames describes the number of knowledge frames activated in the mind of the faculty as they provide their reasoning during the design discussions and interviews. Results in Figure 46 show that all six frames were activated when faculty referenced lesson sequences, however only four of the six knowledge frames were activated when faculty referenced activity sequences.

Illumination levels describe the degree or level to which a specific knowledge frame was referenced across contextual factors. Level counts were extracted from the number of cells shaded in Figure 46 across the nine contextual factors for activity sequences and the nine contextual factors for lesson sequences. A shaded cell means that the knowledge frame was referenced for that specific contextual factor. Level 0 indicates it was never referenced.

Comparing the illumination level between activity and lesson sequences (see Figure 46), two frames were predominantly active when faculty referenced activity sequences: student frame (level 9) and teacher frame (level 5); minor activations take place within the learning environment (level 3) and disciplinary frame (level 1). When faculty referenced lesson sequences, three frames were predominantly active: student frame (level 9), teacher frame (level 7), and course frame (level 9); minor activations take place within the learning environment frame (level 2), institutional frame (level 5), and disciplinary frame (level 2).

The student frame was active and showed high illumination levels for both activity and lesson sequences. The teacher frame was active and showed moderate to high illumination levels for both activity and lesson sequences. The course and institutional frame only activated when faculty were referencing lesson sequences. For both activity and lesson sequences, the disciplinary frame ranked the lowest.

4.2.2.2 Knowledge frames influence on design practice. The student frame and the teacher frame were the central focal points when designing activity sequences, but when the design work extended into broader lessons, the course frame became a high focal point.

When designing activities and lessons, faculty place students at a high focal point. When thinking about students, faculty referenced the need to address students' misconceptions, fears, anxieties. They also highlighted students' need for scaffolding, deliberate practice, and formative assessments towards developing accountability, mastery, intuition, disciplinary fluency, critical thinking, and visual competency in their learning. Faculty recognize that with students in STEM coming into courses with predisposed fears and anxieties, students benefit from collaborative peer support and group-based discussions. Faculty believe that students benefit from different types of feedback from them as subject-matter experts and student assistants in the classroom including early alerts, timely and personal feedback, and data metrics about "how well" they are learning. Faculty believe that the course should provide students a clear structure through a learning cycle and provide transparent design of content, activity and lesson sequences.

When designing activities and lessons, faculty are also evidently thinking about themselves. They believe it is in their role to be the subject matter expert to help students succeed in the course and later in their careers. Because of this, they believe it is in their role to provide accurate and timely feedback, capture misconceptions, correct mistakes, and develop competency through repetitive practice and group activities. To help students succeed in future jobs, faculty believe students need critical thinking, disciplinary fluency, and visual representational competencies rather than memorization of facts.

Faculty demonstrated evidence thinking about the course in their flexible design thinking with non-linear, multi-pathway lesson designs, integrating frequent checks and data-driven remediation through poll quizzes. When designing lessons, faculty interestingly integrate time buffers knowing that in the past they have constantly struggled to finish their lesson plans within the allocated class time. While so, they also design lesson bridges, ensuring topics and activities are sequenced to build upon each other and that students can make connections between lessons and topics. While designing lessons, faculty aim for reusable and transferrable lesson designs across their current course and into their other courses.

While the learning environment frame was not a high focal point as all faculty were already teaching in large classes for several years, class time was a large consideration in lesson design as they were trying to balance number of activities and time spent on activities. Faculty found this task very challenging during the blueprint modeling process. Faculty also strongly consider their time interacting with students in the classroom more important than what students were doing outside of the classroom (i.e., online or at home). Homework was not helpful enough to give an accurate sense of how students were performing. Faculty used poll quizzes to "see" how much students know and gauge what students are feeling about the course. Faculty also think about the instructional materials available to help students visualize 2D and 3D representations.

Institutional considerations were referenced when discussing departmental issues pertaining to content selection, textbook selection, class scheduling, and culture of how tests/assessments were designed. The discipline frame ranked the lowest influencer as faculty did not reference disciplinary norms in their design decisions. However, they were thinking about the job market and how students would be able to acquire job security with the education they were receiving while in college.

4.3 Summary

Findings from the research study offer the following contributions to STEM education research and practice: (1) the variety, frequency, and distribution of lesson elements in faculty lesson blueprints, (2) the identification of six design patterns of practice in lesson blueprints; (3) the emergent contextual factors that drive faculty design decisions as they engage in lesson design, and (4) the knowledge frames, frequency, and illumination levels activated in STEM faculty as they engage in lesson design. The next chapter presents the discussion, implications of the study, recommendations for future research, and limitations to the study.

CHAPTER 5: DISCUSSION

This final chapter provides a discussion on the research results, the implications of the findings, recommendations for future research, and limitations to the study.

Research on lesson design indicates that it is a complex, messy, ill-defined, and wicked process (Masterman, 2013; Masterman & Manton, 2011). Design processes are also tacit, implicit, and intuitive (Markauskaite & Goodyear, 2014). It is not surprising that design work has been regarded as black box in multiple fields including education (Kahn & Bullis, 2021; Kerr, 1983), medicine (Edwards & Elwyn, 2006), human resources, and leadership. This qualitative research study illuminates the "black box" of how faculty as designers engage in design work, examining their design practice codified in lesson blueprints and design knowledge extracted from design discussions and interviews.

5.1 Design Patterns of Practice from Visual Lesson Blueprints

Design patterns emerge from encoding design practices (Goodyear & Retalis, 2010). One of the challenges of higher education compared to other fields like business, informatics, or computer science is that it is difficult to describe the design of learning activities as clear, precise workflows (Rogriguez et al., 2010). Design work is often an *invisible process,* left as tacit design experiences (Carvalho & Goodyear, 2014; Dodd, 2016; Dodd & Gillmore, 2018).

This research study tackled this challenge to attempt to help faculty experience a systematic design process and make design products *visible*. Through the use of the Learning Environment Modeling Language (LEML) from the LEM toolkit (iLED, 2017), this study examined lesson elements as core building blocks of Information (I), Dialogue

(D), Feedback (F), Practice (P), and Evidence (E), which are selected and arranged as lesson sequences in the form of visual lesson blueprints. Six “design patterns of practice” were identified in visual blueprints and these serve as distinct design practices of STEM faculty when designing lessons. Design patterns offer a standard format in the form of design sequences for teachers to craft their design solutions. Design patterns are important because they help unpack what lies in the “black box” of faculty design practice. Design patterns identified in this research presents the range of decisions and choices when selecting activities and sequencing lessons (see Table 26).

Activity sequences are a combination or set of lesson elements arranged into a learning activity that executes within a class session. Three design patterns were identified among activity sequences: (1) prerequisite activity sequence, (2) parallel activity sequence, and (3) conditional activity sequence. Prerequisite sequences are designed for beginning or early parts of the lesson, to elicit prior knowledge or learning experiences, to prepare students for upcoming topics, and to hold students accountable for their learning. Parallel sequences are designed for large classes to work together, interact, and build relationships. Conditional sequences are designed for gathering evidence about learners, just-in-time, using technology response systems (e.g., clickers, poll quizzes) and making an in-the-moment decision on the direction of the lesson based on outcomes or metrics.

The three activity sequence patterns align to research that shows that the use of formative assessment, peer instruction, audience response systems, and collaboration improves student performance (Carstensen et al., 2020). More interestingly, the three activity patterns show diversity in activity-centered design, where activities are still the central focus but the design decisions are influenced by epistemic (i.e., student prior experiences) (Markauskaite & Goodyear, 2014), cognitive (i.e., preparation, formative assessment), social (i.e., collaboration, interaction, relationships) (Goodyear & Carvalho, 2016), and data-driven design characteristics.

Lesson sequences are broader sequences that combine multiple activity sequences into one or more lessons. Three design patterns were identified among lesson sequences: (1) repeating lesson sequence, (2) linked lesson sequence, and (3) structured lesson sequence. Repeating sequences are designed to develop student competency through repetition, elaboration in examples, extension into application areas, and chunking of lessons. Linked sequences are designed to make connections among past, present, future lessons, to define the order and progression of topics, and to build on past lessons. Structured sequences are designed to define organization, structure, alignment, and a process of learning.

The three lesson sequence patterns reveal how faculty as designers can scale up the number of activity sequences and attempt to fit this into a time frame that makes up an entire class session, or fill multiple class sessions. It also reveals that faculty think about how the lesson fits within a broader sequence and progression of the course, possibly into future courses (Bennett et al., 2008, 2017; Kali, Goodyear, et al., 2011; Laurillard, 2012) Existing literature has been focused on traditional lesson planning approaches (John, 2006; Theoharis & Causton-Theoharis, 2011) or course planning (Bennett et al., 2006, 2008, 2017; Stark, 2000, 2002; Stark et al., 1988). These lesson sequence patterns add to the lack of literature on lesson sequencing.

Table 26

Lesson Design Practices, Design Patterns, and Design Characteristics

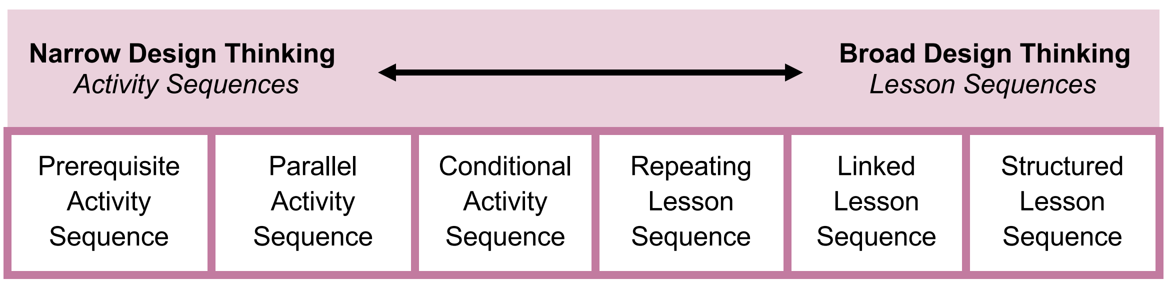
Design practice	Design pattern	Description	Design characteristics
Activity Sequences	Prerequisite Activity Sequence	This sequence describes an activity sequence with two or more elements that execute in succession	Beginning stages Prior experiences Preparation Formative assessment
	Parallel Activity Sequence	This sequence describes an activity sequence with two or more elements that execute concurrently	Collaboration Interaction Relationships
	Conditional Activity Sequence	This sequence describes an activity sequence that is initially held by a condition and executes based on the outcome of a decision point by the faculty	Evidence Data/metrics Decision points Non-linear Multi-pathway
Lesson Sequences	Repeating Lesson Sequence	This sequence describes two or more identical activity sequences that execute in succession	Competency Repetition Elaboration Extension Chunking
	Linked Lesson Sequence	This sequence is described as two or more lesson sequences linked to execute in succession	Connections Progression Order Time elements (i.e., past, present, future) Before and after comparisons
	Structured Lesson Sequence	This sequence describes a lesson sequence with a predetermined structure that prescribes the order of which activity sequences execute	Organization Structure Alignment Process

5.2 Granularity: A Key Influencer to Design Practice of STEM Faculty

The six design patterns manifest varying degrees of granularity which contributes to the design complexity rooted in the lesson design practices of faculty-designers. To understand the degree of granularity, it is best to visualize that the lesson design patterns lie on a continuum between narrow design thinking of activity sequences and broad design thinking of lesson sequences (see Figure 47). What can be observed is that in practice, faculty vary from designing short activity sequences to broader lesson sequences that possibly span over multiple lessons. This shows the cognitive flexibility among faculty to shift between high-level views of lesson progressions (zoomed-out) to low-level details of lesson elements (zoomed-in) (Falconer & Littlejohn, 2009; Goodyear, 2005; C. Jones, 2007; Kali, Goodyear, et al., 2011). It also reflects the positive effects of the LEM modeling toolkit for supporting cognitive thinking and managing the complexities of design work within the degrees of granularity (Figl et al., 2010).

Figure 47

Degrees of Granularity in Lesson Design



Lesson design practices have been less documented in the literature; lesson design patterns are even more scarce. The identification of lesson design patterns in this research study has essentially, "captured pedagogy" (Dalziel et al., 2016, p. ix) to represent and codify faculty pedagogical plans so that it can be documented, communicated, shared, revised, or reused (Britain, 2006; Falconer & Littlejohn, 2009; McGee & Reis, 2012; Persico & Pozzi, 2015). The design patterns also contribute to the scholarship on learning design representations (Baaki et al., 2017; Nguyen & Bower, 2018) and paper-based modelling tools (Quintana, 2018).

5.3 Contextual Factors that Influence STEM Lesson Design

Referencing the conceptual framework of Markauskaite & Goodyear (2014), the authors state that faculty as designers respond to demands from a particular context (Bennett et al., 2008, 2015; Kali, Goodyear, et al., 2011; Norton et al., 2005) and that they have knowledge as fragmented "knowledge-in-pieces" that occur in various contexts rather than as a uniform, systematic personal theory or belief" (p. 239). This research study identified 18 contextual factors from faculty reflections and explanations, half of which were the contextual factors that depict the reasons for designing activity sequences and the other half were the contextual factors that depict the reasons for designing lesson sequences (see Figure 46). Each one contributes to a "why" of a design decision, eliciting rationale and sense-making in faculty design practices. The next section highlights several contextual factors from the study.

STEM courses pose significant challenges in terms of the amount of material to be learned, the pace of instruction, and the need to achieve sufficient levels of mastery to support subsequent learning (Mettler et al., 2020). STEM courses rely on prior knowledge (Taylor et al., 2021). The variation in student levels of prerequisite knowledge and skills in STEM challenges faculty utilize valuable class time to focus on reviewing pre-requisite or basic concepts than using that time to explore learning at a deeper level (Liu et al., 2017). With content-related challenges, the faculty participants in this study found it important to deliberately interweave different forms of teaching-and-checking iterations, where new information (I) presented is followed by a practice or dialogue activity to immediately gauge or sense how students understood the information (I). Feedback (F) often follows practice (P) or dialogue (D) activities. Table 13 in Chapter 4 included the variety of activity types associated with each information (I), practice (P), dialogue (D), and feedback (F) lesson element.

Faculty use various methods to gauge what students know in the classroom. Short activity sequences in lesson blueprints designed by faculty show that they were arranging lesson elements either as a prerequisite, parallel, or a conditional sequence to gather information for the purpose of formatively making judgments about the current state of students. Information collected is designed to help faculty infer what students know and how well they know it, presumably for the purpose of providing early alerts, timely and personalized feedback, and pathways for remediation. Faculty also believed that formative assessments offer students active engagement and practice towards developing mastery and automation, but also holds students accountable for their learning. It is important to note that formative assessments in this research are predominantly in-class activities, planned for completion within a class session. These provide immediate and just-in time information about students, as opposed to alternate forms of formative assessment in homework or projects which may offer delayed information about students.

The unique aspect of using non-linear, multi-pathway learning sequences was evident in faculty design of conditional activity. This design sequence emphasizes the design knowledge of faculty to use student data in the practice of data-driven decision making (DDDM) (Mandinach, 2012) to support data-informed teaching and data-informed learning, and data to infer multi-pathway remediation and feedback in the classroom. Consequently, this conditional activity sequence offers a reporting mechanism that enables both faculty and students to use assessment results to focus their efforts to measure and improve educational outcomes (Pellegrino, 2002). This study speaks to recent calls for research to document faculty use of student data in practice (Herman et al., 2012; Shapiro & Wardrip, 2015).

5.4 Scale: A Key Influencer to Design Knowledge of STEM Faculty

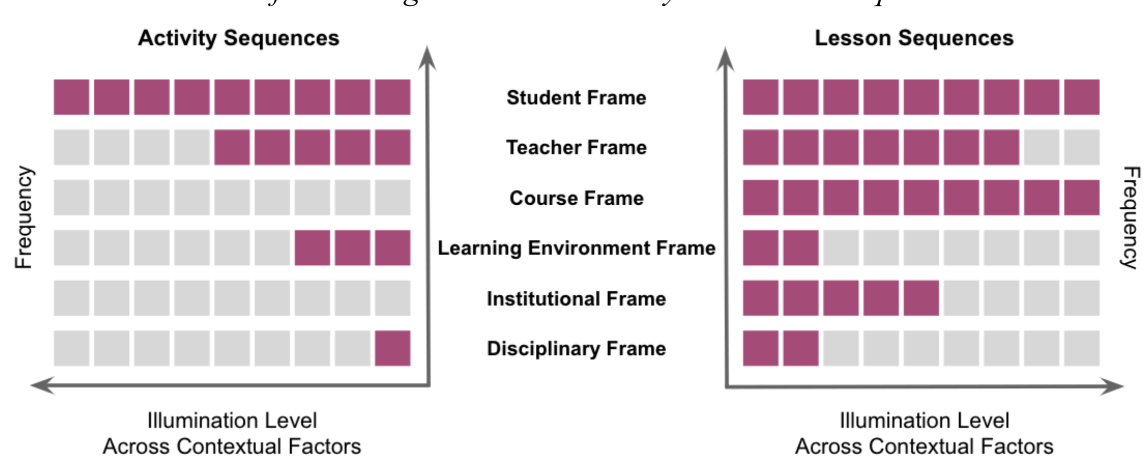
The broad focus of this study is centered on how design knowledge influences design practice. As faculty design lesson blueprints, there is complex, mental work involved, activating the design knowledge that they have accumulated from in past teaching and learning experiences (Markauskaite & Goodyear, 2014).

The conceptual framework for this study is guided by the epistemic knowledge model of Markauskaite and Goodyear (2014) which breaks down design knowledge into multiple fine-grained knowledge frames (e.g., student frame (SF), teacher frame (TF), course frame (CF), learning environment frame (LEF), institutional frame (IF), disciplinary frame (DF)) which serve as “mental frames” or “intuitive pedagogy” that guide faculty rationale for decision making in particular situations (Markauskaite & Goodyear, 2014, p. 239). This study mapped transcripts from faculty reflections and explanations to trace the activation behavior of each frame (see Chapter 4).

Markauskaite and Goodyear (2014) found evidence for all six frames in their research of lesson sequences. This study, however, showed differences between the knowledge frames activated for activity sequences and lesson sequences (see Figure 48). Similar to Markauskaite and Goodyear’s (2014), all six frames were activated when faculty referenced lesson sequences, however only four of the six knowledge frames were activated when faculty referenced activity sequences in this study. Unique to this study is the examination of illumination levels across contextual factors. Greater illumination levels were seen when faculty referenced lesson sequences in comparison to activity sequences (see Figure 48).

This distinction is important because it alludes to a key finding in this study: that scale is the dominant influencer between design knowledge and design practice. The scale of design work matters. When the scale of the design work increases (e.g., from activity to lesson), both the frequency of knowledge frames activated and the levels of illumination in the faculty mind concurrently increases. This implies that faculty are mentally activating multiple frames when designing activities and lessons but are battling with more mental decisions and contextual factors when the scope of design is larger. This finding contributes to a layer of design complexity rooted in the design knowledge of STEM faculty-designers.

Figure 48
Activation Patterns of Knowledge Frames in Activity and Lesson Sequences



5.5 Design Knowledge Development through Learning Cycles

Multiple researchers claim that design knowledge is dynamic, and can co-evolve within the context the faculty is situated in. Design knowledge has the potential to gradually develop as faculty encounter new ideas and experience diverse pedagogical interventions (Kali, Goodyear, et al., 2011; Markauskaite & Goodyear, 2014).

This study employed a pedagogical intervention through a workshop that posed a design challenge to faculty to apply the 5E learning cycle to modify or improve their lesson blueprints. Learning cycles have been noted to be one of the most powerful strategies in STEM instruction (Duran et al., 2011). This research study acknowledges the powerful effects of learning cycles in design practice and design knowledge as a mediating artifact (Conole, 2009) and knowledge amplifier (Cross, 2006).

Learning cycles serve as a means to scaffold and support faculty in design practice. Results from this study showed that when promoted with a pedagogical intervention, faculty were willing and open to the idea of using learning cycles as a framework to reimagine or improve their lessons in design session 2. When utilizing a learning cycle, faculty showed their ability to develop design knowledge and apply design frameworks into their lesson designs. However, it is also important to recognize the supporting structures in place that may have influenced the faculty towards accepting the challenge such as the workshop design process and 1-to-1 discussions with an instructional designer.

While faculty were willing and open to the idea of using a learning cycle, they were not easily receptive to just any learning cycle. The design prompt asked faculty to consider using the 5E learning cycle; only one of the three faculty resonated with this cycle; the other two faculty preferred to create their own to fit their lesson goals. This aligns with Svendsen (2015) who found that faculty differ in using the 5E learning cycles such that they would customize learning sequence and prioritize activities that are aligned to their own needs and environment. It was also interesting to highlight that two of the three faculty who applied a learning cycle across multiple lessons did not follow the exact same sequence for both lessons as seen in their original learning cycle. This shows the variability of how faculty sequence lessons designs using learning cycles (Pedaste et al., 2015).

In terms of design knowledge, discussions and interviews from faculty reveal that learning cycles serve as an effective tool to aid faculty in decision making and lesson planning such as: (1) providing a structure or map to lessons; (2) linking a clear sequence between lesson topics and activities; (3) creating alignment between lesson outcomes and activities; (4) defining a sequential order or narrative between activities; (5) defining purpose of activities as they connect to the phases of each step in the learning cycle; and (6) planning for broader lesson sequences by reusing design patterns. Faculty interviews also showed that learning cycles helped them shift into a backwards design mindset where the central driver of lesson design was focused on the learning outcomes rather than topics to cover for the class session.

Faculty also explained that learning cycles are helpful in achieving content goals through connecting content to real-life contexts, promoting cycles of practice and problem solving, structuring group-based activities in the classroom, extending learning to scenarios and alternate examples, and integrating quick checks through poll quizzes which research has shown to be important in improving student learning experience and engagement (Calma et al., 2014)

Beyond benefits to faculty decision making and content goals, faculty also explained how learning cycles can positively benefit students in STEM courses. Faculty design discussions and interviews state that learning cycles can: (1) provide transparency to help students see big picture connections; (2) offer a process of learning to aid deeper understanding, retention, and learning support; (3) offer a checklist for students to work through lessons and stay on task; and (4) offer a breadcrumb trail to know where students are headed in the lesson, which in turn helps students manage their learning workload.

Prior research shares positive benefits of learning cycles on students' conceptual understanding of STEM topics (Cigdemoglu & Geban, 2015). Research has shown that learning cycles can indeed support faculty in lesson sequencing and ordering learning experiences (Tanner, 2010). German (2017) suggests that learning cycles provide a conceptual storyline for both students and instructors to drive the lesson activities and discussions and to clarify relationships between learning concepts. Learning cycles serve as a backward design and outcomes-oriented design approach to help faculty transform their lessons into active and student-centered.

5.6 Implications

The findings of this study have implications on university faculty design knowledge and practice both for qualitative research and for centers for teaching and learning.

5.6.1 Implications for Qualitative Research with Visual Data

This research study utilized innovative methods for data collection, preparation, modeling, and analysis (see Chapter 3) that involve multiple data sources. Traditional data collection methods for qualitative research are focused on gathering information from what people say (through interviews and questionnaires) and what people do (through observations). This research study applied the "say-do-make" framework (Sanders, 1999, 2001, 2002) to generate and collect multiple sources of data from the faculty designer in textual, verbal, and visual forms. Design artifacts in the form of lesson blueprints capture textual and visual data, while design discussions and interviews capture verbal data. Multiple formats of data provided the researcher a deep and rich contextual understanding underlying the thinking and experiences of faculty designers. With challenges of working with visual data, the researcher developed a unique method for collecting, preparing and analyzing visual data to elicit new knowledge models and derive deeper understanding from lesson blueprints, design discussions, and interviews.

In this study, the researcher developed a unique two-phased, hybrid inductive-deductive analysis approach to guide the data collection, data preparation, and data analysis (see Figure 16). Phase 1 outlines the seven-step inductive analysis process of lesson blueprints which begins at modeling lesson blueprints, to digitizing, flowcharting, schematizing, timelining, abstracting to defining design patterns of practice (see Table 11). Phase 2 outlines a six-step deductive analysis process which begins with conducting interviews and design discussions, transcribing and reviewing data, initial coding, identifying themes, reviewing themes, and defining contextual factors and mapping knowledge frames.

One of the early challenges of the researcher upon engaging in data analysis was that no lesson blueprint looked the same, but each had similar elements and features prescribed by the LEM toolkit. To aid analysis, the researcher used online diagramming tools (e.g., Draw.IO, Powerpoint) and qualitative data analysis tools like MAXQDA Codeline to combine, shape, clean up, model, transform, and standardize the representations of lesson blueprints from handwritten sequences in paper-based LEM lesson blueprints to multiple visual data formats such as flowcharts, text-based sequences, time-based sequences, and abstract illustrative diagrams. This data transformation helps researchers derive patterns and insights from visual data.

This research also offers an advancement in collecting data about design knowledge and practices by using the medium of a live professional development workshop to engage faculty in design work that would be followed by immediate discussion and articulation of the design thinking. These events in very close succession (within a three-hour period) afforded the research data to be more accurate and precise, preventing results that are influenced by data decay, forgetting, exaggeration, inaccuracies, and inconsistencies between what the faculty are thinking (design knowledge) and what the faculty actually did in practice (design practice). A live workshop also provides an authentic setting to systematically gather research data first hand, immediately, “as close as possible” to the design context.

Overall, this qualitative research felt like a treasure hunt, digging for authentic design knowledge and practice deeply rooted in faculty. The novel method of using lesson blueprints was an extremely useful tool for both the researcher and the faculty-designer to develop shared understanding and a common language about lesson design. Essentially, the blueprints were a necessary springboard towards eliciting design knowledge.

5.6.2 Implications for Centers for Teaching and Learning (CTLs)

One of the major reflections that the researcher had after the research culminated was that there is a need to bridge gaps between faculty design knowledge and instructional designer’s design knowledge. While both are design knowledge, faculty design knowledge is rooted in their discipline and their teaching experience, while instructional designers design knowledge is rooted in their training on instructional theory and design principles. Both design knowledge bases need to be equally recognized to develop more effective and efficient professional development, design processes and design tools.

Supporting faculty in their design process to ultimately become better designers will require a different approach. Traditionally, it is common to expect that a university center for teaching and learning would offer faculty development seminars or workshops on *design*. However, design knowledge and practices in such faculty development programs are often drawn from the knowledge base of instructional designers. For faculty, this knowledge base can be foreign, almost like a second language which, in turn, may pose difficulties in comprehension and application to individual contexts. It is therefore important to recognize the value of faculty design knowledge and consider them an active and "helpful actor" when engaging in collaborative design work (Goodyear & Dimitriadis, 2013, p. 4). Since faculty teaching experiences drive their design decisions, faculty might indeed serve as a positive complement to instructional designers' knowledge base and vice versa. Knowledge about how faculty design and why they make design decisions has the potential to bridge the gaps of instructional designers towards empathizing with faculty design challenges. The intersection between knowledge bases of an instructional designer and faculty can result in new sets of design principles that target specific contextual needs and learner challenges.

Results from this research study show that faculty are influenced by multiple contextual frames and require design support for each frame. This research shows that faculty who engage in lesson design work within the range of narrow activity sequences and broader lesson sequences, that possibly span over multiple lessons. This implies that faculty development and instructional design supports will need to meet faculty needs at varying levels of design work. It is reasonable to expect that CTLs will need to develop design resources, templates, toolkits, and examples to help faculty engage in design processes more efficiently. Lessons design patterns that can be replicated can drive more efficient course efforts, even saving time. With better understanding of the challenges that faculty encounter in design, instructional design professionals can more effectively support faculty in these areas. Faculty development programs for design need to be on-going for both new and experienced faculty users and this requires determining immediate training needs.

5.7 Recommendations for Future Research

The findings of this study expand on existing literature on university faculty design knowledge frames and design practice. Further research is needed to build a comprehensive knowledge base from understanding the epistemologies of faculty design knowledge that enables effective design for cognitive, social, relational, and affective learning, as well as, understanding each knowledge frame deeper.

Researchers may expand on design knowledge that presupposes design barriers, challenges, constraints, and in contrast, enablers and positive design experience. Research on design practices that might be of interest include roles of instructors working on codesign teams, relationships or interactions between instructional designers and faculty engaging in design work, individual and shared decision-making processes, design thinking processes, and the use and application of design toolkits.

Design literacies for faculty in specific disciplines is scant; additional research is required to identify the nuances between designing general design versus discipline-specific design knowledge, principles, and practices. The changing roles of faculty as designers from the time the data was gathered for this study through the COVID-19 pandemic is a relatively new phenomenon and is not yet well-defined. Additional qualitative efforts are useful to provide rich descriptions of faculty designer knowledge and practices and inform researchers interested in designing large-scale quantitative research.

This research utilized novel methods for data collection, preparation, and analysis that involve visual data. It is recommended that design research continues to apply similar methodologies to generate and collect multiple sources of data in textual, verbal, and visual forms to provide richer understanding underlying the knowledge frames, contextual factors, design ideas, and experiences of faculty. Alternative methodologies may include surveys on design knowledge, longitudinal studies (Derting et al., 2016), collaborative dialogues (Markauskaite et al., 2022), and teacher logs (Glennie et al., 2017).

As a purposive sample was utilized for this study, including a larger scope or diverse population sampling is recommended. This research focused on deriving design patterns of practice, contextual factors that drive faculty design decisions, and knowledge frames that are limited to the context of large classes, faculty with over five years teaching experience, and in-class STEM learning environments. Future research may identify design patterns and develop toolkits for alternate learning environments beyond the classroom (i.e., online, blended, hyflex, bichronous, adaptive, virtual / in-person labs, or informal learning spaces) for varying class sizes, disciplines, student demographics, grade levels, and geographical locations. Additional research visual lesson blueprints and the use of the LEM toolkit in supporting design work in alternate learning environments and contexts is recommended. Determining differences in design knowledge and practice between novice and experienced faculty can inform faculty development programming on design and competency development.

Validation is required to test the design patterns associated with learning sequences from this study through additional empirical studies in similar STEM disciplines. Such effort could feed into on-going interest among STEM educators and researchers who examine learning progressions as sequences of instruction and model pathways of learning over periods of time, across grades/years (Duschl et al., 2011; Duschl, 2019). Additional work could examine how STEM instructors adopted their "future lesson designs" into their teaching practice and transfer their knowledge gained from the professional development activity (i.e., course modeling workshop) (Derting et al., 2016). With larger sample sizes, researchers might consider applying design patterns in courses and using pattern-based analytics to drive improvements or redesign work (Li et al., 2022)

It is also encouraged to increase collaboration between STEM education researchers and experts in assessment, instructional design, cognitive science, learning sciences, online teaching and learning, educational development, and andragogy to bring evidence-based recommendations for how to design for troublesome topics in different subject matter areas. Such teams may also contribute to the development of competencies and standards for faculty designers.

5.8 Limitations

This study offers insights into faculty experiences of design practice and design knowledge in the context of a single, south-eastern public university. This assumes that findings are limited to the context the faculty are exposed to. Specific to this study, all faculty participants were from STEM fields, had between 7 to 10 years of teaching experience, and taught large class sizes between 60 to 90 students. A potential weakness of this study is that it includes only faculty from STEM fields, which in turn, implies that findings may not be generalized or applied to other fields. Findings require replication elsewhere with different faculty groups to explore the influence of design contexts on design practices. Additionally, due to data collection constraints, the study is limited to a short timeline, allowing the faculty to only engage in a small scope of lesson design rather than a full course design during the course modeling workshop. However, working with a small number of purposively selected faculty to engage in a workshop with 3-hour design discussions and a follow up interview enabled the researcher to be involved in deep conversations. It is necessary to note that the faculty engaged in design workshops still needed support from instructional designers or workshop facilitators on using the LEM modeling toolkit for designing lesson blueprints. This may serve as a limitation in future replications of this study. Lastly, the data collection and workshop event for this study took place prior to the peak of the COVID-19 pandemic (Fall 2019 to Spring 2020); replication of this study may yield different findings.

5.9 Summary

This chapter highlighted key discussion points about STEM faculty design knowledge and practice. In practice, faculty apply an activity-centered design, where activities are still the central focus but design decisions are influenced by multiple contextual factors and knowledge frames. Faculty as designers shift between high-level views of lesson progressions (zoomed-out) to low-level details of lesson elements (zoomed-in). This adds to the complexity of design, establishing that faculty have levels of granularity in their design work which influences the scale of knowledge frames activated as they engage in lesson design. Faculty also demonstrate the ability to develop design knowledge by applying learning cycles to reimagine or improve their lesson design. Implications for qualitative research and centers for teaching and learning were presented as well as future recommendations for research and limitations of the study.

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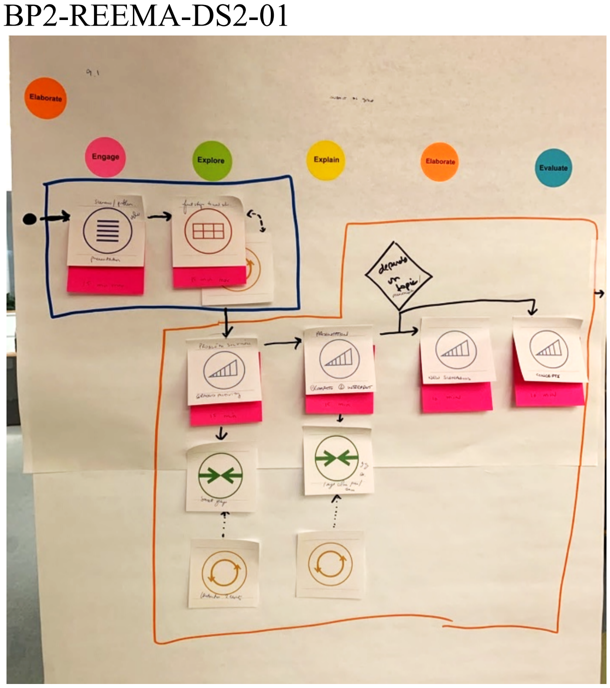
APPENDICES

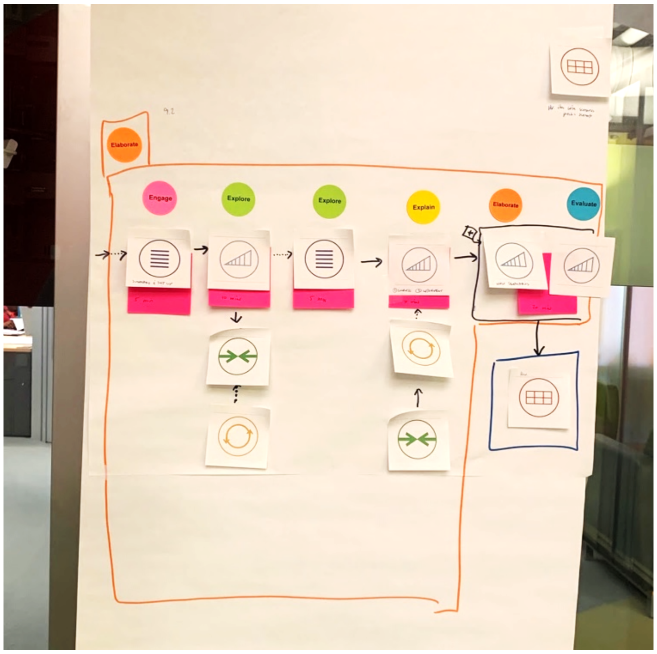
Appendix A: LEM Digitized Blueprints

BP1-REEMA-DS1-01

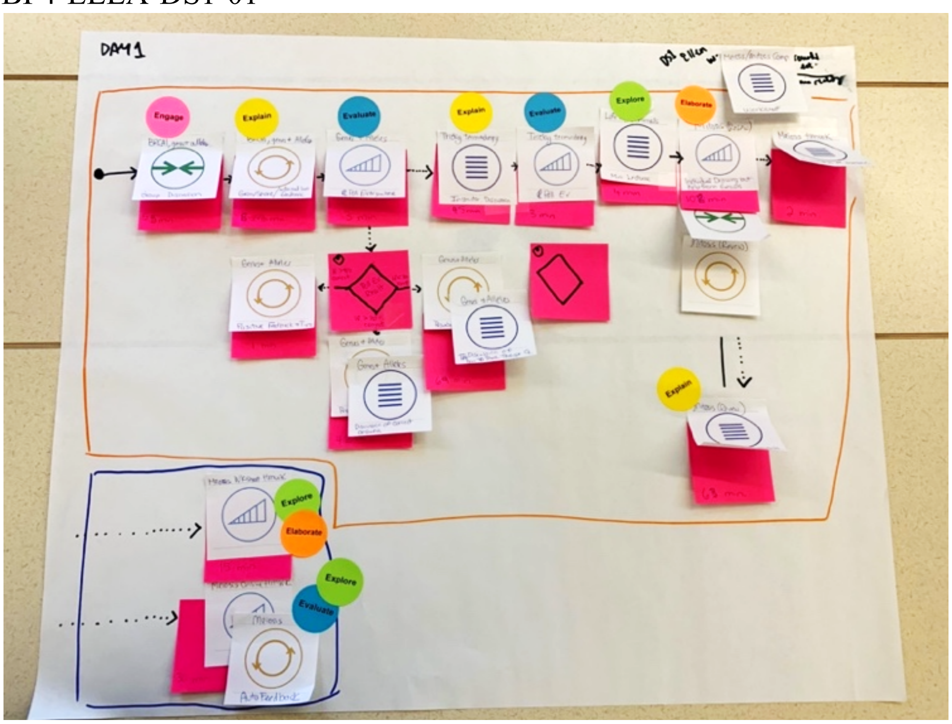
BP2-REEMA-DS2-01



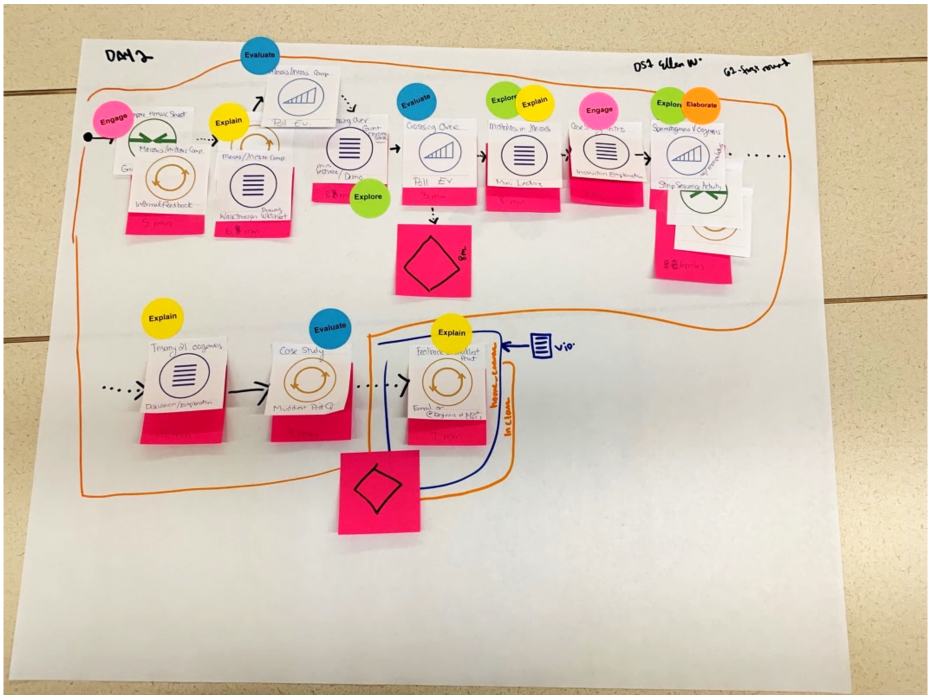
BP3-REEMA-DS2-02



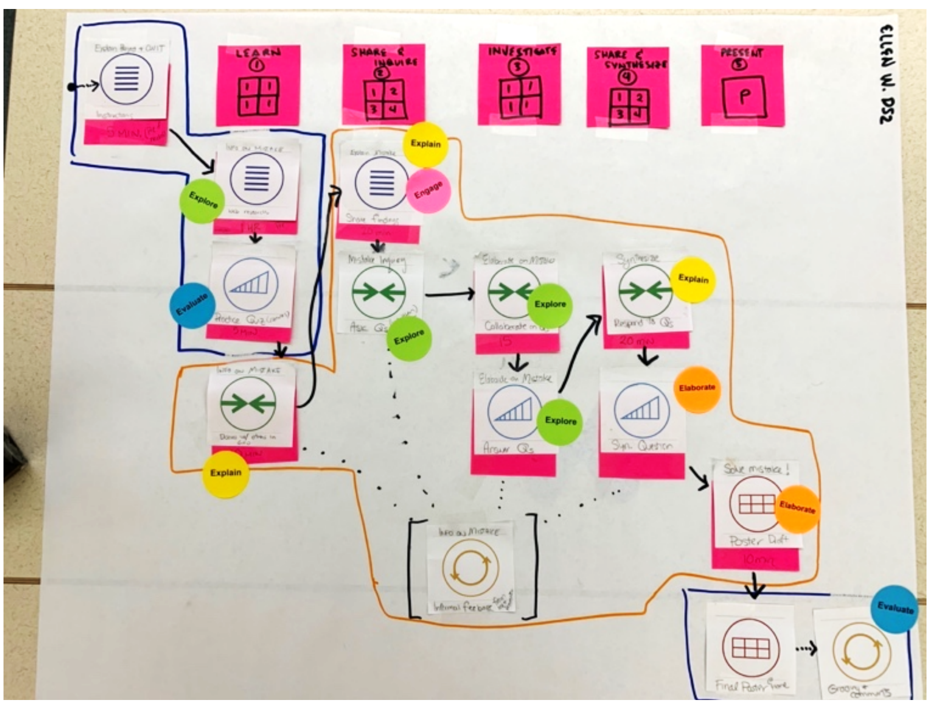
BP4-ELLA-DS1-01



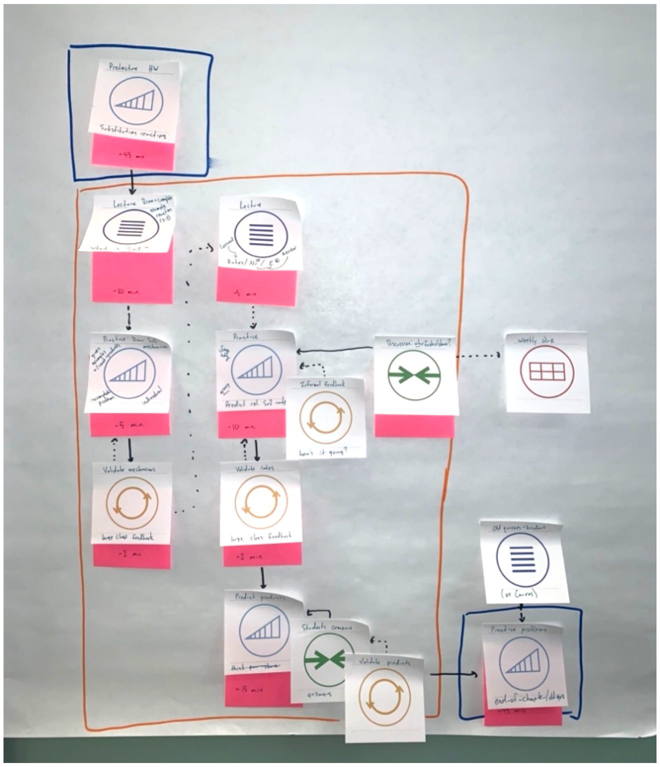
BP5-ELLA-DS1-02



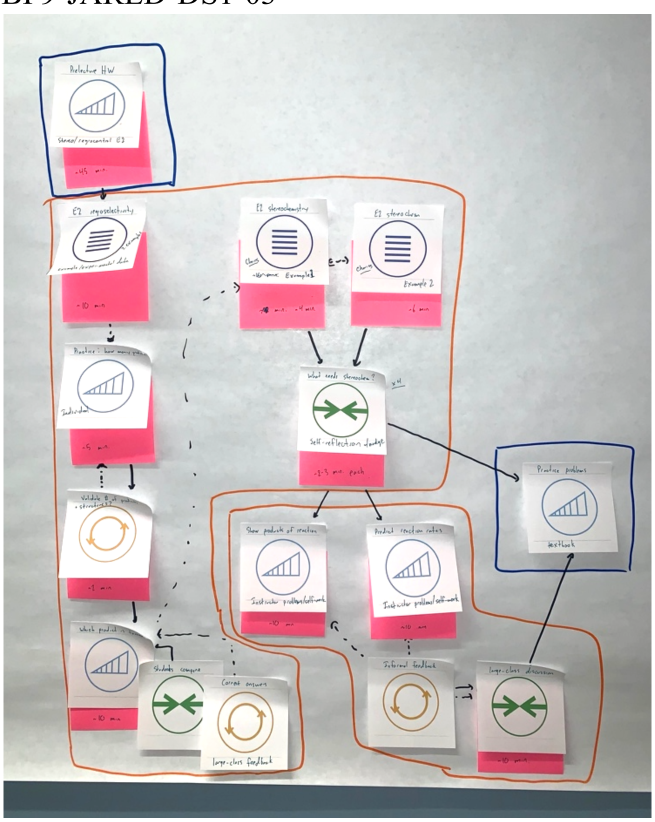
BP6-ELLA-DS2-01



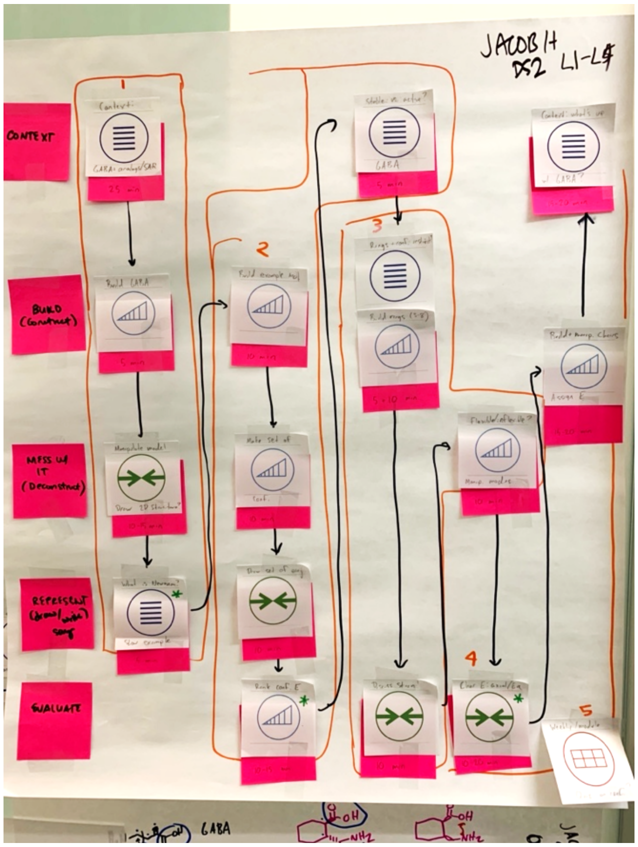
BP7-JARED-DS1-01 and BP8-JARED-DS1-02 Combined



BP9-JARED-DS1-03

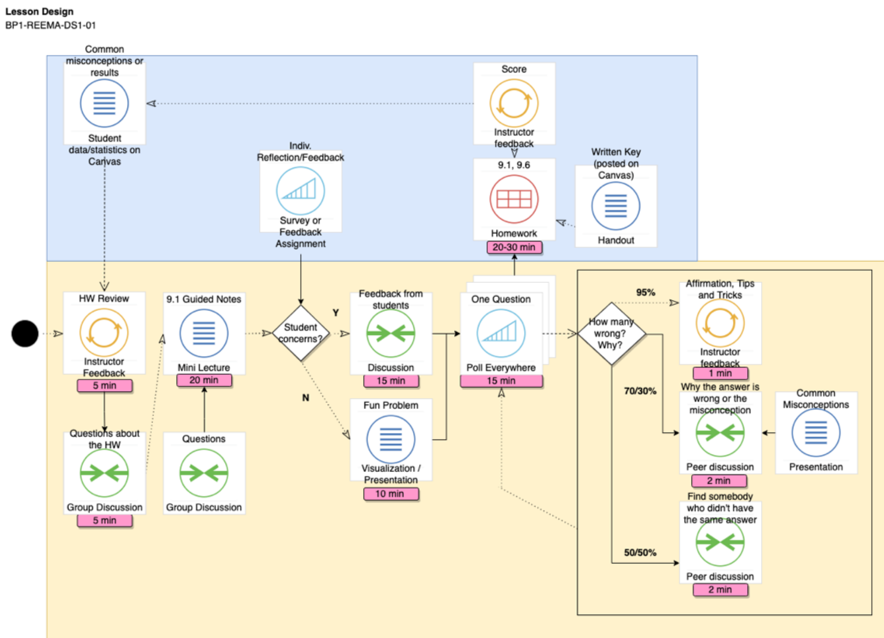


BP10-JARED-DS2-01, BP11-JARED-DS2-02, BP12-JARED-DS2-03, and BP13-JARED-DS2-04 Combined

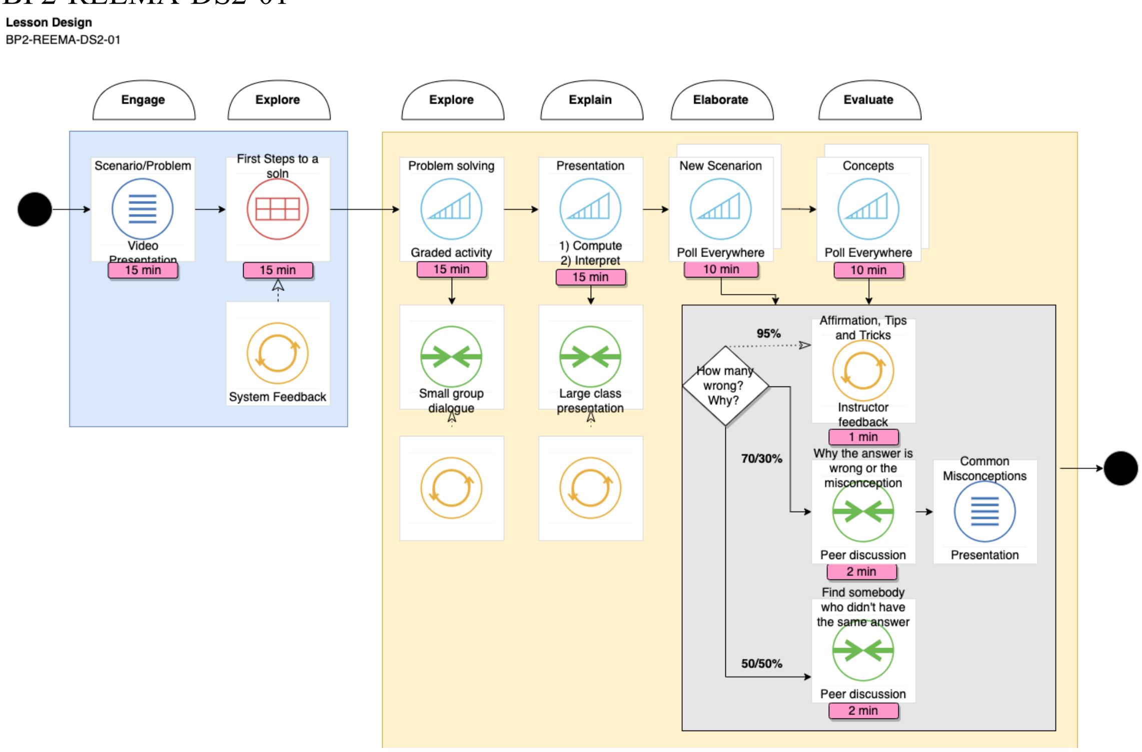


Appendix B: LEM Flowchart Lesson Blueprints

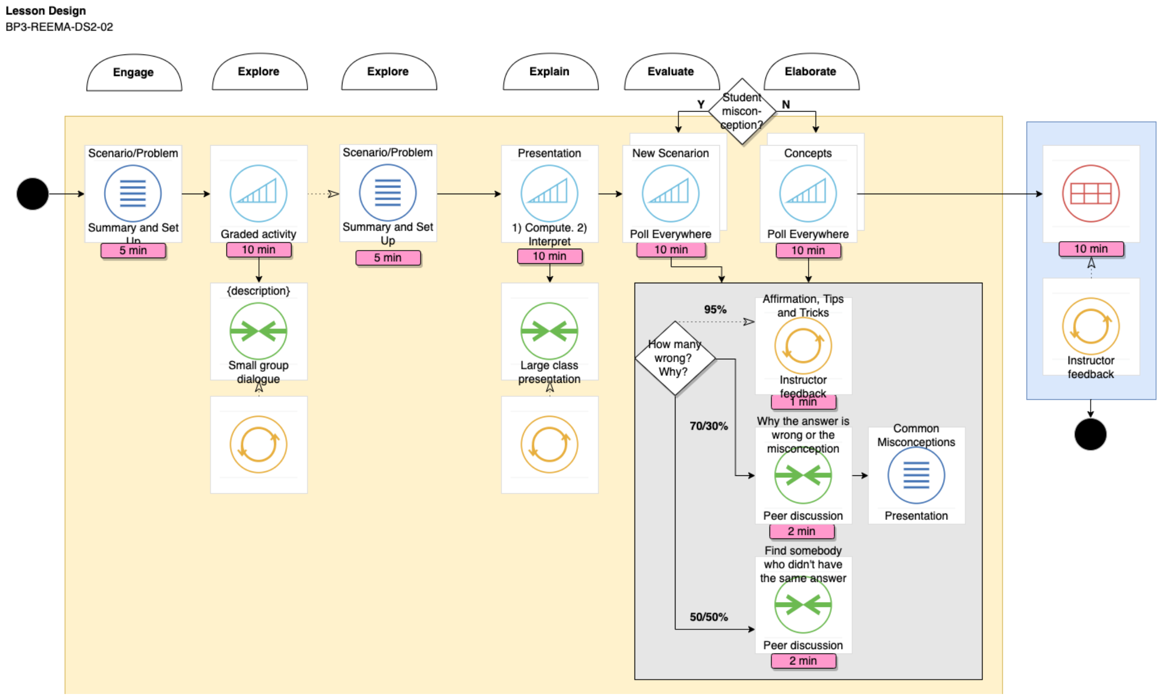
BP1-REEMA-DS1-01



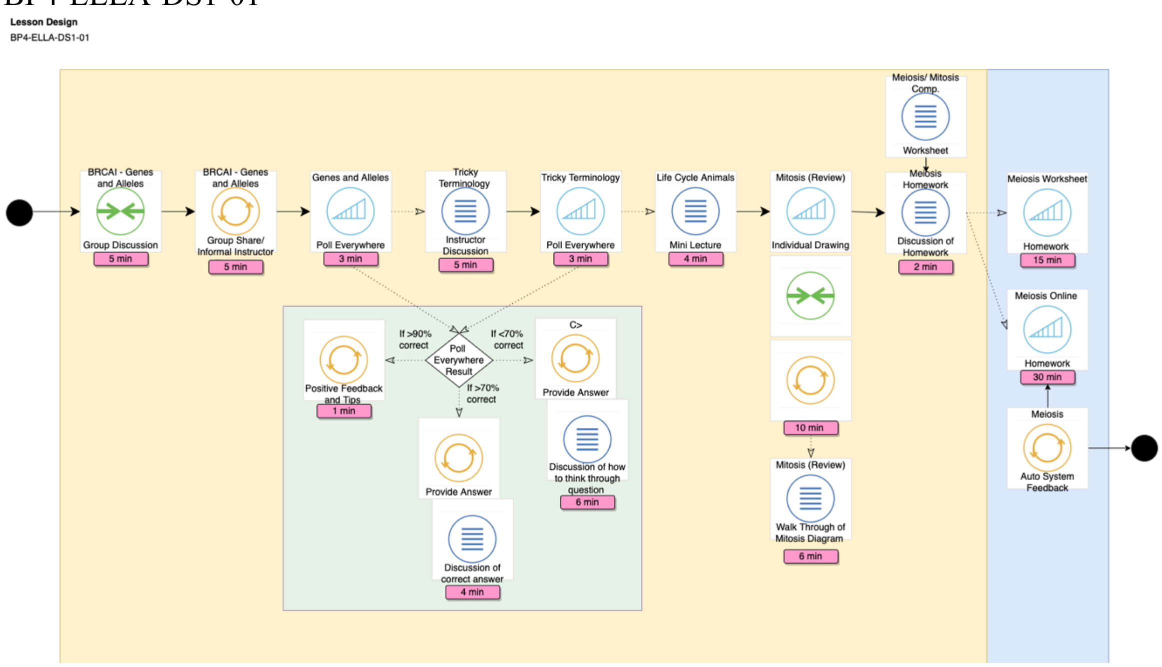
BP2-REEMA-DS2-01



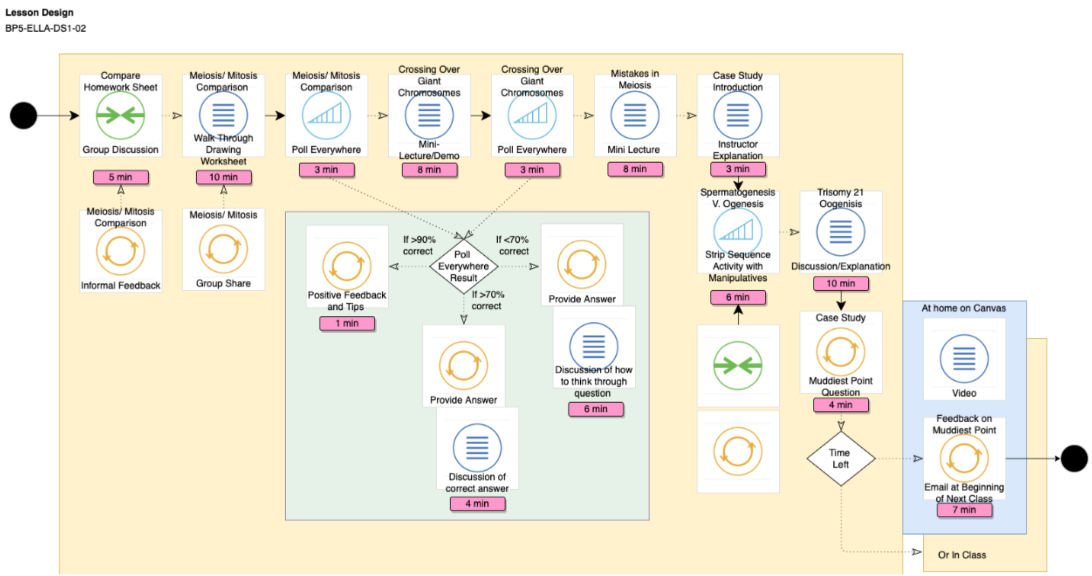
BP3-REEMA-DS2-02



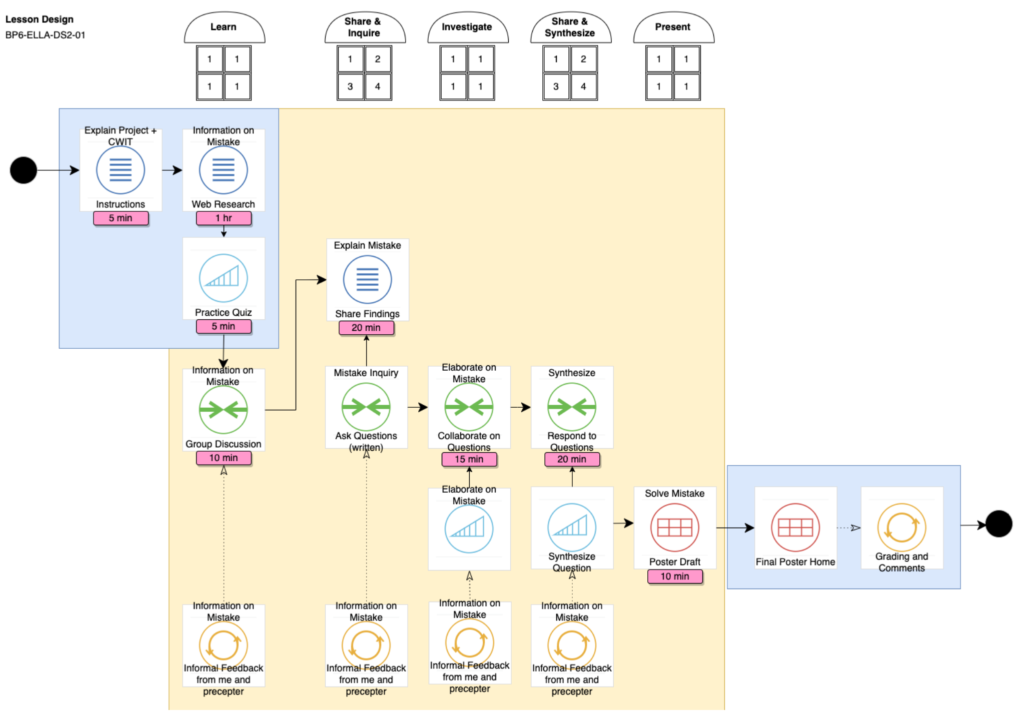
BP4-ELLA-DS1-01



BP5-ELLA-DS1-02



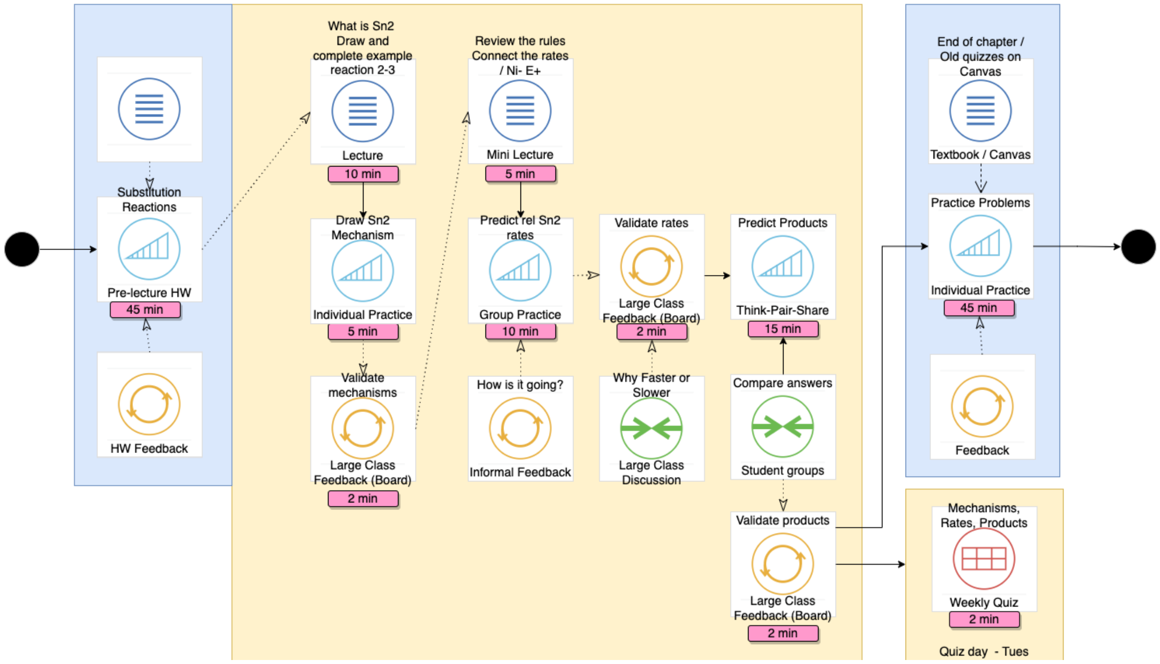
BP6-ELLA-DS2-01



BP7-JARED-DS1-01

Lesson Design

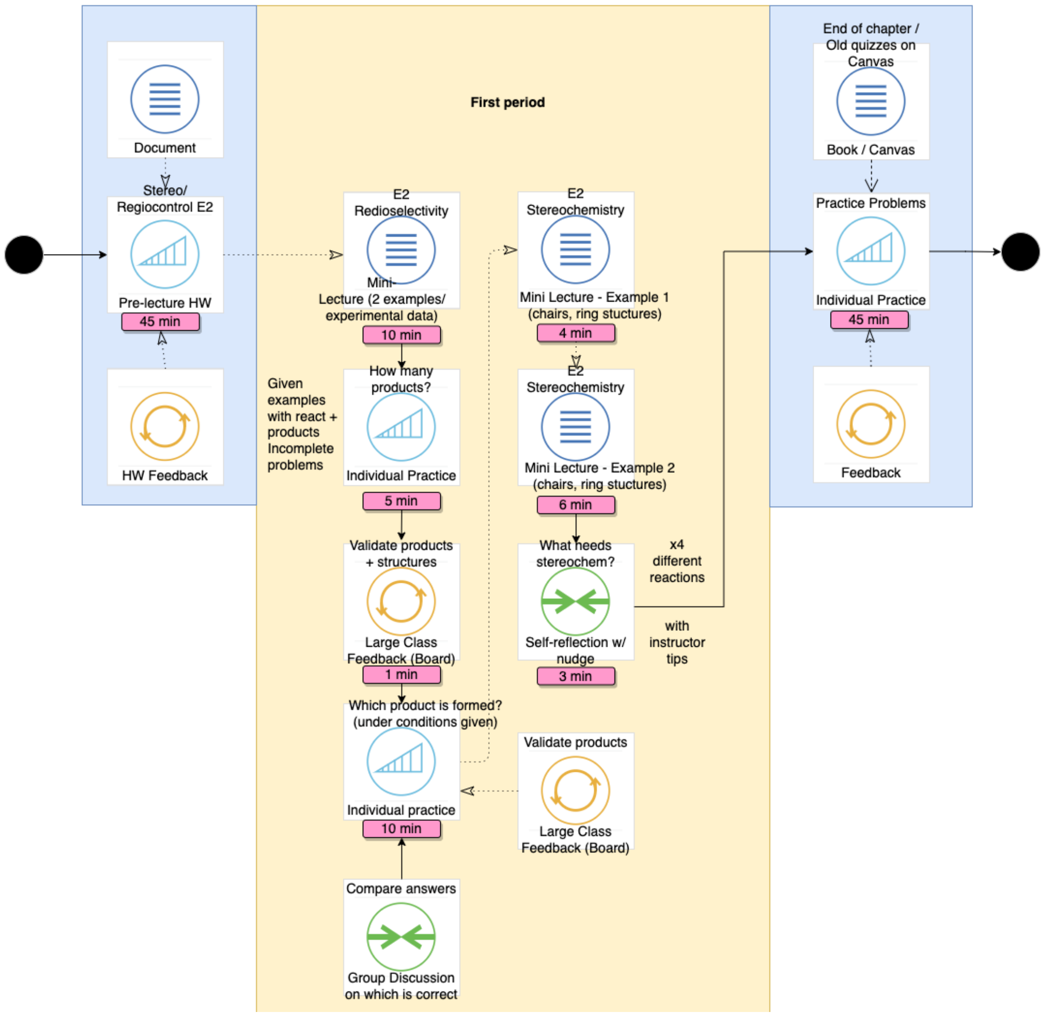
BP7-JARED-DS1-01



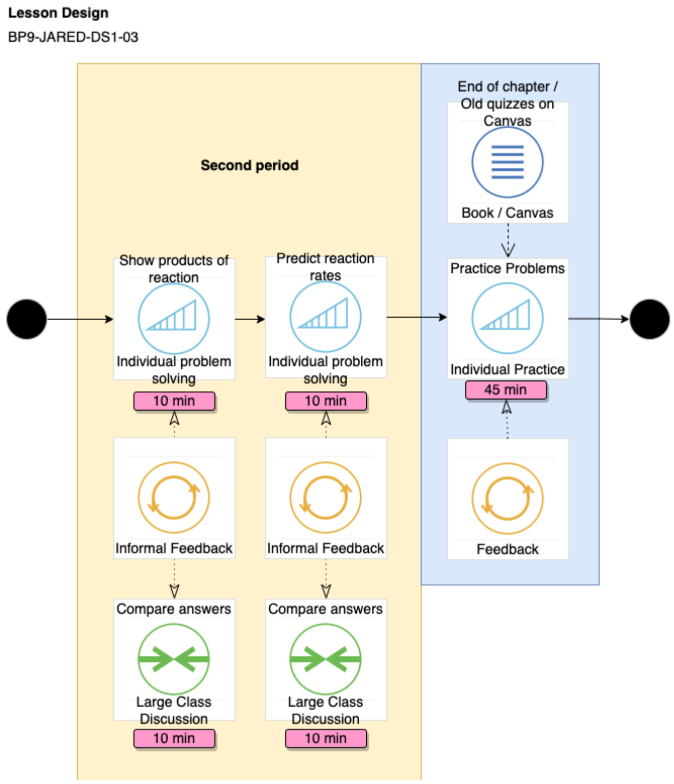
BP8-JARED-DS1-02

Lesson Design

BP8-JARED-DS1-02



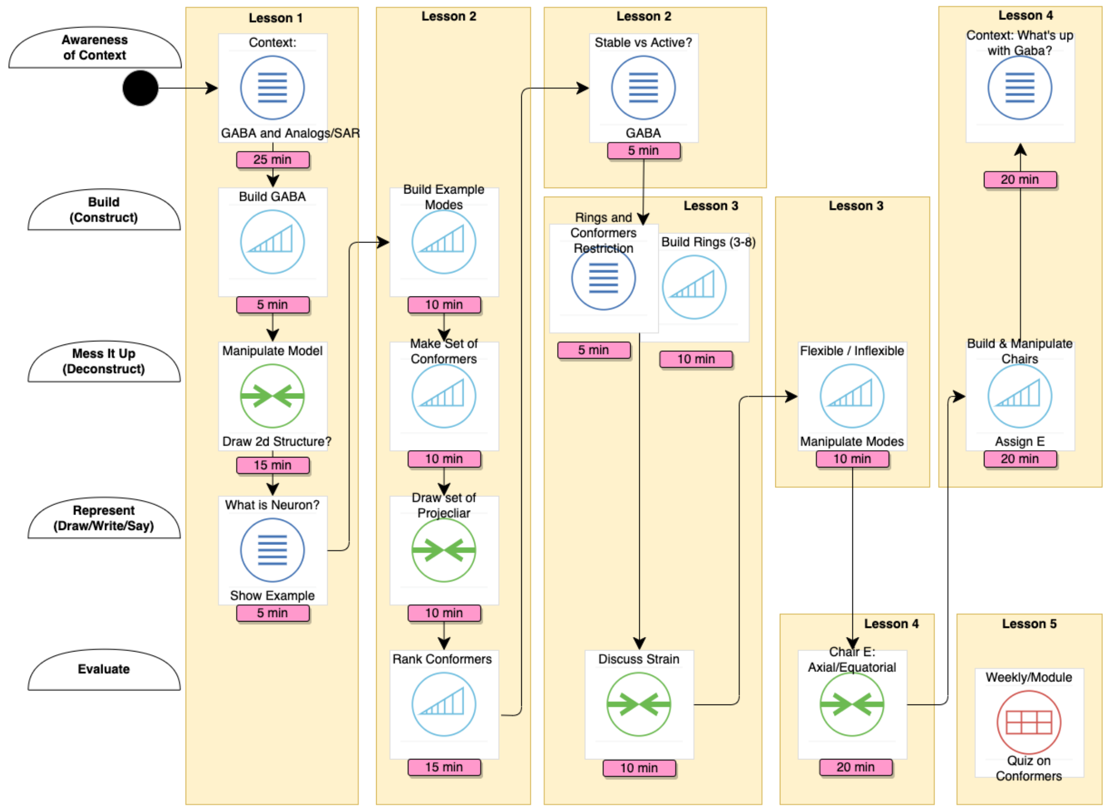
BP9-JARED-DS1-03



BP10-JARED-DS2-01, BP11-JARED-DS2-02, BP12-JARED-DS2-03, BP13-JARED-DS2-04 Combined

Lesson Design

BP10-11-12-13-14-JARED-DS2-01



Appendix C: Schematized (Text-Based) Lesson Blueprints

BP1-REEMA-DS1-01

Feedback - Instructor Feedback - Hw Review [5 min] // homework system
Feedback - Instructor Feedback - Hw Review [5 min]
Feedback - Instructor Feedback - Hw Review [5 min]
Feedback - Instructor Feedback - Hw Review [5 min]
Feedback - Instructor Feedback - Hw Review [5 min]
Dialogue - Group Discussion - Questions about the HW [5 min]
Dialogue - Group Discussion - Questions about the HW [5 min]
Dialogue - Group Discussion - Questions about the HW [5 min]
Dialogue - Group Discussion - Questions about the HW [5 min]
Dialogue - Group Discussion - Questions about the HW [5 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
Dialogue - Group Discussion - Questions about Mini Lecture
Information - Mini Lecture - Guided Notes [20 min]
[Decision Point: Student concerns?]

Y Dialogue - Group Discussion - Feedback from students [15 min]
N Information - Visualization / Presentation - Fun Problem [10 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
N Information - Visualization / Presentation - Fun Problem [10 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
N Information - Visualization / Presentation - Fun Problem [10 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
N Information - Visualization / Presentation - Fun Problem [10 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
N Information - Visualization / Presentation - Fun Problem [10 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
N Information - Visualization / Presentation - Fun Problem [10 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
N Information - Visualization / Presentation - Fun Problem [10 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
N Information - Visualization / Presentation - Fun Problem [10 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
N Information - Visualization / Presentation - Fun Problem [10 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
N Information - Visualization / Presentation - Fun Problem [10 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
Y Dialogue - Group Discussion - Feedback from students [15 min]
Practice - Poll Everywhere - Practice Question 1 [3 min]
Practice - Poll Everywhere - Practice Question 1 [3 min]
Practice - Poll Everywhere - Practice Question 1 [3 min]
[Decision Point: How many correct?]
[Using data in-class to gather student progress]
95% - Feedback - Instructor Feedback - Affirmation, Tips and Tricks [1 min]
70/30% - Dialogue - Peer Discussion - Why the answer is wrong and misconception [1 min]
70/30% - Information - Presentation - Common misconceptions [1 min]
50/50% - Dialogue - Peer Discussion - Find somebody who didn't have the same answer [2 min]
Practice - Poll Everywhere - Practice Question 2 [3 min]
Practice - Poll Everywhere - Practice Question 2 [3 min]
Practice - Poll Everywhere - Practice Question 2 [3 min]
[Decision Point: How many correct?]
95% - Feedback - Instructor Feedback - Affirmation, Tips and Tricks [1 min]
70/30% - Dialogue - Peer Discussion - Why the answer is wrong and misconception [1 min]
70/30% - Information - Presentation - Common misconceptions [1 min]
50/50% - Dialogue - Peer Discussion - Find somebody who didn't have the same answer [2 min]
Practice - Poll Everywhere - Practice Question 3 [3 min]
Practice - Poll Everywhere - Practice Question 3 [3 min]
Practice - Poll Everywhere - Practice Question 3 [3 min]
[Decision Point: How many correct?]
95% - Feedback - Instructor Feedback - Affirmation, Tips and Tricks [1 min]
70/30% - Dialogue - Peer Discussion - Why the answer is wrong and misconception [1 min]
70/30% - Information - Presentation - Common misconceptions [1 min]
50/50% - Dialogue - Peer Discussion - Find somebody who didn't have the same answer [2 min]

BP2-REEMA-DS2-01

Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A

Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Next Activity
Practice - Poll Everywhere - New Scenario 1 [3 min]
Practice - Poll Everywhere - New Scenario 1 [3 min]
Practice - Poll Everywhere - New Scenario 1 [3 min]
[Sub Decision Point: How many correct?] [Using data in-class to gather student progress]
95% - Feedback - Instructor Feedback - Affirmation, Tips and Tricks [1 min]
70/30% - Dialogue - Peer Discussion - Why the answer is wrong and misconception [1 min]
70/30% - Information - Presentation - Common misconceptions [1 min]
50/50% - Dialogue - Peer Discussion - Find somebody who didn't have the same answer [2 min]
Practice - Poll Everywhere - New Scenario 2 [3 min]
Practice - Poll Everywhere - New Scenario 2 [3 min]
Practice - Poll Everywhere - New Scenario 2 [3 min]
[Sub Decision Point: How many correct?] [Using data in-class to gather student progress]
95% - Feedback - Instructor Feedback - Affirmation, Tips and Tricks [1 min]
70/30% - Dialogue - Peer Discussion - Why the answer is wrong and misconception [1 min]
70/30% - Information - Presentation - Common misconceptions [1 min]

50/50% - Dialogue - Peer Discussion - Find somebody who didn't have the same answer [2 min] Practice - Poll Everywhere - New Concept 1 [3 min] Practice - Poll Everywhere - New Concept 1 [3 min] Practice - Poll Everywhere - New Concept 1 [3 min] [Sub Decision Point: How many correct?] [Using data in-class to gather student progress] 95% - Feedback - Instructor Feedback - Affirmation, Tips and Tricks [1 min] 70/30% - Dialogue - Peer Discussion - Why the answer is wrong and misconception [1 min] 70/30% - Information - Presentation - Common misconceptions [1 min] 50/50% - Dialogue - Peer Discussion - Find somebody who didn't have the same answer [2 min] Practice - Poll Everywhere - New Concept 2 [3 min] Practice - Poll Everywhere - New Concept 2 [3 min] Practice - Poll Everywhere - New Concept 2 [3 min] [Sub Decision Point: How many correct?] [Using data in-class to gather student progress] 95% - Feedback - Instructor Feedback - Affirmation, Tips and Tricks [1 min] 70/30% - Dialogue - Peer Discussion - Why the answer is wrong and misconception [1 min] 70/30% - Information - Presentation - Common misconceptions [1 min] 50/50% - Dialogue - Peer Discussion - Find somebody who didn't have the same answer [2 min]

BP3-REEMA-DS2-02

Practice - Graded Practice - Problem Solving [15 min] Dialogue - Small Group Dialogue - N/A Feedback - Instructor Feedback - N/A Practice - Graded Practice - Problem Solving [15 min] Dialogue - Small Group Dialogue - N/A Feedback - Instructor Feedback - N/A Practice - Graded Practice - Problem Solving [15 min] Dialogue - Small Group Dialogue - N/A Feedback - Instructor Feedback - N/A Practice - Graded Practice - Problem Solving [15 min] Dialogue - Small Group Dialogue - N/A Feedback - Instructor Feedback - N/A Practice - Graded Practice - Problem Solving [15 min] Dialogue - Small Group Dialogue - N/A Feedback - Instructor Feedback - N/A Practice - Graded Practice - Problem Solving [15 min] Dialogue - Small Group Dialogue - N/A Feedback - Instructor Feedback - N/A Practice - Graded Practice - Problem Solving [15 min] Dialogue - Small Group Dialogue - N/A Feedback - Instructor Feedback - N/A Practice - Graded Practice - Problem Solving [15 min] Dialogue - Small Group Dialogue - N/A Feedback - Instructor Feedback - N/A Practice - Graded Practice - Problem Solving [15 min] Dialogue - Small Group Dialogue - N/A Feedback - Instructor Feedback - N/A Practice - Graded Practice - Problem Solving [15 min] Dialogue - Small Group Dialogue - N/A Feedback - Instructor Feedback - N/A

Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Graded Practice - Problem Solving [15 min]
Dialogue - Small Group Dialogue - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A

Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Practice - Compute and Interpret - Presentation [15 min]
Dialogue - Large Class Presentation - N/A
Feedback - Instructor Feedback - N/A
Next Activity
Practice - Poll Everywhere - New Scenario 1 [3 min]
Practice - Poll Everywhere - New Scenario 1 [3 min]
Practice - Poll Everywhere - New Scenario 1 [3 min]
[Sub Decision Point: How many correct?] [Using data in-class to gather student progress]
95% - Feedback - Instructor Feedback - Affirmation, Tips and Tricks [1 min]
70/30% - Dialogue - Peer Discussion - Why the answer is wrong and misconception [1 min]
70/30% - Information - Presentation - Common misconceptions [1 min]
50/50% - Dialogue - Peer Discussion - Find somebody who didn't have the same answer [2 min]
Practice - Poll Everywhere - New Scenario 2 [3 min]
Practice - Poll Everywhere - New Scenario 2 [3 min]
Practice - Poll Everywhere - New Scenario 2 [3 min]
[Sub Decision Point: How many correct?] [Using data in-class to gather student progress]
95% - Feedback - Instructor Feedback - Affirmation, Tips and Tricks [1 min]
70/30% - Dialogue - Peer Discussion - Why the answer is wrong and misconception [1 min]
70/30% - Information - Presentation - Common misconceptions [1 min]
50/50% - Dialogue - Peer Discussion - Find somebody who didn't have the same answer [2 min]
Practice - Poll Everywhere - New Concept 1 [3 min]
Practice - Poll Everywhere - New Concept 1 [3 min]
Practice - Poll Everywhere - New Concept 1 [3 min]
[Sub Decision Point: How many correct?] [Using data in-class to gather student progress]
95% - Feedback - Instructor Feedback - Affirmation, Tips and Tricks [1 min]
70/30% - Dialogue - Peer Discussion - Why the answer is wrong and misconception [1 min]
70/30% - Information - Presentation - Common misconceptions [1 min]
50/50% - Dialogue - Peer Discussion - Find somebody who didn't have the same answer [2 min]
Practice - Poll Everywhere - New Concept 2 [3 min]
Practice - Poll Everywhere - New Concept 2 [3 min]
Practice - Poll Everywhere - New Concept 2 [3 min]
[Sub Decision Point: How many correct?] [Using data in-class to gather student progress]
95% - Feedback - Instructor Feedback - Affirmation, Tips and Tricks [1 min]
70/30% - Dialogue - Peer Discussion - Why the answer is wrong and misconception [1 min]
70/30% - Information - Presentation - Common misconceptions [1 min]
50/50% - Dialogue - Peer Discussion - Find somebody who didn't have the same answer [2 min]

BP4-ELLA-DS1-01

Dialogue - Group Discussion - BRCAI-Genes and Alleles [5 min]
Dialogue - Group Discussion - BRCAI-Genes and Alleles [5 min]
Dialogue - Group Discussion - BRCAI-Genes and Alleles [5 min]
Dialogue - Group Discussion - BRCAI-Genes and Alleles [5 min]
Dialogue - Group Discussion - BRCAI-Genes and Alleles [5 min]
Feedback - Group Share/Informal Instructor Feedback - BRCAI-Genes and Alleles [5 min]
Feedback - Group Share/Informal Instructor Feedback - BRCAI-Genes and Alleles [5 min]
Feedback - Group Share/Informal Instructor Feedback - BRCAI-Genes and Alleles [5 min]
Feedback - Group Share/Informal Instructor Feedback - BRCAI-Genes and Alleles [5 min]

Feedback - Group Share/Informal Instructor Feedback - BRCAI-Genes and Alleles [5 min]
Practice - Poll Everywhere - Practice Question Genes and Alleles 1 [3 min]
Practice - Poll Everywhere - Practice Question Genes and Alleles 1 [3 min]
Practice - Poll Everywhere - Practice Question Genes and Alleles 1 [3 min]
[Decision Point: How many correct?] [Using data in-class to gather student progress]
<70% correct - Feedback - Instructor Feedback - Provide Answer [6 min]
<70% correct - Information - Discuss how to think through the question [6 min]
<70% correct - Information - Discuss how to think through the question [6 min]
>70% correct - Feedback - Instructor Feedback - Provide Answer [4 min]
>70% correct - Information - Discuss correct answer [6 min]
>90% correct - Feedback - Instructor Feedback - Positive Feedback and Tips [1 min]
Information - Instructor Discussion - Tricky Terminology [5 min]
Information - Instructor Discussion - Tricky Terminology [5 min]
Information - Instructor Discussion - Tricky Terminology [5 min]
Information - Instructor Discussion - Tricky Terminology [5 min]
Information - Instructor Discussion - Tricky Terminology [5 min]
Practice - Poll Everywhere - Tricky Terminology 1 [3 min]
Practice - Poll Everywhere - Tricky Terminology 1 [3 min]
Practice - Poll Everywhere - Tricky Terminology 1 [3 min]
[Decision Point: How many correct?] [Using data in-class to gather student progress]
<70% correct - Feedback - Instructor Feedback - Provide Answer [6 min]
<70% correct - Information - Discuss how to think through the question [6 min]
<70% correct - Information - Discuss how to think through the question [6 min]
>70% correct - Feedback - Instructor Feedback - Provide Answer [4 min]
>70% correct - Information - Discuss correct answer [6 min]
>90% correct - Feedback - Instructor Feedback - Positive Feedback and Tips [1 min]
Information - Mini Lecture - Life Cycle Animals [4 min]
Information - Mini Lecture - Life Cycle Animals [4 min]
Information - Mini Lecture - Life Cycle Animals [4 min]
Information - Mini Lecture - Life Cycle Animals [4 min]
Practice - Individual Drawing but helps with Graps - Mitosis (review) [10 min]
Dialogue - NA - NA
Feedback - NA - NA
Practice - Individual Drawing but helps with Graps - Mitosis (review) [10 min]
Dialogue - NA - NA
Feedback - NA - NA
Practice - Individual Drawing but helps with Graps - Mitosis (review) [10 min]
Dialogue - NA - NA
Feedback - NA - NA
Practice - Individual Drawing but helps with Graps - Mitosis (review) [10 min]
Dialogue - NA - NA
Feedback - NA - NA
Practice - Individual Drawing but helps with Graps - Mitosis (review) [10 min]
Dialogue - NA - NA
Feedback - NA - NA
Practice - Individual Drawing but helps with Graps - Mitosis (review) [10 min]
Dialogue - NA - NA
Feedback - NA - NA
Practice - Individual Drawing but helps with Graps - Mitosis (review) [10 min]
Dialogue - NA - NA
Feedback - NA - NA
Practice - Individual Drawing but helps with Graps - Mitosis (review) [10 min]
Dialogue - NA - NA
Feedback - NA - NA

Practice - Individual Drawing but helps with Graps - Mitosis (review) [10 min]
Dialogue - NA - NA
Feedback - NA - NA
Practice - Individual Drawing but helps with Graps - Mitosis (review) [10 min]
Dialogue - NA - NA
Feedback - NA - NA
Information - Walk through of Mitosis Diagram - Mitosis (review) [6 min]
Information - Walk through of Mitosis Diagram - Mitosis (review) [6 min]
Information - Walk through of Mitosis Diagram - Mitosis (review) [6 min]
Information - Walk through of Mitosis Diagram - Mitosis (review) [6 min]
Information - Walk through of Mitosis Diagram - Mitosis (review) [6 min]
Information - Walk through of Mitosis Diagram - Mitosis (review) [6 min]
Information - Discussion of HW - Mitosis HW [2 min]
Information - Worksheet - Mitosis
Information - Discussion of HW - Mitosis HW [2 min]
Information - Worksheet - Mitosis

BP5-ELLA-DS1-02

Dialogue - Group Discussion - Compare Homework Sheet [5 min]
Feedback - Informal Feedback - Meiosis/Mitosis Comparison [5 min]
Dialogue - Group Discussion - Compare Homework Sheet [5 min]
Feedback - Informal Feedback - Meiosis/Mitosis Comparison [5 min]
Dialogue - Group Discussion - Compare Homework Sheet [5 min]
Feedback - Informal Feedback - Meiosis/Mitosis Comparison [5 min]
Dialogue - Group Discussion - Compare Homework Sheet [5 min]
Feedback - Informal Feedback - Meiosis/Mitosis Comparison [5 min]
Dialogue - Group Discussion - Compare Homework Sheet [5 min]
Feedback - Informal Feedback - Meiosis/Mitosis Comparison [5 min]
Information - Walk Through Drawing Worksheet - Meiosis/Mitosis Comparison [10 min]
Dialogue - Group Share - Meiosis Worksheet [10 min]
Information - Walk Through Drawing Worksheet - Meiosis/Mitosis Comparison [10 min]
Dialogue - Group Share - Meiosis Worksheet [10 min]
Information - Walk Through Drawing Worksheet - Meiosis/Mitosis Comparison [10 min]
Dialogue - Group Share - Meiosis Worksheet [10 min]
Information - Walk Through Drawing Worksheet - Meiosis/Mitosis Comparison [10 min]
Dialogue - Group Share - Meiosis Worksheet [10 min]
Information - Walk Through Drawing Worksheet - Meiosis/Mitosis Comparison [10 min]
Dialogue - Group Share - Meiosis Worksheet [10 min]
Information - Walk Through Drawing Worksheet - Meiosis/Mitosis Comparison [10 min]
Dialogue - Group Share - Meiosis Worksheet [10 min]
Information - Walk Through Drawing Worksheet - Meiosis/Mitosis Comparison [10 min]
Dialogue - Group Share - Meiosis Worksheet [10 min]
Information - Walk Through Drawing Worksheet - Meiosis/Mitosis Comparison [10 min]
Dialogue - Group Share - Meiosis Worksheet [10 min]
Information - Walk Through Drawing Worksheet - Meiosis/Mitosis Comparison [10 min]
Dialogue - Group Share - Meiosis Worksheet [10 min]
Information - Walk Through Drawing Worksheet - Meiosis/Mitosis Comparison [10 min]
Dialogue - Group Share - Meiosis Worksheet [10 min]
Practice - Poll Everywhere - Practice Question Meiosis/Mitosis Comparison 1 [3 min]
Practice - Poll Everywhere - Practice Question Meiosis/Mitosis Comparison 1 [3 min]
Practice - Poll Everywhere - Practice Question Meiosis/Mitosis Comparison 1 [3 min]
[Decision Point: How many correct?] [Using data in-class to gather student progress]
<70% correct - Feedback - Instructor Feedback - Provide Answer [6 min]
<70% correct - Information - Discuss how to think through the question [6 min]

<70% correct - Information - Discuss how to think through the question [6 min]
>70% correct - Feedback - Instructor Feedback - Provide Answer [4 min]
>70% correct - Information - Discuss correct answer [4 min]
>90% correct - Feedback - Instructor Feedback - Positive Feedback and Tips [1 min]
Information - Mini-Lecture/Demo - Crossing Over Giant Chromosomes [8 min]
Information - Mini-Lecture/Demo - Crossing Over Giant Chromosomes [8 min]
Information - Mini-Lecture/Demo - Crossing Over Giant Chromosomes [8 min]
Information - Mini-Lecture/Demo - Crossing Over Giant Chromosomes [8 min]
Information - Mini-Lecture/Demo - Crossing Over Giant Chromosomes [8 min]
Information - Mini-Lecture/Demo - Crossing Over Giant Chromosomes [8 min]
Information - Mini-Lecture/Demo - Crossing Over Giant Chromosomes [8 min]
Information - Mini-Lecture/Demo - Crossing Over Giant Chromosomes [8 min]
Practice - Poll Everywhere - Practice Question Crossing Over Giant Chromosomes 1 [3 min]
Practice - Poll Everywhere - Practice Question Crossing Over Giant Chromosomes 1 [3 min]
Practice - Poll Everywhere - Practice Question Crossing Over Giant Chromosomes 1 [3 min]
[Decision Point: How many correct?] [Using data in-class to gather student progress]
<70% correct - Feedback - Instructor Feedback - Provide Answer [6 min]
<70% correct - Information - Discuss how to think through the question [6 min]
<70% correct - Information - Discuss how to think through the question [6 min]
>70% correct - Feedback - Instructor Feedback - Provide Answer [4 min]
>70% correct - Information - Discuss correct answer [4 min]
>90% correct - Feedback - Instructor Feedback - Positive Feedback and Tips [1 min]
Information - Mini-Lecture - Mistakes in Meiosis [8 min]
Information - Mini-Lecture - Mistakes in Meiosis [8 min]
Information - Mini-Lecture - Mistakes in Meiosis [8 min]
Information - Mini-Lecture - Mistakes in Meiosis [8 min]
Information - Mini-Lecture - Mistakes in Meiosis [8 min]
Information - Mini-Lecture - Mistakes in Meiosis [8 min]
Information - Mini-Lecture - Mistakes in Meiosis [8 min]
Information - Mini-Lecture - Mistakes in Meiosis [8 min]
Information - Instructor Explanation - Case Study Introduction [3 min]
Information - Instructor Explanation - Case Study Introduction [3 min]
Information - Instructor Explanation - Case Study Introduction [3 min]
Practice - Strip Sequence Activity w/Manipulatives - Spermatognesis v. Oogenesis [6 min]
Dialogue - NA / NA
Feedback - NA / NA
Practice - Strip Sequence Activity w/Manipulatives - Spermatognesis v. Oogenesis [6 min]
Dialogue - NA / NA
Feedback - NA / NA
Practice - Strip Sequence Activity w/Manipulatives - Spermatognesis v. Oogenesis [6 min]
Dialogue - NA / NA
Feedback - NA / NA
Practice - Strip Sequence Activity w/Manipulatives - Spermatognesis v. Oogenesis [6 min]
Dialogue - NA / NA
Feedback - NA / NA
Practice - Strip Sequence Activity w/Manipulatives - Spermatognesis v. Oogenesis [6 min]
Dialogue - NA / NA
Feedback - NA / NA
Practice - Strip Sequence Activity w/Manipulatives - Spermatognesis v. Oogenesis [6 min]
Dialogue - NA / NA
Feedback - NA / NA
Information - Discussion/Explanation - Trisomy 21 Oogensis [10 min]
Information - Discussion/Explanation - Trisomy 21 Oogensis [10 min]
Information - Discussion/Explanation - Trisomy 21 Oogensis [10 min]
Information - Discussion/Explanation - Trisomy 21 Oogensis [10 min]
Information - Discussion/Explanation - Trisomy 21 Oogensis [10 min]

Information - Discussion/Explanation - Trisomy 21 Oogensis [10 min]
Information - Discussion/Explanation - Trisomy 21 Oogensis [10 min]
Information - Discussion/Explanation - Trisomy 21 Oogensis [10 min]
Information - Discussion/Explanation - Trisomy 21 Oogensis [10 min]
Information - Discussion/Explanation - Trisomy 21 Oogensis [10 min]
Feedback - Student Feedback - Muddiest Point Question - Case Study [4 min]
Feedback - Student Feedback - Muddiest Point Question - Case Study [4 min]
Feedback - Student Feedback - Muddiest Point Question - Case Study [4 min]
Feedback - Student Feedback - Muddiest Point Question - Case Study [4 min]
[Decision Point: How much time left?]
Feedback - Student Feedback - Muddiest Point Question [7 min]
Feedback - Student Feedback - Muddiest Point Question [7 min]
Feedback - Student Feedback - Muddiest Point Question [7 min]
Feedback - Student Feedback - Muddiest Point Question [7 min]
Feedback - Student Feedback - Muddiest Point Question [7 min]
Feedback - Student Feedback - Muddiest Point Question [7 min]
Feedback - Student Feedback - Muddiest Point Question [7 min]

BP6-ELLA-DS2-01

Dialogue - Project Group Discussion - Information on Mistake [10 min] [dependency on pre-class]
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Project Group Discussion - Information on Mistake [10 min]
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Project Group Discussion - Information on Mistake [10 min]
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Project Group Discussion - Information on Mistake [10 min]
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Project Group Discussion - Information on Mistake [10 min]
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Project Group Discussion - Information on Mistake [10 min]
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Project Group Discussion - Information on Mistake [10 min]
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Project Group Discussion - Information on Mistake [10 min]
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Project Group Discussion - Information on Mistake [10 min]
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Project Group Discussion - Information on Mistake [10 min]
Feedback - Informal Feedback (instruct&precept) - Information on Mistake

Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake

Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Shares Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Information - Students Group Share Findings - Explain Mistake - [20 min]
Dialogue - Student asks questions (written) - Mistake Inquiry
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake

Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Collaborate on Questions - Elaborate on Mistake [15 min]
Practice - Answer Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake

Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Dialogue - Student Groups Respond to Questions - Elaborate on Mistake [20 min]
Practice - Synthesize Questions - Elaborate on Mistake
Feedback - Informal Feedback (instruct&precept) - Information on Mistake
Evidence - Poster Draft - Solve Mistake [10 min]
Evidence - Poster Draft - Solve Mistake [10 min]
Evidence - Poster Draft - Solve Mistake [10 min]
Evidence - Poster Draft - Solve Mistake [10 min]
Evidence - Poster Draft - Solve Mistake [10 min]
Evidence - Poster Draft - Solve Mistake [10 min]
Evidence - Poster Draft - Solve Mistake [10 min]
Evidence - Poster Draft - Solve Mistake [10 min]
Evidence - Poster Draft - Solve Mistake [10 min]
Evidence - Poster Draft - Solve Mistake [10 min]

BP7-JARED-DS1-01

Information - Lecture - Sn2 [10 min]
Information - Lecture - Sn2 [10 min]
Information - Lecture - Sn2 [10 min]
Information - Lecture - Sn2 [10 min]
Information - Lecture - Sn2 [10 min]
Information - Lecture - Sn2 [10 min]
Information - Lecture - Sn2 [10 min]
Information - Lecture - Sn2 [10 min]
Information - Lecture - Sn2 [10 min]
Information - Lecture - Sn2 [10 min]
Practice - Individual Practice - Draw Sn2 Mechanism [5 min]
Practice - Individual Practice - Draw Sn2 Mechanism [5 min]
Practice - Individual Practice - Draw Sn2 Mechanism [5 min]
Practice - Individual Practice - Draw Sn2 Mechanism [5 min]
Practice - Individual Practice - Draw Sn2 Mechanism [5 min]
Feedback - Large Class Feedback (board) - Validate Mechanisms [2 min]
Feedback - Large Class Feedback (board) - Validate Mechanisms [2 min]
Information - Mini Lecture - Review rules.. [5 min]
Information - Mini Lecture - Review rules.. [5 min]
Information - Mini Lecture - Review rules.. [5 min]
Information - Mini Lecture - Review rules.. [5 min]
Information - Mini Lecture - Review rules.. [5 min]
Practice - Group Practice - Predict Sn2 Rates [10 min]
Feedback - Informal Feedback - How is it going?
Practice - Group Practice - Predict Sn2 Rates [10 min]
Feedback - Informal Feedback - How is it going?
Practice - Group Practice - Predict Sn2 Rates [10 min]
Feedback - Informal Feedback - How is it going?
Practice - Group Practice - Predict Sn2 Rates [10 min]
Feedback - Informal Feedback - How is it going?
Practice - Group Practice - Predict Sn2 Rates [10 min]
Feedback - Informal Feedback - How is it going?
Practice - Group Practice - Predict Sn2 Rates [10 min]
Feedback - Informal Feedback - How is it going?
Practice - Group Practice - Predict Sn2 Rates [10 min]
Feedback - Informal Feedback - How is it going?
Practice - Group Practice - Predict Sn2 Rates [10 min]
Feedback - Informal Feedback - How is it going?
Practice - Group Practice - Predict Sn2 Rates [10 min]
Feedback - Informal Feedback - How is it going?
Practice - Group Practice - Predict Sn2 Rates [10 min]
Feedback - Informal Feedback - How is it going?
Feedback - Large Class Feedback (board) - Validate Rates [2 min]
Dialogue - Large Class Discussion - Why Faster or Slower
Feedback - Large Class Feedback (board) - Validate Rates [2 min]
Dialogue - Large Class Discussion - Why Faster or Slower
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers

Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Practice - Think-Pair-Share - Predict Products [15 min]
Dialogue - Student groups - Compare Answers
Feedback - Large Class Feedback (board) - Validate products [2 min]
Feedback - Large Class Feedback (board) - Validate products [2 min]

BP8-JARED-DS1-02

Information - Mini-Lecture - E2 [10 min]
Information - Mini-Lecture - E2 [10 min]
Information - Mini-Lecture - E2 [10 min]
Information - Mini-Lecture - E2 [10 min]
Information - Mini-Lecture - E2 [10 min]
Information - Mini-Lecture - E2 [10 min]
Information - Mini-Lecture - E2 [10 min]
Information - Mini-Lecture - E2 [10 min]
Information - Mini-Lecture - E2 [10 min]
Information - Mini-Lecture - E2 [10 min]
Practice - Individual Practice - Problem Solving [5 min]
Practice - Individual Practice - Problem Solving [5 min]
Practice - Individual Practice - Problem Solving [5 min]
Practice - Individual Practice - Problem Solving [5 min]
Practice - Individual Practice - Problem Solving [5 min]
Feedback - Large Class Feedback (board) - Validate Products and Structures
Practice - Individual Practice - Which product is formed? [10 min]
Dialogue - Group Discussion - Compare answers
Feedback - Large Class Feedback - Validate products
Practice - Individual Practice - Which product is formed? [10 min]
Dialogue - Group Discussion - Compare answers
Feedback - Large Class Feedback - Validate products
Practice - Individual Practice - Which product is formed? [10 min]
Dialogue - Group Discussion - Compare answers
Feedback - Large Class Feedback - Validate products

Practice - Individual Practice - Which product is formed? [10 min]
Dialogue - Group Discussion - Compare answers
Feedback - Large Class Feedback - Validate products
Practice - Individual Practice - Which product is formed? [10 min]
Dialogue - Group Discussion - Compare answers
Feedback - Large Class Feedback - Validate products
Practice - Individual Practice - Which product is formed? [10 min]
Dialogue - Group Discussion - Compare answers
Feedback - Large Class Feedback - Validate products
Practice - Individual Practice - Which product is formed? [10 min]
Dialogue - Group Discussion - Compare answers
Feedback - Large Class Feedback - Validate products
Practice - Individual Practice - Which product is formed? [10 min]
Dialogue - Group Discussion - Compare answers
Feedback - Large Class Feedback - Validate products
Practice - Individual Practice - Which product is formed? [10 min]
Dialogue - Group Discussion - Compare answers
Feedback - Large Class Feedback - Validate products
Practice - Individual Practice - Which product is formed? [10 min]
Dialogue - Group Discussion - Compare answers
Feedback - Large Class Feedback - Validate products
Information - Mini-Lecture - E2 Stereochemistry - Example 1 [4 min]
Information - Mini-Lecture - E2 Stereochemistry - Example 1 [4 min]
Information - Mini-Lecture - E2 Stereochemistry - Example 1 [4 min]
Information - Mini-Lecture - E2 Stereochemistry - Example 1 [4 min]
Information - Mini-Lecture - E2 Stereochemistry - Example 2 [6 min]
Information - Mini-Lecture - E2 Stereochemistry - Example 2 [6 min]
Information - Mini-Lecture - E2 Stereochemistry - Example 2 [6 min]
Information - Mini-Lecture - E2 Stereochemistry - Example 2 [6 min]
Information - Mini-Lecture - E2 Stereochemistry - Example 2 [6 min]
Information - Mini-Lecture - E2 Stereochemistry - Example 2 [6 min]
Dialogue - Self-Reflection / Instructor Tips - What needs Stereochemistry [3 min]
Dialogue - Self-Reflection / Instructor Tips - What needs Stereochemistry [3 min]
Dialogue - Self-Reflection / Instructor Tips - What needs Stereochemistry [3 min]

BP9-JARED-DS1-03

Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback

Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Practice - Individual Problem Solving - Show products of reaction [10 min]
Feedback - Informal Feedback
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]
Dialogue - Large Class Discussion - Compare answers [10 min]

BP10-JARED-DS2-01

Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
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Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]

Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Information - Lecture - Context: GABA and Analogs/SAR [25 min]
Practice - Build - Build (Construct): Build GABA [5 min]
Practice - Build - Build (Construct): Build GABA [5 min]
Practice - Build - Build (Construct): Build GABA [5 min]
Practice - Build - Build (Construct): Build GABA [5 min]
Practice - Build - Build (Construct): Build GABA [5 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Dialogue - Manipulate Model with Large Class Discussion - Mess It Up (Deconstruct): Draw 2D Structure [15 min]
Information - Show example on another representation; A better way to solve the problem - Represent (Draw/Write/Say): What is a Neuron [5 min]
Information - Show example on another representation; A better way to solve the problem; Not share too much information - Represent (Draw/Write/Say): What is a Neuron [5 min]
Information - Show example on another representation; A better way to solve the problem; Not share too much information - Represent (Draw/Write/Say): What is a Neuron [5 min]

Information - Show example on another representation; A better way to solve the problem; Not share too much information - Represent (Draw/Write/Say): What is a Neuron [5 min]
Information - Show example on another representation; A better way to solve the problem; Not share too much information - Represent (Draw/Write/Say): What is a Neuron [5 min]

BP11-JARED-DS2-02

Practice - Build - Build (Construct): Build Examples Modes [10 min] Refer to video MVI_O319_Jacob DS2
Practice - Build - Build (Construct): Build Examples Modes [10 min]
Practice - Build - Build (Construct): Build Examples Modes [10 min]
Practice - Build - Build (Construct): Build Examples Modes [10 min]
Practice - Build - Build (Construct): Build Examples Modes [10 min]
Practice - Build - Build (Construct): Build Examples Modes [10 min]
Practice - Build - Build (Construct): Build Examples Modes [10 min]
Practice - Build - Build (Construct): Build Examples Modes [10 min]
Practice - Build - Build (Construct): Build Examples Modes [10 min]
Practice - Build - Build (Construct): Build Examples Modes [10 min]
Practice - Mess it Up - Mess it Up (Deconstruct): Make Set of Confomers (Rotations) [10 min] //rotate what they built
Practice - Mess it Up - Mess it Up (Deconstruct): Make Set of Confomers (Rotations) [10 min]
Practice - Mess it Up - Mess it Up (Deconstruct): Make Set of Confomers (Rotations) [10 min]
Practice - Mess it Up - Mess it Up (Deconstruct): Make Set of Confomers (Rotations) [10 min]
Practice - Mess it Up - Mess it Up (Deconstruct): Make Set of Confomers (Rotations) [10 min]
Practice - Mess it Up - Mess it Up (Deconstruct): Make Set of Confomers (Rotations) [10 min]
Practice - Mess it Up - Mess it Up (Deconstruct): Make Set of Confomers (Rotations) [10 min]
Practice - Mess it Up - Mess it Up (Deconstruct): Make Set of Confomers (Rotations) [10 min]
Practice - Mess it Up - Mess it Up (Deconstruct): Make Set of Confomers (Rotations) [10 min]
Practice - Mess it Up - Mess it Up (Deconstruct): Make Set of Confomers (Rotations) [10 min]
Dialogue - Draw - Represent (Draw/Write/Say): Draw Set of Projecliar [10 min // put them on paper]
Dialogue - Draw - Represent (Draw/Write/Say): Draw Set of Projecliar [10 min]
Dialogue - Draw - Represent (Draw/Write/Say): Draw Set of Projecliar [10 min]
Dialogue - Draw - Represent (Draw/Write/Say): Draw Set of Projecliar [10 min]
Dialogue - Draw - Represent (Draw/Write/Say): Draw Set of Projecliar [10 min]
Dialogue - Draw - Represent (Draw/Write/Say): Draw Set of Projecliar [10 min]
Dialogue - Draw - Represent (Draw/Write/Say): Draw Set of Projecliar [10 min]
Dialogue - Draw - Represent (Draw/Write/Say): Draw Set of Projecliar [10 min]
Dialogue - Draw - Represent (Draw/Write/Say): Draw Set of Projecliar [10 min]
Dialogue - Draw - Represent (Draw/Write/Say): Draw Set of Projecliar [10 min]
Practice - Evaluate - Evaluate: Rank Confomers [15 min] // talk about which ones are better or worse (rank)
Practice - Evaluate - Evaluate: Rank Confomers [15 min]
Practice - Evaluate - Evaluate: Rank Confomers [15 min]
Practice - Evaluate - Evaluate: Rank Confomers [15 min]
Practice - Evaluate - Evaluate: Rank Confomers [15 min]
Practice - Evaluate - Evaluate: Rank Confomers [15 min]
Practice - Evaluate - Evaluate: Rank Confomers [15 min]
Practice - Evaluate - Evaluate: Rank Confomers [15 min]
Practice - Evaluate - Evaluate: Rank Confomers [15 min]
Practice - Evaluate - Evaluate: Rank Confomers [15 min]
Practice - Evaluate - Evaluate: Rank Confomers [15 min]
Practice - Evaluate - Evaluate: Rank Confomers [15 min]
Practice - Evaluate - Evaluate: Rank Confomers [15 min]

Practice - Evaluate - Evaluate: Rank Confomers [15 min] Information - GABA - Context: Stable vs. Active [5 min // tie back to context, but introduce stable vs active Information - GABA - Context: Stable vs. Active [5 min] Information - GABA - Context: Stable vs. Active [5 min] Information - GABA - Context: Stable vs. Active [5 min] Information - GABA - Context: Stable vs. Active [5 min]

BP12-JARED-DS2-03

Information - Mini Lecture - Rings and Conformers [5 min] Refer to video MVI_O319_Jacob DS2 Information - Mini Lecture - Rings and Conformers [5 min] // talking about rings; new topic Information - Mini Lecture - Rings and Conformers [5 min] Information - Mini Lecture - Rings and Conformers [5 min] Information - Mini Lecture - Rings and Conformers [5 min] Practice - Build - Build (Construct): Build Rings [10 min] // you do it Practice - Build - Build (Construct): Build Rings [10 min] Practice - Build - Build (Construct): Build Rings [10 min] Practice - Build - Build (Construct): Build Rings [10 min] Practice - Build - Build (Construct): Build Rings [10 min] Practice - Build - Build (Construct): Build Rings [10 min] Practice - Build - Build (Construct): Build Rings [10 min] Practice - Build - Build (Construct): Build Rings [10 min] Practice - Build - Build (Construct): Build Rings [10 min] Practice - Build - Build (Construct): Build Rings [10 min] Dialogue - Discussion - Evaluate: Discuss Strain [10 min // how rings are fighting to constrain] Dialogue - Discussion - Evaluate: Discuss Strain [10 min] Dialogue - Discussion - Evaluate: Discuss Strain [10 min] Dialogue - Discussion - Evaluate: Discuss Strain [10 min] Dialogue - Discussion - Evaluate: Discuss Strain [10 min] Dialogue - Discussion - Evaluate: Discuss Strain [10 min] Dialogue - Discussion - Evaluate: Discuss Strain [10 min] Dialogue - Discussion - Evaluate: Discuss Strain [10 min] Dialogue - Discussion - Evaluate: Discuss Strain [10 min] Dialogue - Discussion - Evaluate: Discuss Strain [10 min] Practice - Manipulate Modes - Mess it Up (Deconstruct): Flexible / Inflexible [10 min] // not floppy like chains; restricted, twist and bend, then represent it Practice - Manipulate Modes - Mess it Up (Deconstruct): Flexible / Inflexible [10 min] Practice - Manipulate Modes - Mess it Up (Deconstruct): Flexible / Inflexible [10 min] Practice - Manipulate Modes - Mess it Up (Deconstruct): Flexible / Inflexible [10 min] Practice - Manipulate Modes - Mess it Up (Deconstruct): Flexible / Inflexible [10 min] Practice - Manipulate Modes - Mess it Up (Deconstruct): Flexible / Inflexible [10 min] Practice - Manipulate Modes - Mess it Up (Deconstruct): Flexible / Inflexible [10 min] Practice - Manipulate Modes - Mess it Up (Deconstruct): Flexible / Inflexible [10 min] Practice - Manipulate Modes - Mess it Up (Deconstruct): Flexible / Inflexible [10 min] Practice - Manipulate Modes - Mess it Up (Deconstruct): Flexible / Inflexible [10 min]

BP13-JARED-DS2-04

Dialogue - Evaluate: Chair E Axial/Equatorial [20 min] Refer to video MVI_O319_Jacob DS2 Dialogue - Evaluate: Chair E Axial/Equatorial [20 min] // write their energies Dialogue - Evaluate: Chair E Axial/Equatorial [20 min] Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]

Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]
Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]
Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]
Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]
Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]
Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]
Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]
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Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]
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Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]
Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]
Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]
Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]
Dialogue - Evaluate: Chair E Axial/Equatorial [20 min]

Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min] // more examples of the chair and ring confomer
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]
Practice - Manipulate - Mess is Up (Deconstruct): Assign E [20 min]

Information - Lecture - Context: What's up w Gaba [20 min // Tie back]
Information - Lecture - Context: What's up w Gaba [20 min]
Information - Lecture - Context: What's up w Gaba [20 min]
Information - Lecture - Context: What's up w Gaba [20 min]
Information - Lecture - Context: What's up w Gaba [20 min]
Information - Lecture - Context: What's up w Gaba [20 min]
Information - Lecture - Context: What's up w Gaba [20 min]
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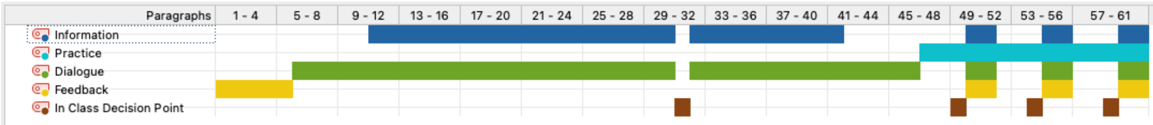
Information - Lecture - Context: What's up w Gaba [20 min]
Information - Lecture - Context: What's up w Gaba [20 min]

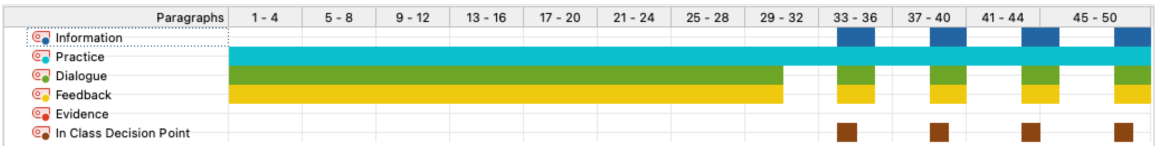
Information - Lecture - Context: What's up w Gaba [20 min]
Information - Lecture - Context: What's up w Gaba [20 min]
Information - Lecture - Context: What's up w Gaba [20 min]

Appendix D: Time-Based Lesson Blueprints

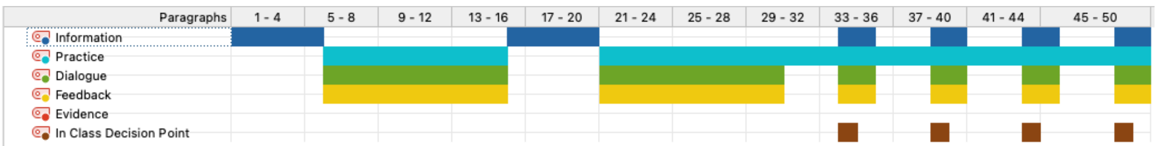
BP1-REEMA-DS1-01



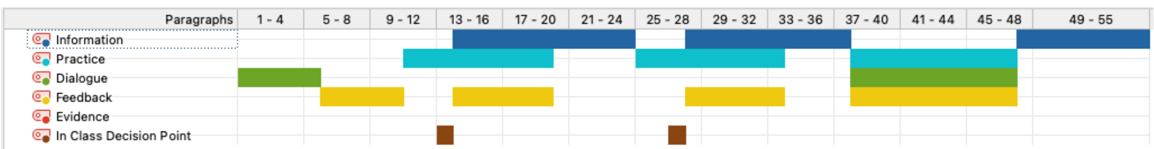
BP2-REEMA-DS2-01



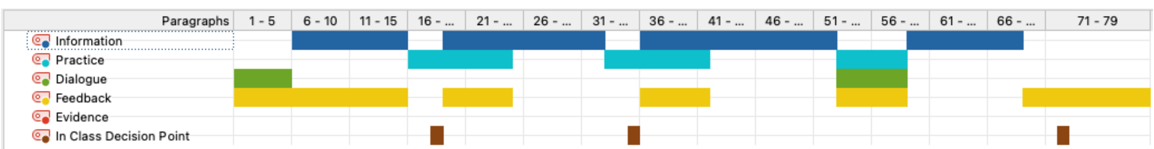
BP3-REEMA-DS2-02



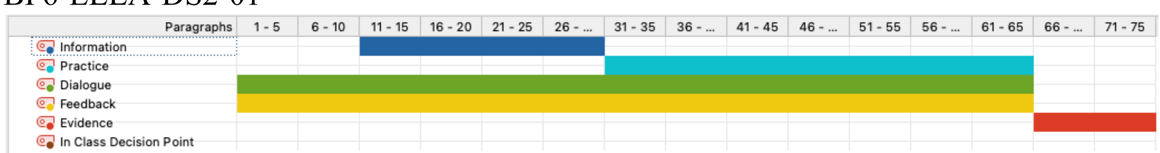
BP4-ELLA-DS1-01



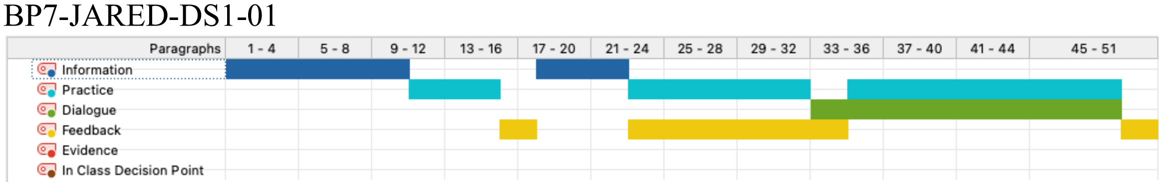
BP5-ELLA-DS1-02



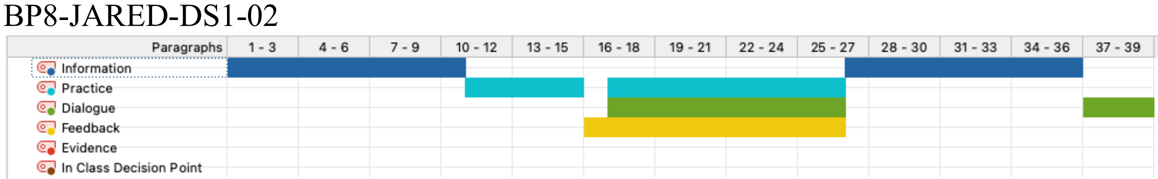
BP6-ELLA-DS2-01



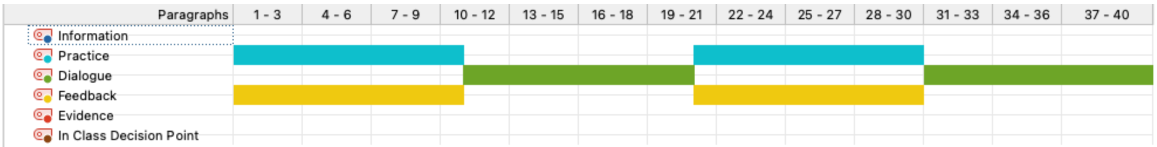
BP7-JARED-DS1-01



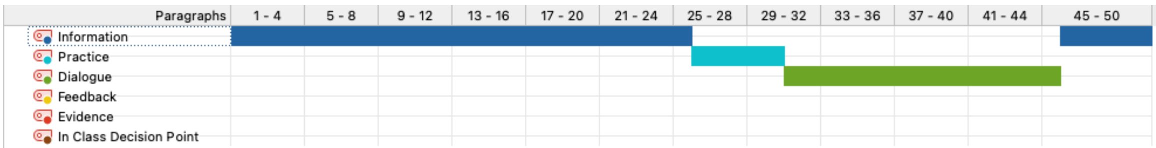
BP8-JARED-DS1-02



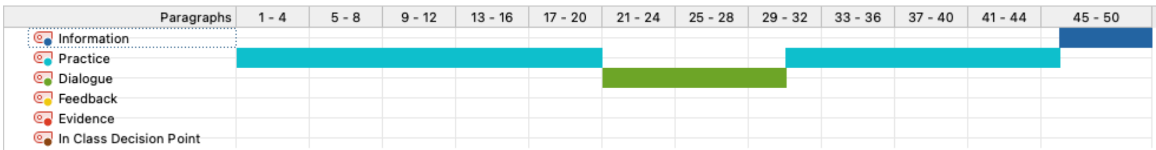
BP9-JARED-DS1-03



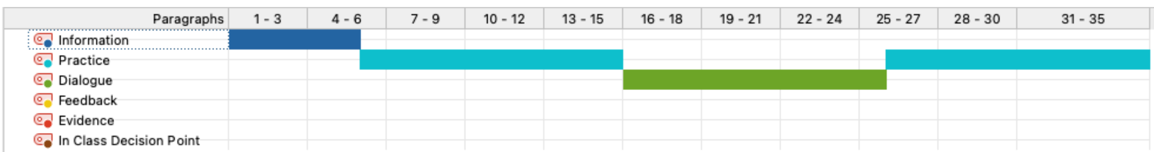
BP10-JARED-DS2-01



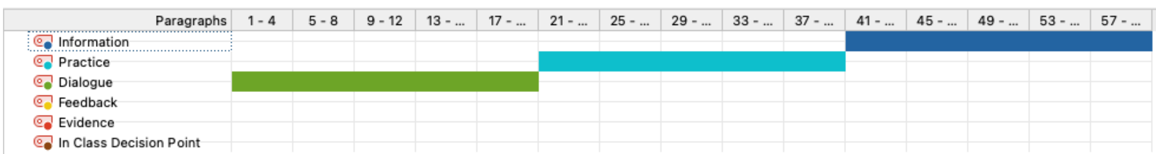
BP11-JARED-DS2-02



BP12-JARED-DS2-03

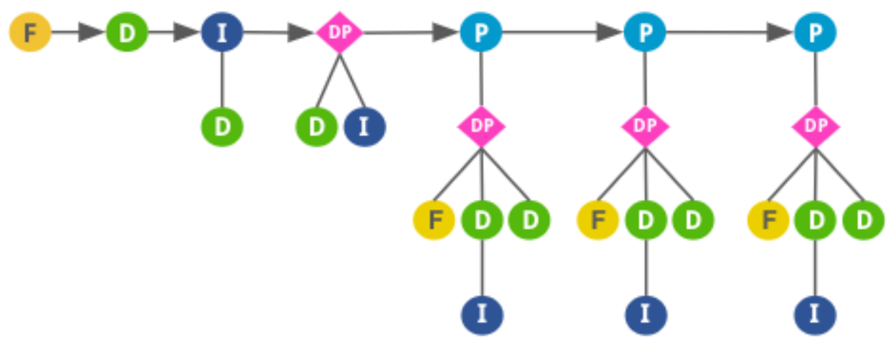


BP13-JARED-DS2-04

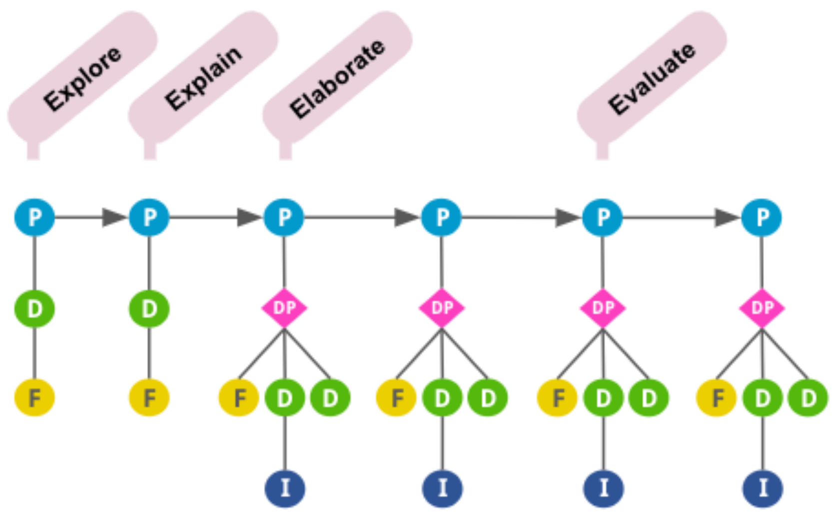


Appendix E: Abstracted Lesson Blueprints

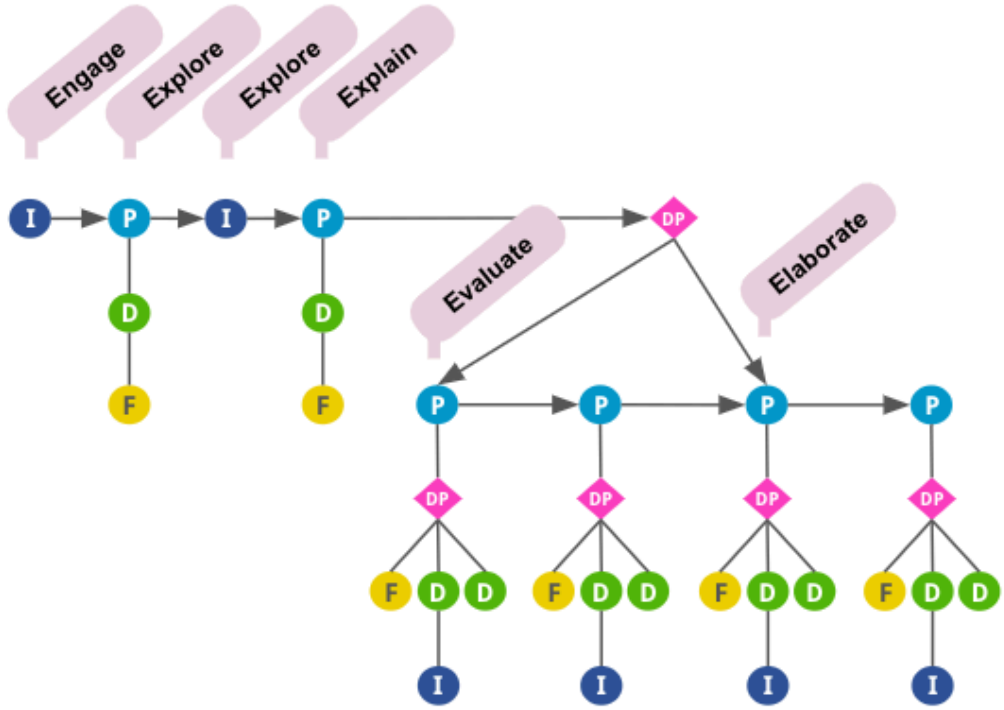
BP1-REEMA-DS1-01



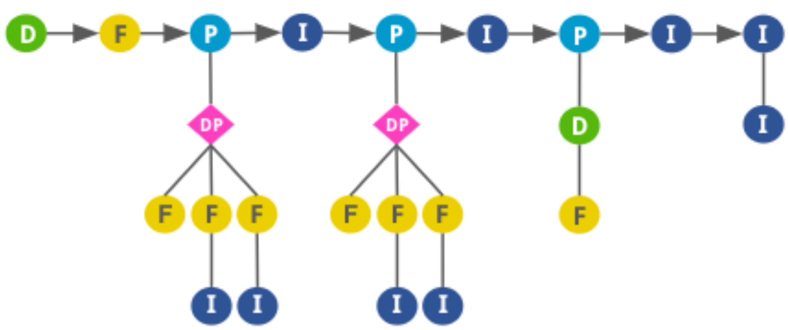
BP2-REEMA-DS2-01



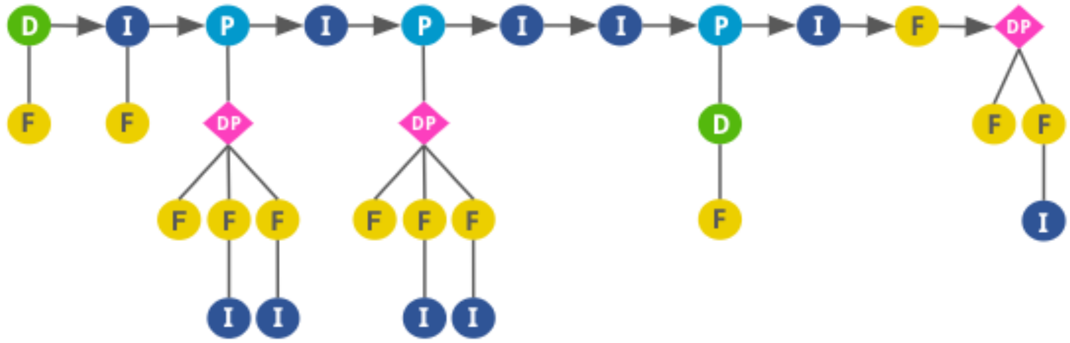
BP3-REEMA-DS2-02



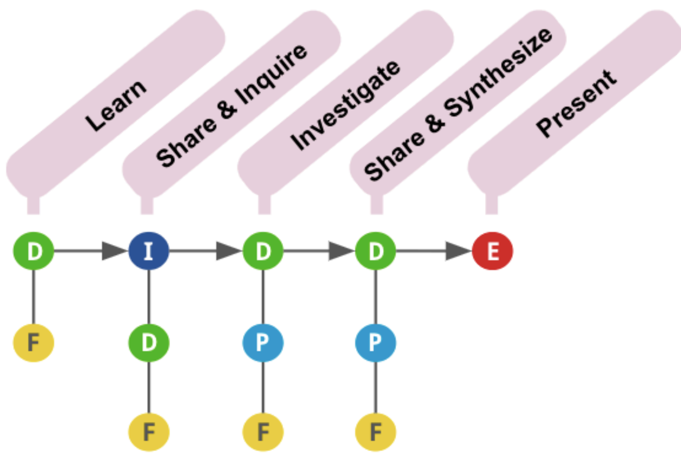
BP4-ELLA-DS1-01



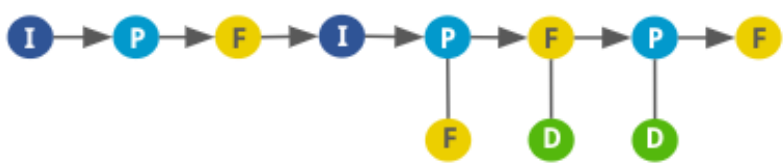
BP5-ELLA-DS1-02



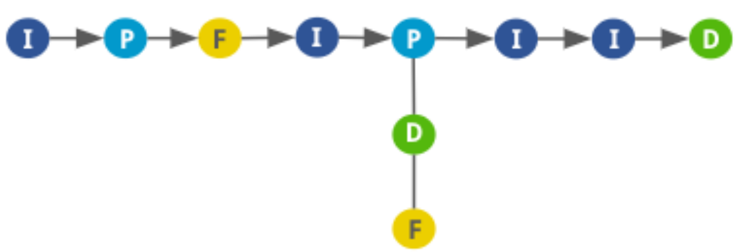
BP6-ELLA-DS2-01



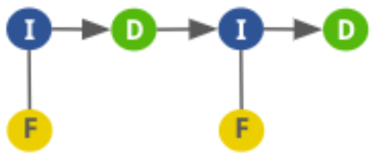
BP7-JARED-DS1-01



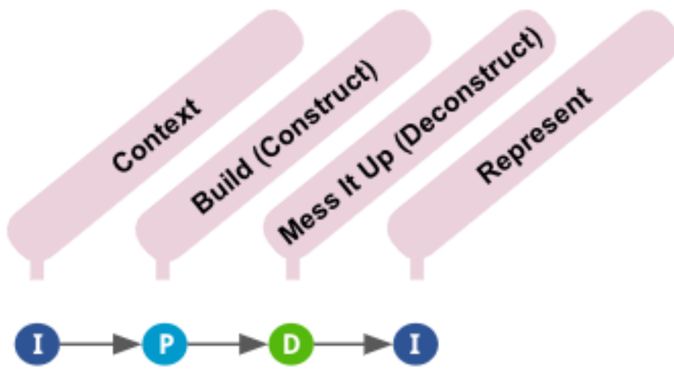
BP8-JARED-DS1-02



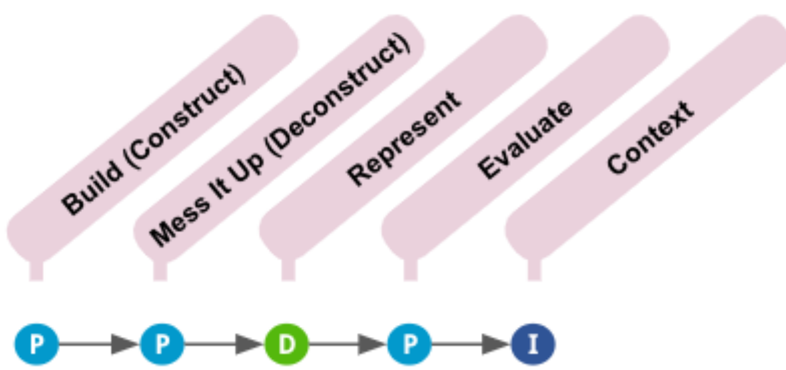
BP9-JARED-DS1-03



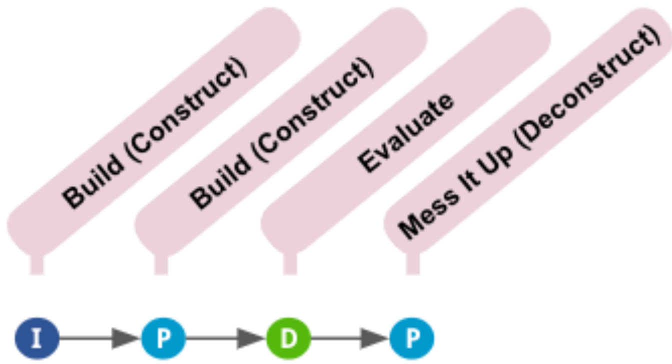
BP10-JARED-DS2-01



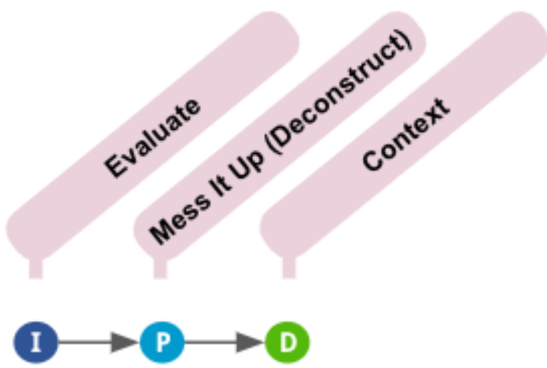
BP11-JARED-DS2-02



BP12-JARED-DS2-03



BP13-JARED-DS2-04



Appendix F: Semi-Structured Interview Protocol (Post-Design)

Thank you for agreeing to participate in this interview. The focus of our interview today is to better understand your experience of using visual blueprints for course design. We will also go over the rationale for your selection of lesson elements and sequencing of lessons. The interview will go for about 60 minutes.

So that I can concentrate on our conversation rather than take notes, would it be alright if I record this interview? (If yes, start the recording. If unsure, explain that the recording will only be used for transcription and only available to the researcher. If still no, then take notes.) Before we start, do you have any questions for me?

Selection of Activities

Repeat the set of questions for each type of activity.

PRACTICE
Based on your visual blueprint, you have selected <name of activity> for practice.
Can you describe the activity in detail? Who are involved in the activity?

> Please explain the rationale for deciding this? What were you thinking?
> Please explain what factors or considerations you were thinking about as you designed this?
> How do you know this will be effective?
> Under a different circumstance, what would you change or do differently?
> Describe the learning environment that will help students succeed in this activity.

EVIDENCE
Based on your visual blueprint, you have selected <name of activity> for evidence.
Can you describe the activity in detail? Who are involved in the activity?

> Please explain the rationale for deciding this? What were you thinking?
> Please explain what factors or considerations you were thinking about as you designed this?
> How do you know this will be effective?
> Under a different circumstance, what would you change or do differently?
> Describe the learning environment that will help students succeed in this activity.

FEEDBACK
Based on your visual blueprint, you have selected <type of activity> for feedback.
Can you describe how you would provide this feedback in detail? Who are involved in the activity?

> Please explain the rationale for deciding this? What were you thinking?
> Please explain what factors or considerations you were thinking about as you designed this?
> How do you know this will be effective?
> Under a different circumstance, what would you change or do differently?
> Describe the learning environment that will help students succeed in this activity.

Selection of Interactions

Repeat the set of questions for each type of activity.

DIALOGUE
Based on your visual blueprint, you had selected <name of activity> for promoting dialogue between students and the instructor. Can you describe the activity in detail? Who are involved in the activity?

Please explain the rationale for deciding this? What were you thinking?
Please explain what factors or considerations you were thinking about as you designed this?
How do you know this will be effective?
Under a different circumstance, what would you change or do differently?
Describe the learning environment that will help students succeed in this activity.

Selection of Learning Environment

Repeat the set of questions for each type of learning space, material, resource, or tool selected.

INSTRUCTIONAL MATERIALS & RESOURCES
Based on your visual blueprint, you had selected <name of material/resource>. Can you describe this material or resource in detail?

Please explain the rationale for deciding this? What were you thinking?
Please explain what factors or considerations you were thinking about as you designed this?
How do you know this will be effective?
Under a different circumstance, what would you change or do differently?
Describe the learning environment that will help students succeed in this activity.

INSTRUCTIONAL TECHNOLOGY & TOOLS
Based on your visual blueprint, you had selected <name of technology/tool>.
Can you describe this technology or tool in detail?

Please explain the rationale for deciding this? What were you thinking?
Please explain what factors or considerations you were thinking about as you designed this?
How do you know this will be effective?
Under a different circumstance, what would you change or do differently?
Describe the learning environment that will help students succeed in this activity.

LEARNING SPACES
Based on your visual blueprint, you had selected <learning space>.

Please explain the rationale for deciding this? What were you thinking?
Please explain what factors or considerations you were thinking about as you designed this?
How do you know this will be effective?

Under a different circumstance, what would you change or do differently?
Describe the learning environment that will help students succeed in this activity.

Sequencing of Lessons
In the workshop, you were asked to assess your visual blueprint using the 5E pedagogical model. You were also asked to consider the sequence of your lesson and how closely it aligns to the 5E model. Help me understand what you were thinking as you were working on this.

LESSON SEQUENCE

Describe the lesson sequence. How does one lesson connect to the next lesson? Please explain the rationale for selecting this sequence? Can you explain what you were thinking when you were designing this sequence? What guided your decision? How will you know if this will be effective?

SELF-ASSESSMENT

How closely does the 5E model align to your lesson?
What are the strengths of your lesson as it relates to the 5E model?
What would you change or improve further?
Please explain the rationale why you would make this change? What were you thinking? What guided your decision?

5E CYCLE

Repeat the set of questions for each 5E phase that was represented in the blueprint:

Which activities were designed for the <Engage/Explore/Explain/Elaborate/Evaluate> phase?
Please explain the rationale for selecting these activities? Can you explain what you were thinking? What guided your decision?
What features of this activity helps it achieve the goal of this phase?
How do you know this will be effective?

Use of Visual Blueprints

1. How would you describe your experience in using visual blueprints to support your course design work?
2. Can you describe some key moments that stood out or struck you during your design sessions?

That's the end of our interview today. Thank you once again for your time.
The next step in our process will be to get these interviews transcribed and analyzed. Only the PI will manage, transcribe, code, and analyze the data. Original audio and video recorded interviews will be transcribed and faculty names on transcripts will be replaced with pseudonyms and coded for themes. Faculty names on design documents will be replaced with pseudonyms.

Original video and audio recordings will be initially stored on a UNCC Dropbox folder only for transcription and until data analysis. Only the lead PI, Kiran Budhrani, will have access to this Dropbox folder. The Dropbox folder will not be sync to any desktop, laptop, or mobile device. Original audio and video recordings will be destroyed after data analysis and all data after data-analysis will be non-identifiable. All non-identifiable data will be stored on a secured UNCC Dropbox folder. The Dropbox folder will not be sync to any desktop, laptop, or mobile device.