INFORMATION ARCHITECTURE AND COGNITIVE USER EXPERIENCE IN DISTRIBUTED, ASYNCHRONOUS LEARNING: A CASE DESIGN OF A MODULARIZED ONLINE SYSTEMS ENGINEERING LEARNING ENVIRONMENT

by

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Dedicated to Katia, who is my light and my rock.

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TABLE OF CONTENTS

LIST OF TABLES 10

LIST OF FIGURES 11

ABSTRACT 14

1. INTRODUCTION 15

  1.1 Problem Context 15

  1.2 Problem Statement 17

    1.2.1 The Challenges of Teaching Systems Engineering 17

    1.2.2 The Challenges of an Online, Asynchronous Format 20

  1.3 Clarifying Focus: An Analogy 22

  1.4 Case Definition 24

  1.5 Thesis Organization 27

2. LITERATURE REVIEW 28

  2.1 Introduction 28

  2.2 Models for Development 30

    2.2.1 The Seven Laws of Teaching 31

    2.2.2 User-Content-Context and User-Task-Context Models 33

    2.2.3 The Evolution of Modern Learning Contexts 37

  2.3 The User 39

    2.3.1 Individual Differences 40

    2.3.2 Tasks 45

    2.3.3 Universal Design Considerations: UDL, UDI, UID 46

  2.4 The Content 49

2.4.1 The SE Languages 50

2.4.2 The Case Study Methodology 52

2.4.3 Domain-Specific Considerations: Teaching Systems Engineering 53

2.5 The Context.. 54

2.5.1 Online Learning Environments... 55

Asynchronous Communication 56

Availability and Fidelity of Communication Media and Information in Distributed Configurations 56

Self-Directed Learning in Distributed Configurations.. 57

2.5.2 Learning Scaffolding 58

2.5.3 Learning Transfer 60

2.6 Interactions.. 61

2.6.1 Cognitive Flexibility Theory 62

2.6.2 Cognitive Load Theory.. 63

2.6.3 The Expertise-Reversal Effect.. 64

2.6.4 Dynamic User Experiences: Adaptable and Adaptive Interfaces............................. 65

2.7 Information and Computer Technology.. 68

2.7.1 Background on Information Architectures 68

2.7.2 Traditional IA Structure.. 69

2.7.3 Non-Sequential Information Structures (NSISs) 72

Benefits and Challenges 73

Literature Limitations.. 77

2.8 Summary 78

3. METHODOLOGY (IA / UX DESIGN SPACE) 81

3.1 Introduction 81

3.2 Initial State of PoSE Material 81

3.3 A Universal Design Perspective 83

3.3.1 Aggregated Principles for Effective Instruction 83

3.4 Learner Tasks within the Learning Environment 88

3.4.1 Learning Tasks 88

3.4.2 Information-seeking tasks 91

3.5 Designer Tasks 92

3.5.1 Persona Development 95

3.5.2 Lecture Captioning 95

3.5.3 Designing the Information Architecture 97

3.5.4 Designing the User Experience 101

Content Modularization 101

Dynamic User Experiences: Adaptation to Support a Variety of Users 104

Wireframing 107

4. RESULTS (IA / UX CASE PRESENTATION) 109

4.1 Introduction 109

4.2 User Personae 110

4.2.1 Adrian 114

4.2.2 Bailey 116

4.2.3 Casey 116

4.2.4 Devin 117

4.2.5 Eli 118

4.3 Content Modularization: Thematic Topics and Video Segments 119

4.3.1 Modularization Design Characteristics ... 121

4.3.2 Developed Process ... 123

4.3.3 Content Modularization Outcomes: Key Takeaways ... 128

4.3.4 Outputs ... 129

4.4 Non-Sequential Modules: Different Entry Points ... 130

4.5 Tag and Indexing Term Identification ... 132

4.5.1 Tagging Design Characteristics ... 133

4.5.2 Process ... 136

4.5.3 Tag Design Outcomes: Key Takeaways ... 140

4.5.4 Tag Outputs ... 142

4.6 Adaptable Information Structure and Navigation ... 149

4.6.1 Adaptation Trigger ... 150

4.6.2 Scaffolded Information Structure and Navigation ... 152

4.6.3 Unscaffolded Information Structure and Navigation ... 155

4.7 Adaptable Information Presentation Customization ... 159

4.7.1 Adaptation Trigger ... 160

4.7.2 Adaptation Behavior ... 161

4.8 Summary ... 162

5. DISCUSSION ... 164

5.1 Summary of Key Design Elements ... 164

5.1.1 User Personae ... 164

5.1.2 Content Modularization and Non-Sequential Presentation ... 165

5.1.3 Tag and Indexing Term Identification ... 168

5.1.4 Adaptable User Experiences ... 172

5.2 Revisiting the Purpose of the Case Design 173

5.3 Limitations 175

6. CONCLUSION 178

6.1 Key Findings 178

6.2 Broader User Experience Design Relevance for Learning Environments 179

6.3 Directions for Future Work 180

APPENDIX A. CONTENT MODULARIZATION NOTES 182

APPENDIX B. CONTENT ANALYSIS AND TAGGING OUTPUTS 206

REFERENCES 224

LIST OF TABLES

Table 1: Mapping the seven laws of teaching to the person-task-context model 37

Table 2: Configurations of spatial and temporal dimensions for instruction.............................. 39

Table 3: UDL, UDI, and UID Principles as presented by Al-Azawei et al. (2016), Burgstahler (2009b), and Fox et al. (2003), respectively 47

Table 4: Types of cognitive loads considered in CLT 63

Table 5: Benefits and challenges of utilizing NSISs 74

Table 6: Aggregated Principles from UDL, UID, and UDI approaches. The principles that are relevant to this case design are identified in italics... 84

Table 7: Quantitative summary of overview and case study introduction segments................. 124

Table 8: Description of modules and their thematic topics and individual video segments....... 130

Table 9: Documents associated with the content analysis of author-created modularized content 138

Table 10: Description of tagging process outcomes 140

Table 11: Precision of initial tag identification process compared to the in-depth, secondary tag identification process 141

Table A.1: Full outputs of the content modularization process 194

Table B.1: Tagging table example for the SE3 module showing the 124 identified tags and their relationships 212

LIST OF FIGURES

Figure 1. Plot of the number of publications in the Scopus Database that include the terms “systems engineering,” “systems thinking,” and “systems science” between the years of 1847 and 2019. 16

Figure 2. The design and development process for a prototype where the steps emphasized by this thesis are highlighted in a red box. 23

Figure 3. System definition of the PoSE course as it is traditionally taught as a system 25

Figure 4: Sequence diagram for the learning process as described by Gregory’s seven laws. Note that “contextual information” is defined as information regarding learner prior knowledge and language use. 33

Figure 5: A Venn diagram showing the three important areas of consideration in information architectures and critical sub-factors that should be considered in relation to each. Image adapted from (Rosenfeld et al., 2015). 34

Figure 6: Mapping the seven laws of teaching to the user-content-context model 36

Figure 7: The adaptive-adaptable continuum. Image adapted from Opperman et al. (1997) 67

Figure 8: Example of a hypertext of NSIS network structure. Unique content files are represented by boxes containing letters to differentiate them. Image adapted from Rosenfeld et al. (2015). . 73

Figure 9: Scope and modules associated with the existing PoSE content 82

Figure 10: HTA of learning tasks within the PoSE course, as defined by the PoSE syllabus and graded exercises. Note that tasks 2-5 are accomplished identically to task 1, and so these details were omitted for readability. Similarly, task 6.3 is associated with identical subtasks as task 6.2, and so these too were omitted for the sake of readability. 90

Figure 11: A flowchart of the tasks that the designer must complete in order to design the IA and UX associated with a learning environment for the PoSE course 94

Figure 12: Operations process chart for the closed captioning process utilizing a professional, external provider 97

Figure 13: HTA for the tasks associated with the design of an information architecture for PoSE 98

Figure 14: Operations process chart for the content modularization process 103

Figure 15: Two-dimensional description of prospective users 113

Figure 16: Three-dimensional description of prospective users 114

Figure 17: Dimensional description of the user persona Adrian 115

Figure 18: Dimensional description of the user persona Bailey 116

Figure 19: Dimensional description of the user persona Casey 117

Figure 20: Dimensional description of the user persona Devin 118

Figure 21: Dimensional description of the user persona Eli 119

Figure 22: Diagram of the levels on which modularization occurs 120

Figure 23: Flow diagram of the UX / IA content modularization process completed for this design 127

Figure 24: Wireframing Modal for selecting a module, permitting adaptation of student access based on previous SE language familiarity 131

Figure 25: Wireframe for module selection confirmation modal 132

Figure 26: Visualization of the semantic relationships of tags. Figure and relationships are adapted from Rosenfeld et al. (2015). 135

Figure 27: Flowchart describing the tag identification process 137

Figure 28: Tag Tree for "Assembly Task" 143

Figure 29: Tag Tree for "Neuron" 143

Figure 30: Tag Tree for "Nonliving System" 144

Figure 31: Word clouds describing the SE5 module (A) excluding assigned readings and (B) including assigned readings 145

Figure 32: Wireframe for an example video screen, supporting user adaptation for tag use and video navigation 146

Figure 33: Wireframe for Tag Interface as opened from a video screen 147

Figure 34: Wireframe for Tag Interface as opened from the lecture notes document 148

Figure 35: Wireframe of the Tag Interface with "Explore More Instances" expanded 148

Figure 36: Wireframe of a content page with scaffolding setting on 151

Figure 37: Wireframe of a content page with scaffolding setting off 151

Figure 38: Wireframe of the help regarding scaffolded versus unscaffolded settings modal 152

Figure 39: Wireframe of systems language page with scaffolding on 153

Figure 40: Hierarchical Structure of SE3 154

Figure 41: Wireframe for system language page with scaffolding off. Completed thematic topics are greyed out, while uncompleted thematic topics (never-accessed and in-progress) are shown as blue hyperlinks. 156

Figure 42: Video screen with the scaffolding setting turned (a) on and (b) off 157

Figure 43: Network diagram showing the navigable pathways between video segments using the tagging interface in the SE3 module. Red links represent a sequential relationship between video

segments. Blue links represent a relationship between lecture segments and their corresponding paragraph or slide-style notes. Green links (around the outer border) indicate roughly comparable video segments. Each of these types of links, as well as the black links, implies the existence of an available tag-based navigation pathway. 158

Figure 44: Wireframe for selecting information presentation modality preference 160

Figure 45: Wireframe for editing information presentation modality from the settings page 161

Figure A.1: Modularization notes for the thematic topics associated with the SE3 module 182

Figure A.2: Notes taken during the process of reviewing the SE3 module content (lectures from 9/12/2017, 9/10/2019, and 9/12/2019) to support thematic topic identification and content modularization 184

Figure B.1: Word clouds describing the SE1 module (A) excluding assigned readings and (B) including assigned readings 206

Figure B.2: Word clouds describing the SE2 module (A) excluding assigned readings and (B) including assigned readings 207

Figure B.3: Word clouds describing the SE3 module (A) excluding assigned readings and (B) including assigned readings 208

Figure B.4: Word clouds describing the SE4 module (A) excluding assigned readings and (B) including assigned readings 209

Figure B.5: Word clouds describing the Engineering case studies module (A) excluding assigned readings and (B) including assigned readings 210

Figure B.6: Word clouds describing all of the PoSE material (A) excluding assigned readings and (B) including assigned readings 211

ABSTRACT

Systems engineering (SE) is an increasingly relevant domain in an increasingly interconnected world, but the demand for SE education is impeded by the challenges of effectively teaching interdisciplinary material that emphasizes the development of a mentality over specific skills. A modularized, asynchronous, distributed course configuration may provide an advantageous alternative to more traditional hybrid course designs. Online courses have been a topic in the educational field since the establishment of the internet. However, the widespread disruptions to higher education due to the COVID-19 pandemic highlighted the demand for and difficulty of developing deliberate and robust learning environments designs that consider a variety of traditional and non-traditional students. This thesis presents a case design of a learning environment for an interdisciplinary-focused, introductory graduate-level systems course that has previously been designed for, and taught in, a hybrid environment. The case design will emphasize the information architecture (IA) and user experience (UX) prototype design of the learning environment as informed by user-centric principles, cognitive theories and analyses, the IA literature, and existing course content. This focus on learner knowledge development ("beyond-the-screen") factors rather than the direct user interface ("at-the-screen") provides design recommendations and insights that are robust to changing user interface trends and preferences. A distribution of learners with varying backgrounds, learning needs, and goals associated with the material will be identified. These individual differences can dramatically impact the effectiveness of potential interventions, particularly when different types of learners have directly conflicting needs. Thus, the online learning environment will utilize adaptable interfaces to move away from a "one-size-fits-all" design approach. Content modularization and non-sequential, tag-based navigation were utilized to address the challenges of teaching highly interdisciplinary material. This thesis emphasizes a learning environment design that aims to teach highly interdisciplinary systems subject matter to a variety of learners with a variety of characteristics in an asynchronous, online format while making use of existing course material.

1. INTRODUCTION

1.1 Problem Context

Systems engineering (SE) is a broad domain that emphasizes the importance of careful and explicit problem and system definitions, as well as holistic approaches to solutions that consider a variety of factors that impact system behavior. SE is characterized by multiple disciplinary histories and falls into both interdisciplinary and transdisciplinary categorizations. Therefore, multiple sub-domains (or perspectives, or “languages”) exist within the larger field. Introductory courses that explicitly address these multiple co-existing perspectives are critical to a meaningful, comprehensive SE education.

It should be noted that, in this case, “systems engineering” is being used to refer to a broad set of systems-based methodologies and approaches. The utilization of the engineering label is not meant to be exclusive of any practitioners of these methodologies regardless of whether they have a formal engineering background. One does not need to be an engineer by training to effectively utilize SE techniques. Instead, the engineering label is meant to describe the application of methodologies to design, build, and intervene in real-world systems.

At both a student level and among working professionals, the demand for SE courses is considerably high. This demand is evidenced by a growing number of academic publications pertaining to systems engineering and the emergence of systems-focused programs within universities. On a finer scale, the demand for SE is reflected in the enrollment for an introductory, graduate-level systems course. In part, this interest may be due to an increasing societal understanding of the importance of systems engineers when faced with increasingly complex and international contemporary problems. Unlike many traditional engineering disciplines, SE emphasizes a “system as a whole” approach that considers factors beyond the designed engineering system (Suranto, 2015). Figure 1 shows the increasing number of publications over time that reference the terms “systems engineering,” “systems thinking,” or “systems science” within the Scopus database alone. However, the dramatic increase in the number of publications since the early 2000s speaks to a research community that is becoming more aware of the critical role that SE plays in solving a myriad of problems in society.

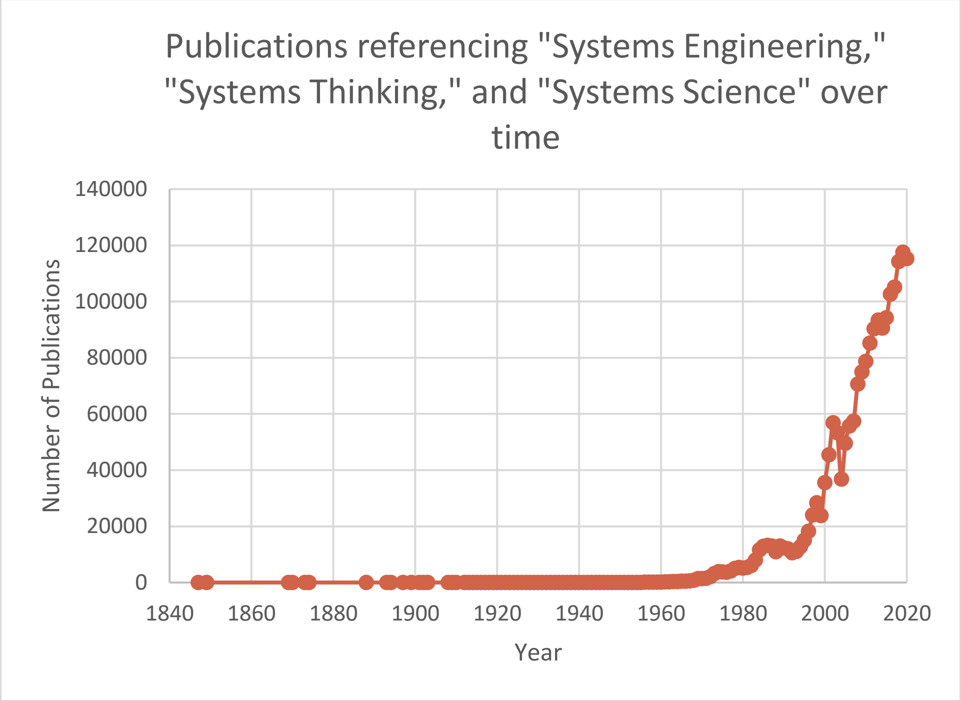

Figure 1. Plot of the number of publications in the Scopus Database that include the terms “systems engineering,” “systems thinking,” and “systems science” between the years of 1847 and 2019

Researchers are not the only entities taking notice of the need for systems engineers; institutions of higher education are increasingly acknowledging the critical role of SE in the future. For example, Purdue University set up the Purdue Systems Collaboratory in 2015, allowing students to take courses specifically focused on learning the system mindset and a selection of tools, skills, and theories and even earn a certificate (Purdue University, n.d.). A variety of other universities have also recognized the relevance of systems-based approaches and set up systems engineering programs in various configurations. Some of these programs are “systems-centric,” while the majority are “domain-centric” (Fabrycky, 2010). Systems-centric programs identify systems engineering as a distinct disciplinary domain that is the major area of study. In contrast, domain-centric programs are those that consider SE in conjunction with another engineering discipline such as industrial or computer engineering (among others). These programs can also operate at a bachelor’s, master’s, or PhD level, with the majority falling into the first two categories (Fabrycky, 2010).

The demand in industry for transdisciplinary, systems-centric programs can be observed in the enrollment of online students in the graduate-level introductory Perspectives on Systems

Engineering (PoSE) course taught at Purdue University since 2014 (and listed as “Perspectives on Systems” as of 2018). These online students are frequently sponsored through company programs to pursue a master’s degree part-time while working. Thus, these working professionals enrolling in a course that is not required for any degree can be viewed as an insight into industry priorities. The first semester that PoSE was taught at Purdue (in 2014), 35 online students were enrolled, a significantly higher number than the threshold for considering the hybrid course a success (Caldwell, 2020b). These enrollment numbers have stayed high through 2020, further validating the demand for a broad SE mindset, especially at an introductory level.

1.2 Problem Statement

The focus of this thesis is how highly interdisciplinary subject matter can be taught to a range of traditional and non-traditional learners with a variety of backgrounds, learning goals, and needs. There are two constraints that are placed on this problem statement. The first constraint is the use of an asynchronous, distributed online format to present the course content. The second is the utilization of existing course material, including lecture notes, readings, and recorded lectures, rather than the synthesis of new materials.

In particular, this case design will describe a prototype solution applied to an introductory, graduate-level systems engineering course (PoSE). This course meets the specification of emphasizing interdisciplinary material and approaches, and the SE subject matter itself poses additional distinct challenges. PoSE has been originally taught as a hybrid configuration (both in-person and asynchronous, online lectures), but transitioning to a fully asynchronous and online format poses challenges of its own. The challenges associated with teaching systems engineering, as well as the online (or distributed) asynchronous format, will be expanded on below.

1.2.1 The Challenges of Teaching Systems Engineering

There are three major challenges associated with systems engineering education that are either rare or unique to the domain. First, SE is challenging to teach due to the highly interdisciplinary nature of the material. Secondly, SE education is difficult because it emphasizes the development of a mindset over the achievement of proficiency in a specific skill, tool, or theory alone. Finally, SE is frequently an applied domain where learning occurs through experience and feedback rather than a more direct transfer of facts and knowledge from the teacher to the learner.

As mentioned previously, SE can be considered both an interdisciplinary and a transdisciplinary domain. Interdisciplinary approaches seek to integrate concepts, methods, and principles of multiple disciplines into a coherent and coordinated whole through analysis, synthesis, and harmonization (Choi & Pak, 2006, p. 351; Lawrence, 2010, p. 127). In contrast, transdisciplinary approaches transcend the traditional boundaries of multiple disciplines by acknowledging the complexity of science, challenging the concept of knowledge fragmentation, and accepting contexts and uncertainties local to each application (Choi & Pak, 2006, p. 351; Lawrence, 2010, p. 127). As such, transdisciplinary approaches are often considered action-oriented and "context-specific negotiation[s] of knowledge" (Lawrence, 2010, p. 127). It is also worth noting that interdisciplinary and transdisciplinary are not strictly mutually exclusive and can instead be complimentary (Lawrence, 2010, p. 126). SE emphasizes often complex interactions between human and non-human actors in order to accomplish a given goal in a wide variety of contexts. Real-world practice of SE can be interdisciplinary, transdisciplinary, or both depending on the approach being taken. However, the material being taught in a systems engineering education context is better described as interdisciplinary. The material may integrate elements from different disciplines, but transcending their boundaries is not necessarily a characteristic of SE curricula. Learners can experience difficulties with interdisciplinary thinking (Spelt et al., 2009) that mandates careful consideration of both the content and learning context.

The broad nature of SE is related to the development of several largely independent sub-domains that all purport to be systems engineering. Caldwell (2009, 2020a) identifies these sub-domains as different perspectives on systems engineering, including: (1) systems thinking, (2) cybernetics and mathematical analysis, (3) component-whole relationships, (4) project deployment management, and (5) digital and information architectures. These can also be conceptualized as different "systems languages" that various practitioners may achieve different levels of proficiency in, ranging from entirely unaware of the language to fully fluent. However, this taxonomy is not currently in widespread use as a means to frame introductory SE content. Ignorance of the different systems languages can result in communication breakdowns between practitioners who are "speaking" different languages.

Domain-centric SE courses and programs further contribute to this challenge. When SE is paired with another engineering discipline, the language(s) being emphasized will more likely be those that are relevant to the goals or methods of the paired discipline. It is easier to slip into teaching the single perspective on SE that best aligns with the existing departmental perspective, rather than present a diverse, holistic view of what SE is. For example, when systems engineering is presented alongside industrial engineering, it may be more likely that the systems languages being presented align with the priorities of industrial engineering (either cybernetics and explicit mathematical modeling or people and process management). While not every program may fall into this trap, the clearer connection to other disciplinary courses creates and perpetuates the potential for a lack of breadth in defining and applying SE. When the systems engineering program is a part of the computer engineering program, the language being emphasized is more likely to be digital and information architectures. A practitioner with an industrial and systems engineering background would have an entirely different view of what SE entails compared to a practitioner with a computer and systems engineering background. If these practitioners had no exposure to the concept of systems languages, they could be unaware of the full scope of systems engineering approaches and perspectives. Systems-centric programs may offer a wider perspective, but even in these programs, all systems languages may not be identified or described fully.

Many courses, both in undergraduate and graduate programs, emphasize teaching a collection of principles or using a set of tools to perform a task. Introductory SE courses, particularly PoSE as it was designed, have a far more challenging goal: to teach a systems mentality or worldview, which has been described as “SE disease” (Caldwell, 2020a). SE disease is characterized by learners being able to identify applications of PoSE and the five SE languages presented within the course to a wide range of both personal and work systems. For example, a learner infected with SE disease may identify elements of systems dynamics at work when presented with historical events, particularly accidents or disasters. Developing SE disease is an individual experience, and the “lightbulb moment” happens at different times for everyone, and for some, it may never happen at all. The challenge with teaching this mentality is similar to the challenges around critical thinking: the desired outcome is the creation of an internal learner process that cannot be easily measured or quantified.

Similarly, SE is highly practical and experience-driven compared to other engineering disciplines, with experience being a primary source of systems-related learning (Armstrong & Wade, 2015). These characteristics are effectively impossible to directly transfer from instructor to learner. While the instructor can design the environment to support the learner in developing the mentality and gaining the necessary experience, they cannot directly impart these elements to learners through lessons the way they might when teaching knowledge or skills. This means that activities that engage learners and encourage behaviors that characterize SE disease and provide relevant experience are critical when it comes to SE education design. However, activities that engage deep processing in learners tend to diverge from the traditional right or wrong, machine-graded activities that often characterize online educational environments.

1.2.2 The Challenges of an Online, Asynchronous Format

Prior to the COVID-19 crisis, online learning was becoming increasingly relevant to the educational system. Online masters' programs, in particular, featured enrollment in a variety of hybrid-configuration courses, with students both on-campus and online. However, across the full range of both graduate and undergraduate-level courses, the implementation and use of online learning environments were highly inconsistent (Masterman, 2017). While there were classes that provided all students access to recorded lecture videos, in many cases, this was at the discretion of the professor, and some course designs did not include lecture recordings of any kind. The use of the LMS system varied from essentially a full online learning environment to simply a convenient means to exchange files with students.

The escalation of the COVID-19 pandemic served to drastically alter how a variety of stakeholders, including students, professors, administration, and policymakers, viewed online education and brought many of these gaps to light. By mid-April of 2020, 188 countries had shut down schools nationwide due to the spread of COVID-19 (Vegas, 2020). While not every educational institution transitioned to remote learning in response to the shutdown, the shift was common within high-income countries. The courses that already utilized a hybrid structure appeared to experience a smoother transition to fully remote learning, with minimal changes to the syllabus and course structure required. However, one of the most powerful impacts of COVID-19 on the educational system was in the tumultuous adaptation of exclusively in-person courses with limited or no precedent in providing a holistic online experience. For most institutions, the transition to remote learning, from initial plan to implementation, took place within one or two weeks, providing little time for course re-design. Thus, there was a wide variability in course structure, particularly in relation to lectures, which served as the major means of information exchange within many of these courses. Lecture configurations included synchronous lectures over virtual meeting platforms (which may or may not be recorded), asynchronous lectures that were recorded either during Spring 2020 or from previous semesters, or even no lectures at all. This variability and perceived shift in quality led to stronger negative student moods, including frustration, anxiety, and boredom (Besser et al., 2020). Students have also reported that their online experiences were less effective and less valuable (Hess, 2020). Ultimately, these attitudes led to a number of lawsuits against institutions of higher education (Binkley, 2020; Hess, 2020) and educators calling for reform (Badiru, 2020). A major takeaway from this situation is something that has been long acknowledged within the education literature: online experiences must be thoughtfully designed and implemented, with consideration for how students learn and with the distinct challenges – and advantages – of the online format in mind.

COVID-19 has also provided a clear insight into the identity and nature of some of the challenges associated with online education. These include maintaining student motivation and engagement with the material (Gold & Pandey, 2020) and retaining attention while interfacing with the online environment, specifically during lecture videos (Villasenor, 2020). Other issues that have been identified include an increased struggle for work-life balance (Washington & Jefferson College, 2020) and server and bandwidth limitations (Bao, 2020). The medium (depending on camera and audio recording availability and configuration) can deprive learners of necessary nonverbal and other implicit cues that would be present in a face-to-face environment, a challenge faced by instructors as well. Synchronous, co-located interaction also supports shorter feedback cycles for responding to student questions, a process that becomes more logistically difficult even within a synchronous online environment. Some of these concerns can be more easily designed for than others. Motivation, engagement, and attention can be considered within course design, and the provision of paraverbal and nonverbal information can be considered in relation to content. However, issues of work-life balance are largely out of scope, beyond ensuring that the workload is clear that the timescale of the course is flexible. Similarly, server maintenance and configuration are out of scope, and many factors that impact bandwidth are as well. However, certain transformative design approaches can be used to mitigate the negative impact of situational constraints such as lower bandwidth. For example, shorter or lower quality videos require less bandwidth to load. Other elements, such as the length and ease of the feedback cycle for student questions, are inherent to the nature of an online system and cannot be "designed out."

1.3 Clarifying Focus: An Analogy

The purpose of this thesis is to describe a prototype design for an online, asynchronous educational resource to teach interdisciplinary subject matter (i.e., the systems languages) to a variety of learners with different backgrounds, goals, and needs. The focus of the case design is twofold: information architecture (IA) design and user experience (UX) design. The IA design emphasizes sub-systems for content management and structuring, including labeling, organization, navigation, and searching. The UX design involves functional aspects which the user must interact with in order to perform tasks at a "beyond-the-screen" level. The design does not emphasize the redevelopment of the content being taught itself; instead, it focuses on the environment's presentation of and the learners' interactions with the content.

Consider the scenario of purchasing a plot of land with an existing home on it. However, for some reason, this existing structure does not adequately meet the needs of the new owners and their family. The new owners need to build a new home or, at the very least, heavily renovate the existing structure. This gives them two potential courses of action: use the existing foundation and update or replace the structure on top or lay a new foundation. Using the existing foundation may save time and money, but it comes at the risk of the old foundation having been worn down over time and is unsound, no longer being up to code, or may simply not align with the owners' needs. Laying a new foundation may be more expensive or time-consuming, but it comes with more confidence and control over the final structure.

Similarly, before partial or full prototypes can be developed in the design process, it is important to first provide a foundation for the product by understanding the problem and the customer, designing the IA that will apply to the existing content, and designing critical elements of the UX. These can be conceptualized as "beyond-the-screen" elements that support the user's experience of the online environment and learning goals but do not address concerns of specific visual elements (text fields, buttons, etc.) at an “at-the-screen” level (Caldwell & Rogers, 2000). Pre-existing foundations (IA design recommendations or conventions regarding organization, navigation, labeling, and searching) exist for online, asynchronous learning environments. However, these existing design conventions could be subject to a variety of issues, ranging from including assumptions that are invalid to the PoSE application to a lack of understanding of current technological capabilities due to the passage of time. These foundations may also not be ideal for the intended use of the system. Building a new product on new foundations allows the designer more control over the final product, with the added benefit of the capacity to implement lessons learned from the successes and failures of various “old foundations.”

The foundations of learning must be revisited and reconsidered when transitioning a course to a fully online, asynchronous format. The online configuration allows for greater freedom of information presentation and structuring, and these advantages should be considered within the design process. Additionally, the foundations of other asynchronous, distributed educational resources cannot be assumed to be relevant due to the distinct, interdisciplinary nature of the PoSE material. Past IA solutions for educational content should be evaluated, and relevant assumptions should be challenged.

These processes associated with laying new foundations will make up the case design on which this thesis focuses. The role these steps play in the overall development process is reinforced in Figure 2.

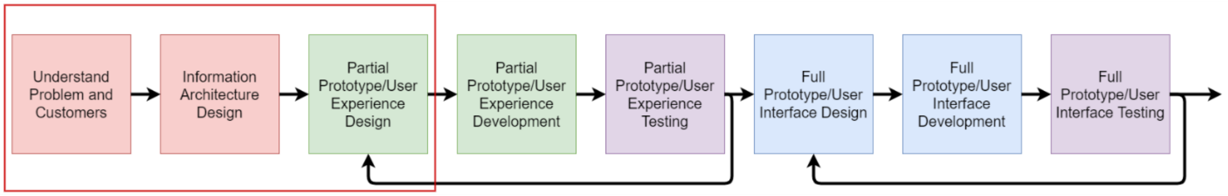

Figure 2. The design and development process for a prototype where the steps emphasized by this thesis are highlighted in a red box.

Regardless of this configuration, however, it is valuable to reconsider and redesign the foundations for online educational environments. Spending the time to consider a variety of factors that may influence user learning success is critical to developing fully asynchronous solutions to the demand for more accessible, broad-focus SE education. The universal challenges of online education and distinct challenges associated with teaching SE are worth further in-depth investigation and the application of a distinct design approach to meet the goals of the educational resource. Developing the new "foundations" for an asynchronous, online SE educational resource will be the objective of this thesis, rather than evaluating the final, developed functionality and interface.

This thesis does not aim to present a superior method of instruction compared to face-to-face, synchronous education. Instead, it is meant to present an alternative approach to education that utilizes the benefits of multimedia and non-sequential information structures to support an asynchronous learning experience that allows a variety of delivery patterns. This educational approach will be robust to a variety of conditions in the wider world that may limit physical access on an individual or community level. The case design will be informed by subject-matter experts on the content and literature regarding computer-based environment design, principles of online and traditional educational practices, and individual factors that may influence task performance.

1.4 Case Definition

The case under consideration is a graduate-level SE survey course as described by Caldwell (2009, 2020a). The goal of this course is to introduce learners to five different systems languages (referred to as "flavors" in the literature) and facilitate the identification of these languages in real-world systems. This definition considers an instructional designer's perspective on the system. For simplicity, the course will be referred to as Perspectives on Systems Engineering (PoSE). PoSE can be segmented into three major units that students experience as the semester progresses: (1) learning about the five SE languages, (2) applying knowledge about the SE languages to case studies, and (3) implementing the SE languages perspective in a final, team-based project. The course as defined here will emphasize the first and second units, while the third will be considered out of scope, as the team-based application unit is significantly different from the other two units due to being rooted in team cooperation and interaction rather than lecture content and individual effort. As such, units one and two are more appropriate to consider in the context of creating an online, asynchronous educational resource. This course as it existed initially is depicted in Figure 3 to illustrate the current implementation of PoSE at Purdue University.

PoSE is presented in a hybrid format that engages both in-person and online learners. In-person learners may be either graduate students or upper-level undergraduates (juniors or seniors) enrolled with the instructor's permission. Online learners are commonly full-time working professionals who are pursuing a master's degree part-time. However, online learners may also include undergraduates or full-time graduate students, as was the case during the COVID-19 pandemic. Learners who have not yet developed a comprehensive understanding of the five systems languages are inputs to the PoSE course. These learners are then transformed by the course components, with each component contributing to learning, until they become the outputs: learners with knowledge of the SE languages and their application. The course is under the control of the PoSE instructional team, which consists of the instructor and any teaching assistants assigned to the course.

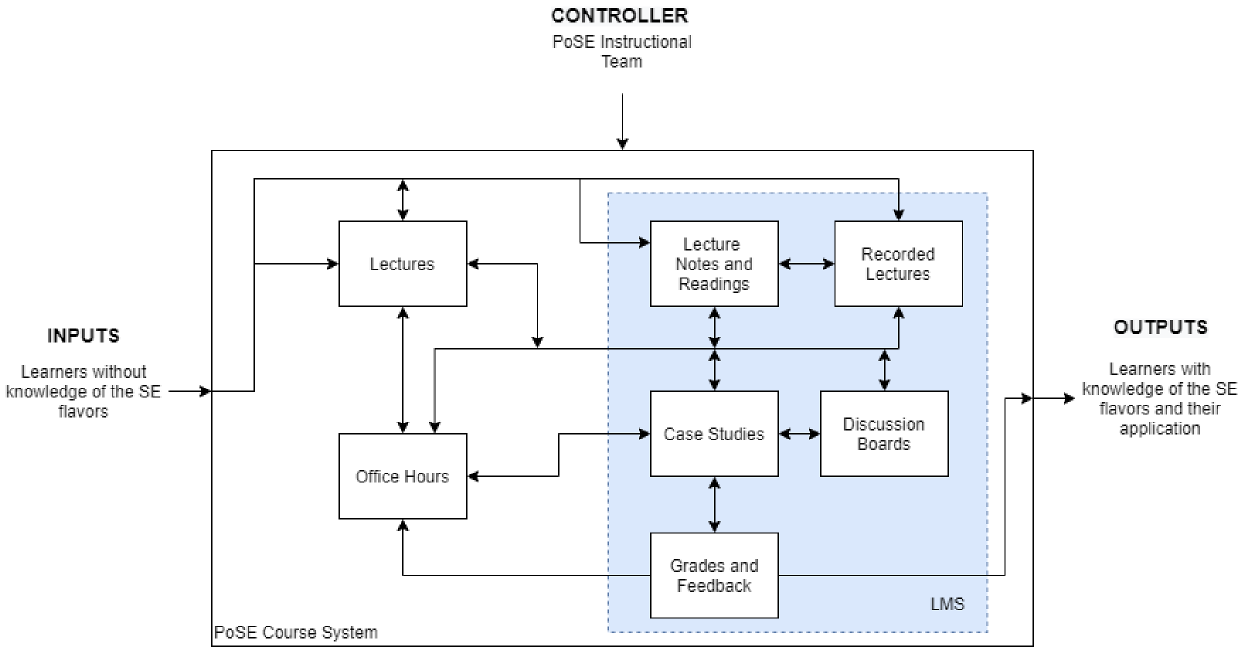

Figure 3. System definition of the PoSE course as it is traditionally taught as a system

The learning transformations may occur synchronously (in real-time) or asynchronously through interactions with the course content and instructional team. The course content consists of lecture notes, readings, synchronous lectures, recorded lectures, and case study assignments. These case study papers act as assessments of the learners' ability to identify and analyze the different systems languages in real-world examples. The content, as discussed above, is interdisciplinary and integrates knowledge and approaches from multiple different disciplines. The course content can be accessed synchronously (at the same time the professor is presenting and interacting with it) or asynchronously. Critically, although lectures are offered synchronously, these presentations are recorded, processed, and available to students later for (re)viewing. This process is not the main overall emphasis of this thesis and, thus, is not depicted in detail in Figure 3. The way students interact with the asynchronous recorded lectures is fundamentally different from how students interact with synchronous lectures, so it makes sense to treat them as two different components.

Interactions with the instructional team occur primarily through office hours, grades, and feedback, though there is some interaction possible during synchronous lectures. In this case, office hours refer to any means of instructor-learner interaction that provides information for the learner. These may occur asynchronously through email or synchronously through either in-person or online meetings. The synchronous office hours may occur throughout the day in order to accommodate distance students in various time zones. These interactions can be utilized to ask questions about the material presented in the synchronous lectures, lecture notes and readings, or recorded lectures or to clarify instructor expectations or feedback regarding assignments.

Finally, there are opportunities for peer-to-peer interactions that may contribute to learning. Asynchronous discussion forums are provided to support interactions between all students, including those that are not co-located. Although in-person peer interactions may occur, especially amongst the in-person cohort, these are not necessarily facilitated by the course design itself and are therefore considered out of scope.

The PoSE course components are intricately intertwined with one another; this is a hallmark of a complex system. The full transformation process where learners acquire knowledge about and experience applying the systems languages occurs over a time scale of weeks. Each individual transformation occurs on a variable scale ranging from a few minutes to several hours or even days. Finally, this initial course definition describes the current configuration, not the final design recommendations.

1.5 Thesis Organization

The remainder of this thesis is organized as described here. Chapter 2 will begin by discussing and mapping different models for teaching, developing curricula, and designing tasks. The chapter will then review existing literature associated with personal, content, context, interaction, and information and computer technology (ICT) factors that are relevant to fully understanding the problem and the resulting design solution. Chapter 3 discusses the case design approach that was applied within the thesis in detail. This will include universal design principle analysis, persona development, learner task analysis, and analysis of the tasks that must be completed by the designer (the author). Chapter 4 describes the outcomes of the procedures discussed in Chapter 3 and presents the prototype design descriptions through the use of wireframes. This will also include descriptions of the processes associated with content modularization and tag identification, as well as the role that the outputs of those processes have in the IA and UX design. The dynamic user experiences will also be described in terms of their behavior and triggers. Chapter 5 will elaborate on the interpretations and implications of the design and the limitations of the case design approach. Finally, Chapter 6 will emphasize the relevance of this design type and identify opportunities for related future work in the various fields that shaped this design.

2. LITERATURE REVIEW

2.1 Introduction

An interdisciplinary approach will be applied to the case design of the PoSE learning environment. This learning environment is meant to support a range of learners with a variety of characteristics in learning highly interdisciplinary systems engineering material that is characterized by the development of a mentality rather than a set of skills. The constraints placed on the design consist of the transformative use of existing course content in an asynchronous, online format. This chapter will draw from literature associated with several domains, including information architecture (IA), user experience (UX), cognitive human factors, and education.

First, three models for development will be described. The first is the "seven laws of teaching" as described by Gregory (1886), a set of "laws" that pertain to requirements for effective teaching. These laws will then be mapped onto two similar design models that originate from the IA and human factors literature: the user-task-context model (Ringsted et al., 2006) and the person-content-context model (Rosenfeld et al., 2015). The utilization of these three models informs the design approach that will be applied within the case design. An expanded variant of the user-content-context model will be utilized to organize the remainder of this chapter. This will consist of factors related to the user, the content, the learning context, interactions between these three domains, and information and computer technology (ICT).

Factors specific to the prospective users (or the learners) of the PoSE educational resource will be discussed. Individual differences that are relevant to learning outcomes will be identified, and those individual differences that can be designed for will be highlighted. Different task profiles relevant to the PoSE course will also be described. This case design's emphasis on designing for a diverse learner base will further be addressed through the introduction of three universal design frameworks that are specific to the education domain.

Next, the content being taught in the PoSE course will be described, including the "systems languages" (or "SE languages"), as well as background on the case study methodology. This will provide insight into the content covered within the PoSE course, which in part will serve to inform the design of the online, asynchronous learning environment. Domain-specific considerations will also be covered, as they relate primarily to the content being presented within the course.

In a fully online, asynchronous course configuration, the context in which learning occurs is defined as the digital learning environment (or educational resource). As such, contextual factors address topics that are critical to consider in designing the learning environment. This includes a discussion of the differences between online and more “traditional” (synchronous, co-located) instruction. These include limitations of the digital communication medium as well as the increased emphasis on self-directed learning. Courses of all configurations need to provide appropriate levels of instructional scaffolding in order to support learners in accomplishing learning tasks, but this can be even more important to emphasize in online, asynchronous formats. In the scope of this case design, instructional scaffolding will primarily be considered as a component of the learning environment design (rather than content design). Learning transfer relates to the overall course goal of enabling learners to apply their knowledge outside of the context of the learning environment. Principles associated with increased learning transfer will be discussed and characterized as within or beyond the scope of the case design.

Relevant theories and topics that represent strong interactions between the user, content, and context factors are presented next. Cognitive flexibility theory addresses learning highly complex material and represents an interaction between personal and content factors that will inform the design of the learning environment context. Cognitive load theory is a theory regarding the limitations of human cognitive performance and reflects an interaction between user factors, the complexity of the content itself, and the presentation of the content as determined by the learning context design. The expertise-reversal effect is an observed dynamic that emphasizes the conflicting needs of some types of learners, presenting an interaction between personal factors, content, and the contextual presentation of the content. These conflicting user needs can be addressed through the utilization of dynamic user experiences in the learning environment design.

ICT factors consist of a review of the information architecture domain that builds on some of the theories presented as interactions. The IA design of the PoSE learning environment represents a significant piece of the scope of the case design, so past work in this domain should be reviewed and considered. Therefore, information architectures will be introduced and described in terms of four traditional sub-components (i.e., organization, navigation, labeling, and searching).

Non-sequential information structures (NSISs) are a means of organizing content that supports non-sequential navigation through the information space. Past applications of NSISs to education contexts will be discussed, and the benefits and challenges associated with them will be identified and discussed as a function of learner characteristics. The benefits of NSISs, especially to learners with high levels of prior knowledge and self-regulation, make them relevant to consider in the design of the distributed, asynchronous, and self-directed learning environment.

2.2 Models for Development

Three models will be primarily considered to support the design process associated with the case design. The first is the "Seven Laws of Teaching" (Gregory, 1886) that originated in the 1880s to provide instruction on the communication of knowledge from a teacher to a learner. The seven laws represent conditions that must be met in order for effective learning to occur. The education literature has grown and progressed since the 19th century, but the laws continue to be supported by other, more modern theories in the domain. The connections between the laws and these modern theories will be identified below. However, Gregory's seven laws identify a set of conditions that governs effective learning that are relevant to consider within the design process. The instructor-driven nature of this model is not perfectly aligned with the self-driven nature of online learning, so two additional models were introduced to further address what factors should be considered within the case design approach. These models are described below as the "person-content-context" and the "user-task-context" model, which have been more recently developed to consider aspects of human information search and use in online learning settings.

The second model originated from the IA literature: the person-content-context model (Rosenfeld et al., 2015). This model advises designers to consider the characteristics of the user (including tasks they may be performing in the information environment), the content, and the context in which the users are operating. The third model, the user-task-context model (Ringsted et al., 2006), comes from the human factors literature and has been applied to curriculum design in the past. It emphasizes the learning task characteristics over the content and similarly emphasizes user and context factors.

All three of these models provide valuable insight into the case design process. The connections between these models will be further explored below. First, Gregory's (1886) seven laws will be described. Then they will be mapped to the person-content-context and user-task-context models. Finally, the characteristics of modern educational contexts and how they have evolved over the last 140 years will be discussed.

2.2.1 The Seven Laws of Teaching

Regardless of the nature of the environment in which the learning will occur, it is worth revisiting fundamental cornerstones of education and the teaching function. John Gregory's (1886) "Seven Laws of Teaching" represents an early attempt to describe instructor-based content delivery that utilizes a "systems approach" through considering processes, components, and flows associated with teaching. As such, in revisiting Gregory's (1886) work on teaching, it is worth remembering Gregory's system definitions and orientation:

> Teaching, in its simplest sense, is the communication of knowledge. This knowledge may be a fact, a truth, a doctrine of religion, a precept of morals, a story of life, or the processes of an art. It may be taught by the use of words, by signs, by objects, by actions, or examples…but whatever the substance, the mode, or the aim of teaching, the act itself, fundamentally considered, is always substantially the same: it is a communication of knowledge (p. 2-3).

Although the seven laws that Gregory identifies in this work may seem, by his own admission, to be simple and obvious, they are still critical to consider when approaching teaching and learning tasks (Gregory, 1886). The rules are as follows:

(1) The Law of the Teacher describes the teacher as being someone who needs to know and understand the material to be communicated accurately.

(2) The Law of the Learner defines the learner as the individual who gives the material and the teacher their attention.

(3) The Law of Language says that language is used as a communication medium between learner and teacher, and thus the language used must be common to both parties. Note that this can have a meaning beyond which language (e.g., English) is being spoken and can be re-interpreted to address the use of specific terminology or jargon that can impair understanding and learning.

(4) The Law of the Lesson states that the lesson to be given must be accessible to the learner from their current knowledge state. That is, the content within the lesson

should build on previous knowledge or truth that the learner has already accrued. This emphasis on learner prior knowledge having a significant influence on learning outcomes is aligned with constructivist learning theories, including the 3P model of teaching and learning (Biggs, 2003).

(5) The Law of Teaching Process explains teaching as a process through which the learner's mind is engaged and used to guide them to the relevant conclusion or truth, and supporting the learner in discovering the information themself is essential to consider. The importance of the learner being actively engaged in the learning process and discovery of relevant information is reflected in the deep approach to learning within cognitivist learning theory (Biggs, 2003).

(6) The Law of the Learning Process describes learning as thought and reflection processes that occur within the learner's mental models of the new concept; activities that reinforce and structure these processes can be useful at this stage. Consideration of learning as a function of thought and reflection aligns with the perspective described within experiential learning theory (McCarthy, 2010). Additionally, the emphasis on processes that occur within learner mental structures reflects the principles of cognitive learning theory (Greeno et al., 1996).

(7) The Law of Review emphasizes the importance of reviewing, re-thinking, and reproducing the knowledge communicated in the lesson. A similar theme can be extracted from the emphasis placed on the reflective process within experiential (McCarthy, 2010) and transformative learning theories (Mezirow, 1990).

These laws can be understood to describe the education system as a sociotechnical system with components, transformations, and interactions. The education system has a purpose: the communication of knowledge, as defined by the state of knowledge and the ability of the instructor to present that knowledge to the learners in a consistent and accessible way to facilitate their internalization of that knowledge. The process associated with this goal in an instructor-driven environment is depicted in Figure 4. Actors include the teacher and the learner, roles which are described in the Law of the Teacher and the Law of the Learner. There are processes or task activities that take place within the system in the pursuit of the goal, including teaching, learning, and reviewing as described by the Law of the Teaching Process, the Law of the Learning Process, and the Law of Review. Additionally, there are elements of context that impact the quality of the interactions between the learner and teacher, as described in the Law of Language and Law of the Lesson.

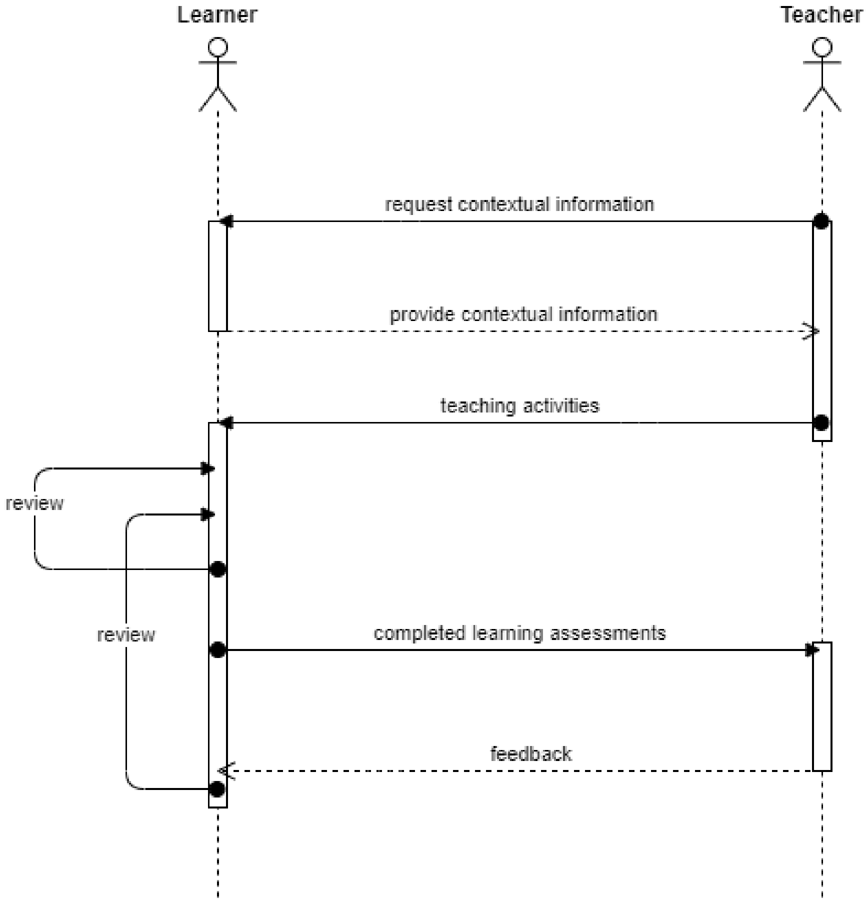

Figure 4: Sequence diagram for the learning process as described by Gregory's seven laws. Note that "contextual information" is defined as information regarding learner prior knowledge and language use.

2.2.2 User-Content-Context and User-Task-Context Models

Gregory's seven laws of teaching can be connected to two similar models for effective design from two different domains to support an interdisciplinary case design approach. The first is the user-content-context model from the IA domain and emphasizes that good information architectures are informed by (1) user characteristics, tasks, and needs, (2) the content it contains, and (3) the context in which the architecture will exist and be used (Rosenfeld et al., 2015, p. 32).

This is illustrated in Figure 5, which emphasizes that these factors are not independent of one another but rather influence one another. Additionally, all three factors are dynamic over time.

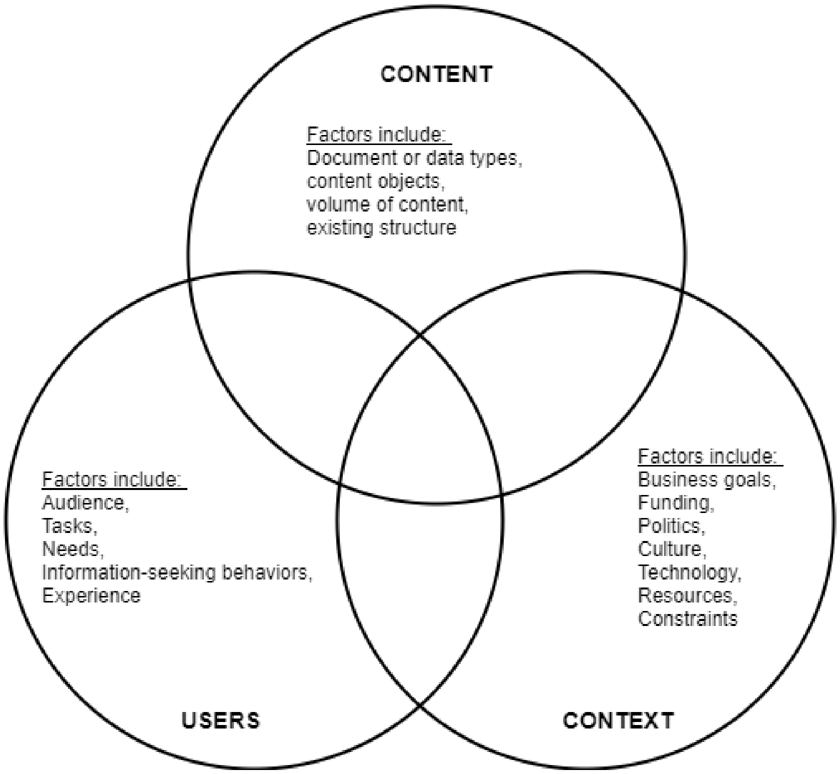

Figure 5: A Venn diagram showing the three important areas of consideration in information architectures and critical sub-factors that should be considered in relation to each. Image adapted from (Rosenfeld et al., 2015).

This is similar to the person-task-context model used in the human factors domain to design curricula (Ringsted et al., 2006). Similar to the user-content-context model, this model emphasizes the person or user that will be interacting with the system and the context in which those interactions will take place. The main difference is the emphasis on the learning task in the person-task-context model. In the user-content-context model, the tasks that individual users are carrying out are allocated as relating more to the individual. This reflects the focus on the organization of content to support user needs in a context in the IA domain, whereas the human factors domain emphasizes work (and, at a finer grain size, task) design. In the context of an online learning environment, the learning tasks are primarily resourced and constrained by the content in the system. These models, then, can be considered highly complementary and will be utilized throughout the case design to inform and organize different design elements and approaches.

The seven laws of teaching can be mapped onto both of these two models; however, the mappings are imperfect. One of the reasons for this is that both the user-content-context model and the person-task-context model tend to have an implicit assumption of a self-directed (learner-driven) orientation to the learning task at hand, without extensive teacher scaffolding of the content knowledge. In this case, this would imply self-directed learning. In contrast, Gregory describes learning as a highly directed process that is highly scaffolded by the teacher. Therefore, although some laws can be more directly mapped to some elements of these models, these mappings do not represent the only possible mapping of the laws to the models. The mapping of the seven laws to the user-content-context model is shown in Figure 6 and is characterized by many of the laws falling into the intersections between the different elements of the model.

The law of the learner is best considered as a user factor within the user-content-context model. The law of language and the law of the teacher both relate to contextual factors. Language is a contextual element and the teacher, from this perspective, is not a user within the system but an entity that influences the context of the learning environment. The law of the lesson relates the contextual factors of a user's prior knowledge to the content being learned and thus appears in the intersection between content and context. Similarly, the law of the learning process emphasizes both the content being learned and the internal user processes necessary for learning to occur. The law of the teaching process addresses both the contextual factors that govern instruction (such as the instructor themselves) and the user's individual differences and task profile. Finally, the law of review has to do with individual user tasks, which inform content factors in a context that triggers the need for review. This context may be a learning assessment or a real-life obstacle, and this influences the way the user may go about reviewing the material.

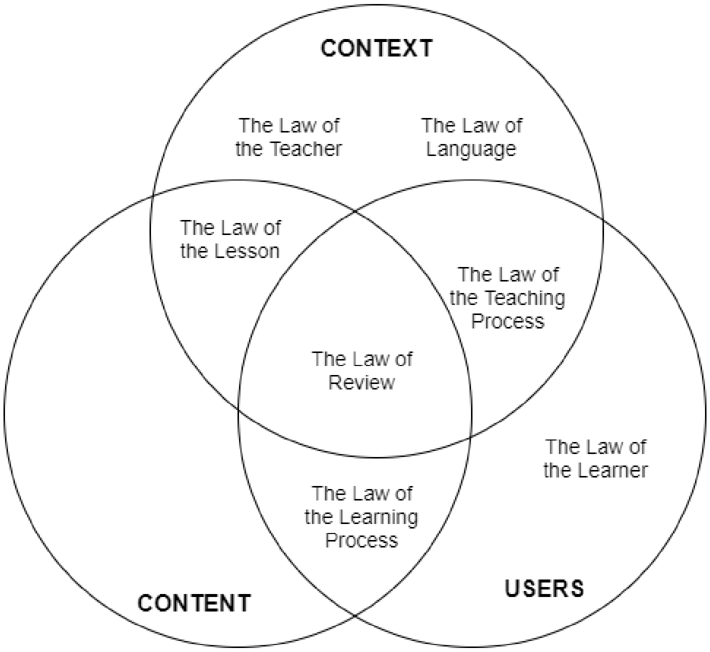

Figure 6: Mapping the seven laws of teaching to the user-content-context model

Table 1 presents the more straightforward mapping of the seven laws to the person-task-context model that contrasts with the complexity of the Venn diagram utilized for the user-content-context model. This relative simplicity is due in part to the ability to reconcile the characteristics of a "task" to the learning task being performed and the learning processes referenced by the seven laws. Similarly to the user-content-context model, the law of the learner best maps to the person element in the person-task-context model: this describes who is doing the learning task. Task factors include the laws of the learning and teaching processes as well as the law of review. These all represent task elements that occur as part of the learning process. The learner is guided through the material and must engage in self-reflection and internal processing of the content: this represents a learning task. The learner may engage in review as an additional learning activity that serves to reinforce the lesson and provide the learner with practice in accessing their new or updated mental knowledge structures. The laws of language and the lesson both represent contextual factors in that they take into account context such as what language is being utilized and the learners' current levels of knowledge in order to inform an effective instructional process. The law of the teacher in some instructional configurations may best be represented as a "person" factor, but the teacher is not an active participant in self-directed learning environments. Instead, their expertise is a characteristic of the instructional context.

Table 1: Mapping the seven laws of teaching to the person-task-context model

Person-Task-Context Model	Law of Teaching
Person	Law of the Learner
Task	Law of the Teaching Process
	Law of the Learning Process
	Law of Review
Context	Law of the Lesson
	Law of Language
	Law of the Teacher

2.2.3 The Evolution of Modern Learning Contexts

It is important to acknowledge how much has changed since Gregory wrote his seven laws of teaching in the 1880s. Modern educational contexts can both greatly resemble and meaningfully diverge from those of Gregory's time. Significant technological advances have the potential to revolutionize instructional delivery. However, the utilization of ICT in the classroom varies widely across courses and instructors (Masterman, 2017). That is, although educational contexts that take advantage of the increased accessibility and information presentation flexibility afforded by digital environments exist, others make little to no usage of even the basic functions of learning management systems (LMSs). Through 2020, co-located, synchronous lectures were still a significantly dominant means of knowledge dispersion from the teacher to the learner.

The number and types of people that can (and commonly do) qualify as learners in a higher education context have changed significantly since the 1880s, in part due to sociocultural change and the accessibility offered by technological advances. The distribution of cognitive individual differences (capabilities and limitations) relevant to learning has not experienced significant change throughout the human population as a whole. However, this shifting concept of who can be a learner (in terms of demographics, characteristics, and contexts) has experienced an evolution over the last 140 years. Similarly, the learning tasks and content have evolved together, particularly as the amount of information in a domain has increased and new instructional strategies (i.e., gamification) have risen into favor. However, the contexts in which learning takes place and the ICT that saturates those contexts have been subject to greater change than Gregory could have envisioned in 1886. The introduction of online learning environments has drastically changed where, when, and how learners interact with their courses and materials.

Instruction can be characterized on two dimensions: spatial and temporal. The spatial dimension ranges from co-located instruction, where the instructor and students are present in the same physical space, to distributed instruction, where the instructor and students (as individuals or as a group) are physically in different spaces. The temporal dimension ranges from synchronous instruction that occurs in real-time to asynchronous instruction with no real-time interaction. In the 1880s, distributed, synchronous instructional designs were not possible, but now all configurations have become viable and widely used. Examples of what these configurations look like in practice are shown in Table 2. It is worth noting that multiple configurations may coexist in the same course. For example, some students may be co-located with the instructor and choose to interact on a synchronous time scale, while other students may be distributed and interact on an asynchronous time scale; this is known as a “hybrid” class. In contrast, “hyflex” classes can be described as providing both co-located and distributed synchronous experiences, with students able to attend in the classroom or online. Some students may interact in multiple configurations with the same instructional material. For example, they may initially interact in a co-located, synchronous configuration and later interact in a distributed, asynchronous configuration. For the purposes of the case design, an emphasis will be placed on the design of a learning environment that supports distributed, asynchronous learning.

Table 2: Configurations of spatial and temporal dimensions for instruction

		Spatial Dimension	
		Co-located	Distributed
Temporal Dimension	Synchronous	Instruction in a Traditional Classroom Setting	Instruction via a web-based audiovisual “meeting” software
	Asynchronous	Tutorials or independent office hours	Instruction via recorded multimedia (i.e., videos)

Additionally, instruction can either be externally directed or self-directed. This property of instruction is rarely independent of the temporal dimension of instruction. Synchronous instruction tends to be externally directed by the instructor, who is able to adapt the instruction in real-time in response to student questions or needs. In contrast, asynchronous instruction tends to be self-directed, with the locus of control placed on the learner to interact with the course materials (including pre-recorded lectures) effectively. As such, the properties of self-directed learning are relevant to the PoSE case design.

Computer-based instruction has altered the dynamics of instructional design in terms of access to and presentation of the course material. Learners in a higher education context primarily (but do not universally) interact with course materials through a human-computer interface, usually a learning management system (LMS). Where once only a single method of information presentation was possible due to the constraints of the physical environment, technology now enables instructors to create experiences that can be adapted to individual student needs. These dramatic changes are reflected in the inclusion of interactions and ICT considerations, as well as a broader view on context than is implied by Gregory’s seven laws.

2.3 The User

A variety of traditional and non-traditional learners should be considered in the design of a distributed, asynchronous learning environment. These learners might have a range of learning goals, needs, and physical contexts in addition to a diversity of backgrounds. For the purposes of the PoSE case design, the learner (not the teacher) is the user, as they will be performing the self-directed learning tasks.

The user model as defined by the IA literature includes consideration of the user as an instance of a sample from the human population, as the person model from the human factors literature does. However, the IA user model also includes consideration of different user tasks and needs. In this section, individual differences will be identified and briefly described; two different types of relevant user tasks will also be discussed. Many of these elements will come up again in more detail in Chapter 3.

2.3.1 Individual Differences

Individual differences refer to a wide range of human characteristics which naturally vary within the total population. These are a part of the user model and generally refer to psychological traits that are relatively static over time. Individual differences can inform and impose constraints on the design of the system, but it is critical to emphasize that the system is being designed for the human; the human is not being designed for the system. There are a number of individual differences that have been identified as being relevant to learning and academic outcomes, including intellectual ability, personality, learning style, achievement motivation and goal orientations, objective functions, motivation, ability to regulate attentional resources, and prior domain knowledge or expertise. These user characteristics are all considered to be those that are universal to all types of educational environments and were identified through reviewing the user characteristics that determine academic success (see Busato et al., 2000) and those that were commonly targeted by dynamic educational environments (see Akbulut & Cardak, 2012).

Some of these dimensions do not lend themselves to intervention. Instead, they simply represent characteristics that naturally vary within a population. ***Intellectual ability***, often discussed as intelligence, is known to be a powerful predictor of academic outcomes (Busato et al., 2000; Furnham et al., 2009). It is critical to consider intellectual ability (the potential to learn, apply critical thinking, and solve problems) as distinct from the level of prior domain knowledge or expertise (the degree of exposure to the material that an individual already has). Learning outcomes are also related to different dimensions of ***personality*** in some studies (Busato et al., 2000; Busato et al., 1998; Furnham et al., 2003). Contentiousness in particular is positively associated with academic success (Busato et al., 2000). While measures of both personality and intellectual ability are subject to criticism, there is little question that variation in both these characteristics exists over the human population. However, unlike many of the other individual differences listed above, there is not a systematic means of instructional intervention that can impact (change or support) the intellectual ability or personality of a learner. Therefore, these two individual differences will be de-emphasized.

Learning styles have also been linked to learning outcomes (Akbulut & Cardak, 2012; Busato et al., 2000; Busato et al., 1998). Though there are a number of models of learning styles that are considered within the literature, many of these approaches have been subject to criticism, particularly when they treat learning styles as a static user characteristic. Although different learners may have different preferences regarding how they approach learning, instructional interventions that treat the dimension as a constant can be detrimental (Riener & Willingham, 2010). However, the Felder-Silverman learning style model (FSLSM) is one of the more commonly utilized in ICT-enhanced learning contexts (Akbulut & Cardak, 2012; Graf et al., 2007) and does not attempt to sort learners into different categories that are then treated as constants. FSLSM describes learners on four dimensions rather than categorizing them into one of a few groups (Graf et al., 2007). These dimensions include: active-reflective information processing, sensing-intuitive learning, visual-verbal information presentation, and sequential-global understanding (see Graf et al., 2007 for additional details). As such, the learning styles described by FSLSM are better defined as “common patterns of student preferences for different approaches to instruction” (Felder, 2020, p. 3). These descriptions should not be considered as invariant, strict, mutually exclusive categorizations that serve as reliable indicators of learner strengths and weaknesses (Felder, 2020). Although learning styles cannot be manipulated directly, there has been some research into designing instructional environments to appeal to learners with a range of different preferences regarding content delivery (El-Bishouty et al., 2019).

Achievement motivation and goal orientation consider similar constructs. ***Achievement motivation*** can be defined as the internal factors that drive an individual to pursue success and excellence. Achievement motivation has been considered as a factor in education research as well, both in the context of higher education and in earlier education, that emphasize the positive relationship between higher achievement motivation and a high level of academic performance

(Busato et al., 2000; Busato et al., 1998; Wang & Eccles, 2013). Achievement motivation can be considered unidimensionally (Busato et al., 2000; Busato et al., 1998; Hermans, 1976) or multidimensionally in relation to mastery, work orientation, competitiveness, and personal unconcern (Helmreich et al., 1978; Spence & Helmreich, 1978). An individual who scores high in mastery would be motivated to achieve a high degree of proficiency in the subject or task being taught. A high work orientation would indicate that an individual places great value on working hard. An individual with high competitiveness is motivated by out-performing their peers. Finally, someone with a high degree of personal unconcern is not motivated by how other people view their success or failure. This dimension is framed differently than the others, with a high score indicating a lack of a motivating factor influence.

Goal orientations are generally considered on three dimensions: mastery, performance approach, and performance avoidance (Church et al., 2001). Mastery goals emphasize the attainment of high levels of competency related to a subject or task (Ames, 1992). Performance approach goals emphasize receiving positive, favorable judgments in terms of the individual's performance, while performance avoidance goals emphasize avoiding negative or unfavorable judgments regarding performance or competency (Church et al., 2001; Mattern, 2005; Poondej et al., 2013). Mastery goal orientations are usually associated with positive academic outcomes, including higher levels of critical thinking (Ames, 1992; Church et al., 2001; Elliot & McGregor, 2001; Poondej et al., 2013). On the other hand, adoption of performance avoidance goals tends to be related to negative outcomes in terms of their academic performance and other relevant factors.

There is a clear similarity between this goal orientation literature and the achievement motivation considerations discussed above. Goal orientations are informed by learner motivations, so it would seem reasonable to draw a connection between the mastery goal orientation dimension and the mastery dimension of achievement motivation, for example. Additionally, both the performance approach and performance avoidance goals would appear to have some relationship to the personal unconcern dimension of achievement motivation. Goal orientations, then, allow some implicit insight into motivations and relate to achievement motivation, but it is also critical to consider the objectives that a learner may have. Similarly to learning styles, an individual's achievement motivation or goal orientation cannot be manipulated, but different instructional designs may appeal to different individuals. For example, a gamified approach to learning may appeal to a learner that scores high on the competitiveness dimension of achievement motivation.

Objectives refer to a learner's desired outcomes associated with interacting with instructional material. A learner may hold more than one objective in mind (they are not mutually exclusive), but the relative priority afforded to each objective varies naturally among learners depending on their desired outcomes and personal sense of the material's value. A similar approach known as a fundamental objectives hierarchy has been applied to project stakeholders in the past in order to understand what their relative priorities are (Buede & Miller, 2016). Objectives may include getting a certain letter grade (such as an A) in the course. This objective function is distinct from goal orientations and motivations because this objective could be a reflection of a learner who scores high on any of the achievement motivation dimensions or has any of the goal orientations. However, it is possible in some cases to infer a goal from the utilized objective function. For example, if a learner is utilizing an objective function to maximize learning, it is likely that they have a mastery goal and are highly motivated by mastery of the material (and thus score highly on the mastery dimension of achievement motivation). Other potential objective functions may include maximizing learning, maximizing the learning of material relevant to a current or future career, earning a grade such that they can pass the class, or maximizing the grade in the class subject to a time constraint. Any given learner may experience varying levels of any of these objective functions or other considerations, including their employment status, interest in the subject, and even other time commitments. Examples of motivation, focus, and experience are provided below and are used as considerations in the design of user personas in later chapters.

Both intrinsic and extrinsic ***motivation*** are related to higher academic performance (Ayub, 2010). These dimensions differ from achievement motivation in that the latter actually emphasizes the aspects of the task that serve as motivators, rather than the level of motivation present. Additionally, the ***ability to maintain and regulate attention*** clearly influences learning outcomes (Le Pelley et al., 2016; Steinmayr et al., 2010). Self-regulation, or the individual's ability to monitor and manage their behavior and emotions, is relevant to maintaining attention as a metacognitive skill[1]. While all of the identified individual differences contribute to academic achievement (and thus, presumably, positive learning outcomes), these represent a subset that become even more critical to consider in an online, asynchronous environment. Motivation to engage with course materials (Rogers-Shaw et al., 2017) and greater self-regulation skills (Artino & Stephens, 2009) have been identified as critical factors to success in online-based, distributed learning. For example, it has been shown that learners with high motivation and high self-regulation tend to perform better in online, distributed learning environments. Specific design interventions related to self-regulation will be discussed later.

A learner's ***level of prior domain knowledge or expertise*** is particularly critical in the context of different instructional interventions, including non-sequential delivery (McDonald & Stevenson, 1998), varying degrees of learner control (Lawless & Brown, 1997; Scheiter & Gerjets, 2007), and graphical representations (Kalyuga et al., 1998; Potelle & Rouet, 2003). A distribution of prior domain knowledge will be present in PoSE as a function of the inclusion of both traditional and non-traditional learners. Non-traditional learners may have vastly different backgrounds and experiences compared to traditional, residential graduate students. Learners with higher prior domain knowledge tend to have better learning outcomes than those with lower prior knowledge (Müller-Kalthoff & Möller, 2003). With instructional interventions, it is critical to provide enough support for novices to be able to learn (Kalyuga, 2007). However, the same support that is critical to novices may be sub-optimal for more experienced learners (the expertise-reversal effect). Therefore, it is especially important to consider the role of prior domain knowledge or expertise in designing an online learning environment.

There are other user characteristics that are more relevant in distributed, asynchronous course configurations but may not have a direct relationship to learning outcomes. The primary factor to consider in the case of an online learning environment is access to sufficient internet bandwidth (Sreehari, 2020). There are a number of reasons why access to bandwidth would vary among learners, including socioeconomic status and where they live. For example, rural

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[1] Though motivation and self-regulation skills are often discussed as two different constructs, it is worth noting that when defining self-regulation as the ability to regulate one's own behaviors and emotions, it is possible to conceptualize motivation as being an outcome of self-regulation. In this way, both attention and motivation are influenced by an individual's level of self-regulatory skills.

communities experience less reliable internet connections with lower bandwidth (Hollman et al., 2020).

In summary, there are a number of user characteristics that influence the learning process. In contrast to Gregory's emphasis on instructor-led learning, the person-task-context and user-content-context models directly address the needs, processes, and learning contexts of motivated, engaged learners with growing levels of expertise and self-efficacy. Although these characteristics cannot be directly manipulated, a subset of them could viably be considered within the design. Those that can be designed for and are relevant to the PoSE case design include learning styles (as defined by FSLSM, as learner preferences for instructional delivery), objective prioritization, self-regulation, and prior domain knowledge, and access to appropriate bandwidth.

2.3.2 Tasks

Within the user-content-context model, personal factors include consideration of the tasks that the users may be performing within the digital environment. In an online, asynchronous learning environment, there are two major types of tasks that users will be working to accomplish. First, learning tasks are defined as any tasks associated with accumulating or expressing knowledge. An example of a learning task might include watching a video lecture or writing a position paper in response to a presented case study. The number of learning tasks that a user needs to complete may vary depending on individual differences (i.e., prior domain knowledge), and different people may prefer different configurations of learning tasks (i.e., preferring reading lecture notes to watching videos). However, the content being covered by the learning tasks is relatively constant for all learners in the system, so there may be variability in how the tasks are approached, but the tasks themselves are not subject to high variability.

The second type of tasks users may perform in an online, asynchronous learning environment is information seeking in response to some information need. This information need is informed by the individual (i.e., goals, prior knowledge) and their context and may align with different information need profiles (i.e., known-item, exploratory, exhaustive, and refinding). Therefore, there will be a greater degree of variation in the information-seeking task compared to the learning tasks.

2.3.3 Universal Design Considerations: UDL, UDI, UID

Universal design (UD) is a critical, user-centric approach that holds values when applied to the design of any system, including the interdisciplinary, dynamic, broadly delivered course system at the heart of this thesis. There are seven core UD principles that address equity, flexibility, simplicity and intuitiveness, perceptibility, error tolerance, minimization of physical effort, and physical accessibility (Story, 2001). These principles provide broad guidance for designing for a distribution of individuals who may have different physical or cognitive abilities. However, many more domain-specific frameworks have also been developed. There are three such frameworks in the education domain: (1) Universal Design for Learning (UDL), (2) Universal Design of Instruction (UDI), and (3) Universal Instructional Design (UID; Rao et al., 2015). Each of these frameworks approaches the design of an educational or instructional environment from a slightly different perspective, and each provides some valuable and unique insight into design. Additionally, the frameworks have significant overlap and thus can be viewed as being complementary perspectives rather than mutually exclusive design recommendations. UDL, UDI, and UID principles are shown in Table 3, but each will be briefly discussed below. Importantly, the UDL, UDI, and UID principles also echo aspects of Gregory’s Laws of the Language, Lesson, Teaching Process, and Learning Process.

UDL emphasizes curriculum design to support learners with a distribution of abilities through focusing on providing flexibility regarding the means of representation, expression, and encouragement (Burgstahler, 2009a; Rogers-Shaw et al., 2017). These principles can be further broken down into nine guidelines and 31 checkpoints (Al-Azawei et al., 2016), but these will not all be discussed here. First, the course material should be subject to multiple means of representation. This allows users to acquire knowledge via a number of different sources or modalities that may better appeal to their preferences or abilities. For example, providing captions along with a video allows learners who experience difficulty with hearing or auditory processing to comprehend the material. Next, multiple means of expression allow learners to demonstrate their knowledge in various ways, such as assessments that include both multiple-choice quizzes and essay-style position papers. Finally, there should be multiple means of engagement in order to capture learner interests and increase motivation (Burgstahler, 2009a). This is especially important in an online environment, where much of the learning is self-directed (Rogers-Shaw et al., 2017) and may include open discussions, Q&A sessions, or other active learning techniques (Al-Azawei et al., 2016). Applying the principles of UDL has shown to be effective in traditional, blended, and online environments (Al-Azawei et al., 2016). These UDL principles link most directly to Gregory's (1886) descriptions of ensuring accessibility in the laws of the Language and Lesson to the learner and how the Teaching and Learning Processes serve to increase learner engagement with the content.

Table 3: UDL, UDI, and UID Principles as presented by Al-Azawei et al. (2016), Burgstahler (2009b), and Fox et al. (2003), respectively

Framework	**Principle**
UDL	Multiple means of representation
	Multiple means of expression
	Multiple means of engagement
UDI	Diverse and inclusive class climate
	Accessible communication methods to facilitate regular, effective learner-instructor interactions
	All materials should be physically accessible and usable by all learners
	Utilize multiple, accessible means of content delivery
	All course materials should be accessible, engaging, and flexible
	Provide regular and specific feedback
	Learner progress should be regularly assessed through multiple methods of tools and should inform instruction
	Plan for additional accommodations that are not met through instructional design

Table 3 continued

UID	**Create welcoming classrooms**
	Identify the course's essential components
	Communicate clear expectations to the learners
	Provide learners with timely and constructive feedback
	Consider and integrate the use of natural learning supports, including technology
	Consider a distribution of learner individual differences
	Provide multiple ways for learners to demonstrate their knowledge
	Encourage learner-instructor interaction

UDI focuses on universal design regarding the implementation of instruction by considering the course materials and instructional strategies to manage communication and class climate (Burgstahler, 2009b). Some principles, including that content should be delivered through multiple mediums and should be engaging and flexible, represent similar design considerations as the principles of UDL. UDI, as an overall framework, seems to emphasize the synchronous, co-located instructional configuration, which most directly aligns with the context of Gregory's teacher-directed learning model to support "communication of knowledge." This is exhibited through the principle addressing physical accessibility and usability of materials, although the principle might be expanded to ensuring appropriate information bandwidth and software to access course materials in a hybrid or online context.

The UID framework emphasizes a set of principles that guide instructors in creating an accessible, effective instructional environment (Goff & Higbee, 2008). Many of these principles are highly similar to those discussed in the context of the UDL and UDI frameworks; this further highlights their similarities. Others, such as the use of natural learning supports, seem to relate to the core UD principle of presenting intuitive designs and the use of learning scaffolding (discussed later) as a means of supporting learners through complex learning tasks that may otherwise be out of reach. Gregory's (1886) Laws of the Learning Process and Review may be seen as compatible with the UID principles of appropriate scaffolding to support effective Learner integration, reflection, and reproduction of Lesson material in appropriate contexts.

As noted, all three frameworks have similar themes that present key takeaways when it comes to the IA and UX design of an asynchronous, online educational resource. The first is the criticality of multiple presentation modes. This highlights that any audio or video should be captioned, and graphics should have alternative descriptions (Burgstahler, 2009a; Sapp, 2009). Additionally, there should be multiple means for learners to express their understanding of the material, expectations should be clearly communicated, and feedback should be constructive and timely. Instructors should seek to motivate and engage learners through multiple strategies and facilitate a welcoming, inclusive class climate to support learner learning. Finally, regular learner-instructor interactions should be encouraged.

2.4 The Content

Comprehensive SE educational material that presents the broad scope of the domain and the perspectives it contains is critical to the progression of the domain. Understanding and effectively influencing the complex systems that saturate the world provides an approach to solving the "big problems" society faces today. When looking at the UN's 17 Sustainable Development Goals (SDGs), all of them relate to abstract or physical complex systems (United Nations, n.d.). That is not to say that each goal has to do with only one system: most goals are actually characterized by an entanglement of multiple systems. For example, the relevant systems to the goal of ending poverty are not only financial and economic systems and (even though these systems can be complex themselves) addressing only this aspect would not sufficiently solve the problem. Social and political aspects must also be considered, as must the physical environment around the people impacted by poverty. If there is no adequate supply of food, water, or health supplies or if the needed infrastructure is lacking, these elements would limit the effectiveness of interventions within financial or economic contexts. If the systems relating to poverty are too narrowly defined and the influence of external factors are not considered, interventions may fail or be woefully incomplete. When it comes to addressing big problems, the window of opportunity to do so before any intervention may be minimally effective is small compared to the complexity of the underlying systems and needed solutions. Big problems related to complex systems are not a new phenomenon, but the invention of the internet and the rise of computing have come with both challenges and benefits. The interconnectivity that has become expected in everyday life increased the complexity of many systems. However, the same interconnectivity also enables collaboration and access to diverse perspectives that allow for clearer and more thorough system definitions and interventions.

The PoSE content specifically emphasizes the utilization of the "systems languages" taxonomy to support the exchange of perspectives in the SE domain. It is common in conversations about SE for people – researchers and practitioners alike – to be operating under two different definitions of SE while assuming a common understanding. This leads to misunderstandings, miscommunications, and ultimately, disengagement and dismissal of others' perspectives and expertise. This result is in direct conflict with the value that SE places on considering a variety of perspectives when analyzing a system and ultimately impairs progress in addressing big problems.

PoSE content aims not only to provide learners with an understanding of the systems languages, but also to develop a worldview that enables learners to apply their knowledge to real-world systems challenges. The content, instructional approaches, and domain-specific considerations are all relevant to informing the design of the asynchronous, online learning environment. First, the systems languages taxonomy that permeates the content will be summarized to provide necessary background information regarding the topic of emphasis. Next, the case study methodology that enables learners to practice applying their knowledge will be described. Finally, the domain-specific considerations associated with teaching systems engineering content will be addressed.

2.4.1 The SE Languages

The original systems languages (also described as "flavors") taxonomy was introduced by Caldwell (2009) and consisted of SE1 through SE4. This taxonomy emphasizes the variety of perspectives that different disciplines may have on what "systems engineering" involves in terms of emphasis. A later revision to the taxonomy added the SE5 classification as well (Caldwell, 2020a). Each of the classifications will be described briefly.

SE1, also referred to as the Systems Thinking approach, usually involves non-technical, high-level discussions of systems as a set of components that interact with one another to accomplish an overall goal. System dynamics considerations, including emergent behavior, inputs, outputs, and feedback flows, are also included within SE1. This approach to systems engineering is considered to be more accessible to non-engineers, as it does not require rigorous mathematical knowledge. Therefore, this language often comes into play in contexts that are not considered traditional engineering challenges.

Cybernetic and Operations Mathematical Analysis, or SE2, is a more traditional, mathematically rigorous approach to systems that includes information theory and cybernetics. Like SE1, SE2 is concerned with component interactions and system behavior principles over time, but the approach to these elements is more explicitly mathematical. This approach is perhaps most familiarly embodied by the field of operations research in Industrial Engineering.

SE3, or Engineering Component-Whole Relationships, primarily focuses on how the components of a system function together as a whole to accomplish a given goal. This approach usually involves recursively defining components (and sub-components) by their sub-components until the sub-components cannot be reasonably broken down into finer functional units. Thus, SE3 operates at a range of grain sizes within a single system. SE3 emphasizes emergent behaviors that may stem from the combination of simple components to form a more complex system.

SE4 is also known as the Engineering Deployment Process and has to do with the management and implementation of large-scale engineering projects and solutions. This approach to creating systems emphasizes principles of project management that allow practitioners to track complex project progress. Many of these techniques can be found within the management of NASA and Department of Defense projects specifically. These projects require the systematic management of a large number of components that are manufactured and managed by direct employees and contractors, as well as proper integration of the different components and accurate, clear communications across respective teams with countless direct employees and contractors sharing for the quality of the components and their quality.

Finally, Digital and Information Architectures, or SE5, emphasizes the importance of collecting and organizing information. Though this architectural organization process often takes place in a digital environment in the 21st Century, it is worth noting that SE5 pre-dates modern computer technology, as libraries have long offered a systematic method for organizing, storing, and retrieving information. However, the ability to effectively design digital and information architectures to manage information is increasingly important as the amount of information available to people increases. Without effective labeling through metadata tags, most information would be difficult to find through search, essentially rendering it inaccessible to most of the population.

Though this taxonomy is a significant element of the material that is being taught within the PoSE course, it is also highly relevant to the case design being described as well, particularly the SE5 perspective, which relates to how the course information is being organized and managed.

2.4.2 The Case Study Methodology

The engineering case study methodology, as it appears in PoSE, has roots in the Harvard Business School case method, where students are provided with a real-world business scenario and asked to make an argument for a course of action (MacLellan, 2018). The engineering case study is similar in that it presents a real-world challenge associated with an engineering system of some kind, and learners are asked to apply their understanding and perspectives to analyze or solve the problem at hand. Case studies have also been implemented into training programs because they encourage participants to think critically and learn through both investigation and discovery (Rothwell & Whiteford, 2009, p. 159). The case study methodology provides learners with the opportunity to "practice" applying their knowledge and understanding to real-world contexts that may more closely resemble what they will experience outside of the classroom (Herreid, 1994; Steiner & Posch, 2006; Vivas & Allada, 2006). These approaches are useful for emphasizing the transdisciplinary approach that systems engineering strongly benefits from and that PoSE emphasizes (Steiner & Posch, 2006).

When it comes to teaching the case method, particularly in person, it is worth noting that instructors take on a very different role than that of a traditional lecturer. Instead, they act as the "planner, host, moderator, devil's advocate, fellow-student, and judge" (Harvard Business School, 2003, para. 1). Synchronous classes may play out as discussions, which may be highly structured, but are not scripted lectures. Thus, the instructor must prepare extensively to manage both the content and the process of this discussion. In an online, asynchronous environment, of course, this level of interaction is not feasible in a traditional fashion. Alternative methods for facilitating such discussions must be considered within the design of the course.

2.4.3 Domain-Specific Considerations: Teaching Systems Engineering

There has been specific consideration of how to teach systems engineering. Compared to other engineering disciplines, SE is a highly practical and experience-based discipline that emphasizes the application of experience and critical understanding of technical decisions over the application of specific tools or techniques (Turner et al., 2017). This also contrasts with many individual engineering courses, which usually aim to provide background with specific tools or approaches, usually within a defined domain. Experience is the primary source of SE-related learning, with formal education and training also being strong influencers (Armstrong & Wade, 2015). However, it is worth noting that the same study found that experience did not function independently of other elements: both structured instruction and self-learning methods interacted with experience to enhance learning. Deliberate practice, a highly structured means of improving performance by overcoming weaknesses, is critical to developing expertise. This development process can be lengthy, with several studies concluding that achieving top performance levels requires approximately 10,000 hours of study (Armstrong & Wade, 2012).

The demand for systems engineers has outpaced the development of new, suitably experienced systems engineers. This has resulted in some interventions like the Systems Engineering Experience Accelerator, which aims to increase experience more quickly through the use of realistic, simulated scenarios (Turner et al., 2017; Wade et al., 2012). These scenarios are meant to provide challenging experiential learning in an environment where mistakes do not have real-world consequences. These simulations, however, would provide higher value to an already moderately knowledgeable learner base who would apply their existing SE knowledge, skills, and experience. When it comes to teaching novices with little or no background knowledge, other challenges specific to the SE discipline arise.

SE as a discipline is also strongly characterized by interdisciplinary and transdisciplinary approaches. This is reflected in the fact that systems engineers often begin their academic or professional careers in another, more specific engineering discipline (Armstrong & Wade, 2012). Despite the trend of pairing systems engineering with other disciplines (such as industrial, biological, or computer engineering), especially at an undergraduate level (Fabrycky, 2010), interdisciplinary learning does not benefit from strict adherence to principles of truth proposed or reinforced by any one domain (Lian, 2000). There is also evidence that there is a primary emphasis on problem-solving – rather than critical problem definition work that serves as a core of SE – in many undergraduate engineering courses (Fabrycky & McCrae, 2005). This provides additional barriers for engineers looking to gain an introductory knowledge of systems engineering. Not only is experience the primary source of learning, but the vastly different interdisciplinary and problem definition focus mandate further adjustment and may represent areas of lacking shared background knowledge among SE learners. It should be noted that the specific mechanisms of learning processes (or end goals of learner outcomes) are not the focus of this thesis. The goal of this design case approach is to facilitate a range of learners at various levels of preparation, skill, and use of the SE material.

As has been previously mentioned, introductory SE courses seek to impart a worldview that enables learners to begin to view the systems around them differently and gain the experience that characterizes much of SE education. This worldview has been described as "SE disease" and is characterized by learners being able to identify applications of PoSE and the five flavors presented within the course to a wide range of both personal and work systems (Caldwell, 2020a). A learner infected with "SE disease" may identify elements of systems dynamics at work when presented with historical events, particularly accidents or disasters. The development of this worldview is an individual transformative experience that does not lend itself to direct transfer from the instructor to the student. The desired outcome of teaching this mentality is the creation of an internal learner process that cannot be easily measured or quantified, which complicates both the teaching and evaluation process. Some of these challenges may be addressed through instructional approaches that address complex, interconnected material such as cognitive flexibility theory, which is described later.

2.5 The Context

Contextual factors include those that primarily relate to the design of the immediate digital environment in which the learning takes place. Online learning environments vary significantly from the more "traditional" (synchronous and co-located) course configurations and come with their own sets of challenges and benefits. The dynamics of asynchronous communication in a learning context will be discussed. The availability and fidelity of communication media and the role of self-directed learning in distributed environments are also relevant to consider. The constraints of an online learning experience also place the responsibility for providing appropriate scaffolding to support effective learning on the learning environment and delivery design. Finally, transferring knowledge from the learning environment and applying it to external contexts is a primary goal associated with SE education (and, by extension, the PoSE course). Factors, both within the scope of the case design and external to it, will be identified and categorized.

2.5.1 Online Learning Environments

Contemporary learning systems have been previously characterized as existing along at least two dimensions: synchronicity and co-location-distributed contexts. Here, asynchronous, distributed environments will be contrasted with the "more traditional" synchronous, co-located learning environments in order to understand influential factors pertaining to the context. Learning in online environments is markedly different from learning in a classroom setting in terms of synchronicity, information availability and fidelity, and the type of learning task taking place. While these factors are not strictly unique to online learning environments, they do tend to characterize and subsequently pose challenges within the context of online learning environments. There are advantages associated with the flexibility of information presentation in a digital medium, which will be discussed in relation to digital IA design.

Online learning environments (including the prototype design for PoSE) tend to fall into the asynchronous and distributed configuration. While synchronous, distributed learning environments are possible (and even common in the midst of a pandemic), this is not the emphasis of this thesis. Online environments lend themselves strongly to a distributed environment where the instructor and learners are not inhabiting the same physical space. Distributed configurations with asynchronous communication pose unique challenges in regards to information exchange. These include (1) the availability and fidelity of communication media and information and (2) the locus of direction for the learning task (self-directed vs. learner-directed).

Asynchronous Communication

Asynchronicity is characterized by a temporal delay within communication channels between the instructor and learners. For example, an instructor recording a lecture and later uploading it for learners to view when they are able is an asynchronous information exchange (it is not happening in real-time). Discussion boards and emails are other examples of asynchronous communication mediums. The benefits of asynchronous communication in online courses include flexibility and convenience (Poole, 2000) for both the learners and instructors.

However, asynchronous communication inherently involves a communication delay. There are some indications that asynchronous communication in the form of pre-recorded lecture videos has positive influences on learning outcomes compared to synchronous, co-located communication (Kyaw, 2021). Substantial work investigating the impacts of communication delay has been done in the context of team-based tasks. Although learning tasks are not necessarily collaborative, they share characteristics with team tasks in that the learner needs to obtain information from another entity in order to perform effectively. Delay tolerance is influenced by the perceived distance between the two entities communicating, task size or complexity, task importance, situational urgency and remaining time available to respond to the situation, and network bandwidth capacity (Caldwell & Paradkar, 1995; Caldwell & Wang, 2009). Information delays are associated with degraded human performance, which may include adverse impacts on decision-making (Caldwell & Paradkar, 1995), interpersonal relationships between the agents involved (the learner and instructor; Guenter et al., 2014), and a longer recovery time in the case of failures (Fischer & Mosier, 2014). Given these negative outcomes associated with time delays in other task contexts, it may be important to consider and reasonably mitigate the delay in learner-initiated communication with the instructor.

Availability and Fidelity of Communication Media and Information in Distributed Configurations

Depending on the communication medium, there may be critical information that is absent from the signal that would be present in the face-to-face communication that would take place in a “traditional classroom” context. Co-located and synchronous instruction provides learners with paraverbal and nonverbal cues (information) that are not available through all communication media (Taha & Caldwell, 1993). This type of information can be critical to understanding the content (especially the context of the content) and establishing a social presence through facial expressions, eye contact, and body language (Jorgensen, 2003). A strong sense of social presence may be able to limit the perceived learner isolation that can emerge in distributed environments and impact task outcomes. Therefore, it is relevant to consider the "information richness" of the communication mediums being utilized for information exchange as a contextual factor that may influence learner performance on a learning task. Mediums that operate with a higher degree of fidelity to face-to-face interactions, such as audiovisual recordings that show the instructor's face, can be regarded as having a higher "information richness" and thus a greater social presence (Handke et al., 2019). Mediums such as audio-over-notes, audio-only, or text-only have lower richness (and lower social presence) due to the lack of these paraverbal and nonverbal cues. However, it is critical to note that high levels of information richness are not universally desirable or appropriate in all task contexts. One example of this might be a large Excel sheet where the goal of the information exchange centers around the data contained within it. A synchronous, co-located verbal presentation of this information would not be appropriate to the task in the same way that an asynchronous, distributed communication mechanism (i.e., email) may be.

However, there are ways to supplement even these low richness mediums in a meaningful way. For example, emoticons or emojis can be utilized to communicate some degree of paraverbal information. Other practices that can increase social presence include addressing classmates by name, self-introductions, utilization of humor, emotional expression, and discussion of experiences outside the context of the learning environment (Jorgensen, 2003). Regardless of these supplemental approaches, it is critical to ensure that all necessary learning task-related information (including paraverbal and nonverbal information) is available to and able to be understood by learners.

Self-Directed Learning in Distributed Configurations

The identity of the entity (instructor or learner) responsible for directing the learning process is a critical factor to consider in relation to online learning environments. Learning in co-located, synchronous learning environments (or "traditional classrooms") is generally instructor-directed. Even in more collaborative learning environments, the instructor still has a significant degree of control and the critical role of the facilitator. On the other hand, learning in an asynchronous, distributed context tends to be self-directed. Self-directed learning can be defined in several different ways, but most emphasize the learner as the locus of control and responsibility for their learning through planning, completing, and evaluating performance on learning tasks (Song, 2005, p. 6). Furthermore, self-directed learning can be linked to two core concepts: learner self-regulation skills and learner autonomy (or learner control).

Self-directed learning has been shown to have positive outcomes in relation to “the type of learners it develops” (Abdullah, 2001, p. 2); specifically, learners are capable of taking responsibility for managing their own learning (Wilcox, 1996). These learners have also been characterized as more highly motivated, persistent, independent, and goal-oriented (Taylor, 1995), though it is unclear if this is an outcome of self-directed learning or the attributes of a learner that will thrive in a self-directed environment (or both). However, higher learner control has been linked to increased motivation, engagement, and positive attitudes within the learner (Yildirim et al., 2001).

There are a number of significant barriers and constraints to effective self-directed learning. Depending on the design and presentation of material, learners may experience anxiety and information overload due to the amount of information and a “mind wandering” phenomenon characterized by a lack of focus (Kohan et al., 2017). Students also reported that the role ambiguity induced by self-directed learning was a challenge to self-efficacy and completing required learning tasks; many did not feel as though they were prepared to manage their learning effectively on their own (Kohan et al., 2017). These barriers serve to reinforce a theme that has been present throughout the literature: few learners will be able to be initially self-directed (Usher & Johnston, 1988).

2.5.2 Learning Scaffolding

Scaffolding to support learning is critical in any educational environment but can be even more so in an online, asynchronous environment. Scaffolding can be defined as a variety of instructional techniques used to progressively refine a learner’s understanding by decreasing the initial cognitive load (Beed et al., 1991; Great Schools Partnership, 2015). These support structures are then meant to be gradually withdrawn, ultimately providing the learners with independence in terms of their own learning. The concept is far from a new one, with most literature identifying Vygotsky’s (1978) concept of zones of proximal development as the root of scaffolding considerations. Scaffolding is most effective when it is temporarily instituted to support learners in accomplishing tasks that they would be unable to achieve by themselves (Maybin et al., 1992). As was described in the prior section, however, learners may find a lack of scaffolding as a constraint limiting their effectiveness if it is not available when needed.

Scaffolding can consist of a wide array of specific instructional activities or approaches. First, it is important to consider the difficulty level of the task compared to the learner’s skill set (Fisher & Frey, 2010). Further approaches might include modeling behaviors for the learner, cueing or highlighting specific actions or strategies to approach problem-solving as a joint effort, inviting learner engagement, and providing both direct and indirect explanations to support learner progress (Beed et al., 1991; Fisher & Frey, 2010). It can be additionally important to highlight learner success to motivate the learner and allow for constructive failures to occur (Fisher & Frey, 2010). These productive failures are opportunities for the learners to learn from errors, expanding and enriching their understanding of a knowledge space. During the scaffolding process, there may be phases of imitation, collaboration, and more independent learner performance (Tilley et al., 2007).

There is some precedence for scaffolding in non-sequential, adaptive instructional environments. It has been found that adaptable scaffolding is more effective than fixed scaffolding and a lack of scaffolding in terms of increases in understanding of a topic and declarative knowledge acquisition (Azevedo et al., 2005). This emphasizes the importance of implementing the right level of scaffolding on a dynamic continuum rather than as a fixed, binary consideration. Fixed scaffolding is often found to be ineffective, possibly because of their lack of adaptation to individual learner needs (Azevedo et al., 2004; Azevedo et al., 2005), further emphasizes the need for dynamic scaffolding and represents a situation where trying to fit a single design to all users results in scaffolding that does not support anyone. It is worth noted that the dynamic nature of adaptable scaffolds – manually adapted to users by tutors in the Azevedo et al. (2005) experiment – is made exceptionally difficult in the context of virtual learning environments (Sharma & Hannafin, 2007). Even adaptive scaffolding informed by algorithms may be subject to error and less responsive to emergent needs, as fading would be in response to pre-defined criteria.

2.5.3 Learning Transfer

Learning transfer can be conceptualized as the ability to take the knowledge that has been acquired and apply it to contexts outside of the original context in which it was learned. Also called knowledge or training transfer, this concept has been studied extensively in relation to the transfer of knowledge from a training session to the day-to-day job context. Similarly, when considering a system meant to provide learners with exposure to a concept (i.e., systems engineering) to prepare them to engage in certain analysis processes outside the classroom, knowledge transfer becomes essential. Although learning can be defined on multiple levels (i.e., individual, team, organization, inter-organization) and barriers to knowledge transfer can occur at the interface between many of those levels (Yih-Tong Sun & Scott, 2005), the primary focus, in this case, is on barriers to individual learning transfer. Especially for working professionals, one important issue of learning transfer is whether the learner is able to take course material and apply it directly to their concurrent (or anticipated) work projects; this issue is usually deferred or delayed for traditional, full-time students. The ability to transfer knowledge out of the classroom context is a major element of "SE disease," so facilitating this learning transfer would contribute to learners developing the ability to apply course content to other real-world SE organizational settings.

A number of factors are associated with successful learning transfer at different grain sizes, including individual characteristics, content characteristics, and external factors. Individual characteristic factors include motivation to learn, motivation to transfer the knowledge, and personal ability to transfer the knowledge (Kirwan, 2009, p. 150). The content itself and its design represent another relevant factor to consider. Finally, manager support, peer support, and organizational climate are external support factors that influence the magnitude of learning transfer. This last group of factors is out of scope for this project because there is no feasible way to influence the learner's external environment to support learning transfer within the design of a learning environment.

Both motivation and the ability to transfer knowledge are examples of individual differences that can be minimally catered to with a generalized design. While the design can support learner engagement, no design can manufacture or guarantee that learners are motivated. The considerations associated with personal learning motivation include expectations regarding learning applicability and usefulness, the locus of control, goal orientation, and self-efficacy

(Kirwan, 2009, p. 156). Some of these elements, such as the locus of control and goal orientation, have been discussed previously. However, this emphasizes the role of directly setting up expectations regarding the useful application of the presented material.

The design of the content itself, as well as its delivery, also have an influence on knowledge transfer. Principles associated with content design include: (1) setting clear objectives and outcomes, (2) balancing theoretical and practical knowledge, (3) providing relevant reference materials, (4) making the content as relevant as possible to potential areas of application, (5) providing opportunities for practice, and (6) encouraging work on real-world problems in small group contexts (Kirwan, 2009, p. 156). These principles address elements associated with the design and development of the material associated with an academic or training course, but do not emphasize components of the content delivery process that would be addressed within learning environment design. There are two principles associated with content delivery that are known to increase learning transfer. These include (1) modularized delivery and (2) varying the representation method or modality (Kirwan, 2009, p. 156).

2.6 Interactions

While the person, content, and context are important to consider on their own, it is also critical to emphasize the interactions occurring between them. That is, there is a person interacting with the content via an interface tool in a context. In this case, a learner interacts with the SE languages and engineering case study material in a learning environment. These human-computer interactions are not being considered at an interface ("at-the-screen") level but at a UX and IA level ("beyond-the-screen"). At-the-screen considerations include traditional user interface (UI) design such as considering what elements should be present and how they should be placed in order to support the users in accurately performing the tasks they intend to perform. In contrast, beyond-the-screen factors include the information structure of the content, labeling of the material, the sequence and modality of content delivery, and the mechanisms through which the user can interact with the material (i.e., navigation, searching, etc.).

This section will emphasize relevant theories, effects, and potential UX design solutions that are strongly characterized by an interaction between the user, content, and context factors. First, cognitive flexibility theory is a theory of how the interconnected, complex content will influence user learning and will inform elements of the IA design of the learning environment. Then, cognitive load theory will be described, a cognitive theory pertaining to human limitations applied to content in a delivery context. Cognitive load theory will also inform the IA design. The expertise-reversal effect can be characterized as an interaction between the user and the scaffolding designed into the learning environment. Finally, dynamic user experiences are described as a design approach to address conflicting user needs when it comes to learning environment design and will ultimately inform the UX design.

2.6.1 Cognitive Flexibility Theory

Cognitive Flexibility Theory (CFT) is an instructional theory that emphasizes learning of information in the context of complex, highly interconnected (or poorly structured) domains (Spiro et al., 1988). CFT was developed, in part, to challenge learners' underlying worldviews and assumptions of simplicity that lead to epistemological beliefs in right answers, compartmentalized knowledge structures, and knowledge that exists only in the abstract (Spiro et al., 2003).

CFT was developed as an alternative to schema theory, which asserted that knowledge in the human mind is organized in rigid packets called schemata (Spiro et al., 2003). These schemata were connected through associative links and can be constructed and modified through the processes of assimilation and accommodation, respectively. However, CFT presents a more flexible and open model of knowledge structures in the mind.

The core of CFT is the concept that transferable learning should not occur from only a single perspective. Instead, the "crisscrossing" of an information landscape, exploring it from multiple different angles, is critical to developing a rich, holistic understanding of the content (Jacobson & Spiro, 1995; Niederhauser et al., 2000). CFT heavily emphasizes the importance of providing multiple representations of information from different perspectives, highlighting the interconnectedness of the knowledge rather than separating it into "separate mental compartments" (Spiro et al., 2003, p. 7), and stressing the broader application of concepts in a wide range of contexts. Similarly to schema theory, CFT emphasizes the role of active learning as fundamental to enhancing learner outcomes (Niederhauser et al., 2000). CFT is often discussed alongside non-sequential information structures (or hypermedia environments) due to their inherent support for repeated traversals of an information landscape from a variety of different perspectives. As such, CFT applies more heavily to a discussion of beyond-the-screen factors than it provides recommendations for at-the-screen design by focusing on the design of the learning task and the functionality of the technology being utilized.

2.6.2 Cognitive Load Theory

Cognitive Load Theory (CLT) is a cognitive theory about learning that emphasizes that the human mind can only attend to so many different demands at one time. CLT describes three types of cognitive load that increase the demand on working memory: intrinsic, extraneous, and germane (Anmarkrud et al., 2019; de Jong, 2009), as shown in Table 4. Intrinsic cognitive load relates to the inherent characteristics (difficulty and complexity) of a given learning task. The level of intrinsic cognitive load associated with a task cannot be reduced by different instructional approaches and is thus related primarily to the content itself, not its presentation (de Jong, 2009). On the other hand, extraneous cognitive load is caused by the presentation of the instructional material and could be reduced through design interventions. Extraneous load may be influenced by a number of factors, including a lack of prior knowledge, the use of only one sensory modality for content presentation (modality principle), the need for learners to coordinate the same information from multiple information sources (redundancy principle), and disorientation in the information space. Finally, germane cognitive load refers to the load that is caused by the construction of schemas and associated processes as a part of learning.

Table 4: Types of cognitive loads considered in CLT

Type of Cognitive Load	Source	Can it be reduced?
Intrinsic cognitive load	The inherent difficulty and complexity of a task	Not for the same task
Extraneous cognitive load	Material presentation	Yes, through design interventions
Germane cognitive load	Constructing new knowledge structures	Not without negatively influencing learning outcomes

A cornerstone of CLT is the concept that working memory capacity is limited. Cognitive overload occurs when the cumulative cognitive load (intrinsic, extrinsic, and germane) exceeds working memory capacity. This overload impedes learning-related cognitive processing and can result in learner confusion and, ultimately, frustration. Therefore, designers often take steps to mitigate extraneous cognitive load through design interventions, as this is the type of cognitive load that can be reduced through design without negatively influencing learning outcomes. Though this theory can be applied to at-the-screen elements of UI design through limiting the number of elements on one page or otherwise visually designing more important elements to be more likely to draw user attention, this is not the focus of this thesis. Instead, beyond-the-screen interventions at the level of the content design, structuring, and navigation mechanisms are the emphasis.

2.6.3 The Expertise-Reversal Effect

Before discussing the expertise-reversal effect, it is important to understand the difference between knowledge and expertise in a domain. Knowledge can be defined as the combination of content (information) and structure in order to organize information. Expertise, in contrast, is the ability to apply knowledge to a variety of different contexts. Thus, an individual cannot be a domain expert without a high level of domain knowledge but can have a high level of domain knowledge without being an expert. This definition of expertise most aligns with the subject-matter dimension of expertise described in Garrett et al. (2009)

Many learner individual differences influence the learning process and performance in learning-related tasks, but level of prior domain knowledge is one of the most critical characteristics (Kalyuga, 2007). Novices are learners who have a low level of prior domain knowledge or expertise and lack pre-existing knowledge structures that relate to the content being presented. When domain novices encounter new information, it must be processed in working memory, which has a limited capacity (Kalyuga et al., 2003). In contrast, experts are those who do have high domain knowledge and expertise and do have existing knowledge structures in long-term memory that can be accessed to inform their understanding of the material. Once knowledge structures have been repeatedly accessed through practice (which develops expertise), the “cognitive cost” of processing that information again is lower, which reduces the load on working memory.

This accounts for why learning environment designs that may be appropriate for experts are often inappropriate for novices. Critically, this effect does not only apply unidirectionally. The instructional interventions that are necessary for novices to effectively engage in learning can actually impede the performance of knowledgeable or expert users (Kalyuga, 2007; Kalyuga et al., 2003). This phenomenon is known as the expertise-reversal effect. The expertise-reversal effect can be observed in a number of contexts where a learning environment has been designed to reduce novice cognitive load.

For example, novices often benefit from direct instructional guidance (scaffolding), but more experienced learners may experience negative consequences related to having to cross-reference and integrate the redundant information components in the instructional guidance and their existing knowledge structures (Kalyuga et al., 2003). Similarly, though novices benefit from redundant textual information integrated into diagrams, more experienced learners performed better and reported lower mental load when the redundant text was eliminated (Kalyuga et al., 1998). The detrimental effect of supplemental text has been replicated in several other settings as well (McNamara et al., 1996; Yeung et al., 1998).

The needs of these two populations are clearly not conducive to a single, one-size-fits-all design solution. However, instructional designers frequently are encouraged to design the learning environments to address the cognitive load limitations of novices, effectively emphasizing strategies that are only beneficial for learners with limited domain experience (de Jong, 2009). One of the benefits of computer-based learning environments is their unique capacity to adapt, thus providing an opportunity to design for learners at multiple levels of knowledge or expertise.

2.6.4 Dynamic User Experiences: Adaptable and Adaptive Interfaces

The wide range of potential users with a distribution of different characteristics that lend themselves to potentially different (and sometimes conflicting) instructional approaches highlights the value of a dynamic user experience. Dynamic user experiences consist of an adaptation behavior that is triggered in response to user characteristics or preferences. The impact of the expertise-reversal effect clearly refutes the assumption that there is a single one-size-fits-all ideal design. Such designs are often based on the average user, an approach that is frequently deeply flawed and can result in a design that is ineffective for all users. Unlike other design solutions, computer interfaces can examine user behavior and adapt to align with users' needs or preferences (Benyon, 1993).

Two types of interfaces perform this dynamic behavior: adaptable and adaptive interfaces. Although the term "interface" is being used (and is standard in the literature), adaptable and adaptive systems can influence more than the "at-the-screen" user interface. These interfaces can be designed to provide a dynamic user experience where adaptation behavior may include changes to the primary navigation mechanism, information presentation modalities, or information sequence. Adaptable systems allow the user to alter system settings and parameters and adjust accordingly (Opperman et al., 1997). In adaptable interfaces, the locus of control for the adaptation lies with the human. Customization is the process of interacting with an adaptable interface, which may occur in the form of dynamic behavior that the user either requests themselves or agrees to on prompting from the system (Benyon et al., 1987). In contrast, adaptive interfaces automatically adjust to users based on inferences made about user goals, needs, or characteristics, often based on observed behavior (Opperman et al., 1997). As such, in adaptive interfaces, the locus of control for the adaption behavior is placed on the system rather than the human. Personalization refers to the implementation process of these algorithmically-driven changes, often informed by machine learning algorithms.

Technology adaptation behavior (both adaptive and adaptable behaviors) may impact a system's performance or presentation at multiple grain sizes (temporally and hierarchically) and for different purposes (Benyon et al., 1987). The adaptation mechanism can influence elements both at the "at-the-screen" and "beyond-the-screen" levels. Changes that are simply aesthetic without influencing the digital environment's functionality or organization are examples of "at-the-screen" adaption behaviors. However, if the adaptation behavior influences the functionality or the presented information structure, it is influencing "beyond-the-screen" factors and represents a UX consideration. For example, adaptive information presentation may impact what or how much content is shown to the user (Wilson & Scott, 2017). Adaptive navigation support may hide, annotate, highlight, or organize information differently depending on user characteristics, which can dramatically change how the user interacts with the interface.

Adaptive and adaptable interfaces have a history of being applied to learning environments and guiding adaptation based on the learner characteristics and individual differences. Adaptive educational mechanisms can include consideration for a number of these, including intellectual ability, learning styles, cognitive styles, personality, achievement motivation, prior knowledge, and self-efficacy (Nakic et al., 2015; Park & Lee, 2004), though the emphasis on any of these varies in intensity. Learning styles are the most popular variable to consider in relation to an adaptive educational system, according to a 2015 literature review (Nakic et al., 2015). This is to be expected, as learning styles make a great deal of sense as an adaptation variable in the context of an educational system, and it is only logical to adapt the information presentation based on how the student best learns. Other prevalent individual differences to consider included cognitive styles, prior knowledge, learner motivation, and display style preferences.

Although early discussions of adaptable versus adaptive interfaces considered a continuum such as that shown in Figure 7 (Opperman et al., 1997), many (though not all) more recent articles seem to primarily consider these terms to be more similar to binary classifiers. Many of the spectrums that are discussed (Gullà et al., 2015; Opperman et al., 1997) do not seem to be fully inclusive of all reasonable configurations, so consideration to further expansion of the continuum may prove useful. This applies to customization versus personalization as well. There are valid interface configurations where the function allocation of the adaption behavior is not “the human does it all” or “the machine does it all.” It may be worth considering a taxonomy similar to that of Sheridan’s levels of automation (Sheridan, 1992), which would present more of a continuum on which to consider this function allocation. The individual differences identified above as potential adaptation variables are likely more at home in the middle of this spectrum. It is usually considered good practice to provide the user with some control over the adaptation (Gullà et al., 2015).

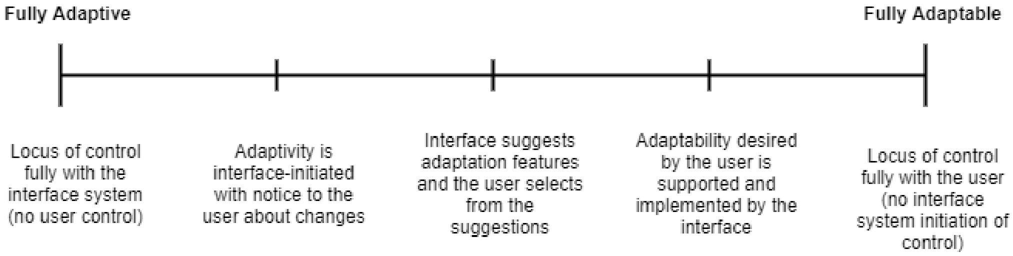

Figure 7: The adaptive-adaptable continuum. Image adapted from Opperman et al. (1997)

These spectrums are only further confounded by the addition of temporal grain sizes to some definitions of adaptable versus adaptive, wherein adaptive interfaces are considered to be those that can change over the course of a session. In contrast, adaptable interfaces make changes based on assumed constants. Contrary to the original definition of a function allocation-based taxonomy, this would create a classification system based primarily on the adaptation variable's nature (whether it is dynamic or assumed constant). As such, this temporal consideration of adaptable and adaptive interfaces will not be considered.

2.7 Information and Computer Technology

Information and computer technology (ICT) has become an integral part of most learning environments, regardless of their position on the spatial-temporal continuum. However, ICT is even more critical in asynchronous and distributed configurations, as all information exchange occurs via communication channel technology. Information architecture design governs the organization and labeling of content within the ICT interface, as well as the navigation and searching functions that users utilize to move through the content.

First, background is provided on information architectures, and their traditional structure is described in detail. Finally, a specific form of organization called non-sequential information structures (NSISs) are defined, their benefits and challenges identified, and the limitations of the literature on such environments are discussed.

2.7.1 Background on Information Architectures

Information architecture (IA) as a field focuses on designing solutions to the problems associated with finding, accessing, and using information. The term IA is also used to refer to a design product describing the organization, navigation, labeling, and search features associated with a particular tool. When it comes to considering IA, it is essential to understand that information environments can be configured to optimize findability and understandability (Rosenfeld et al., 2015, p. 1), which proves to be as much an art as a science. The design of an IA should be informed by the content within the information space, the users that need to access that information, and the context that drives users’ information needs. IAs generally emphasize solving information access problems and mitigating information overload to support task performance

(Rosenfeld et al., 2015, pp. 10-12). First, however, having a clear idea of what information architectures are and where they can be found is important.

The organization of information has long been a challenge for humanity, though the dynamics around accessibility and the locus of power to organize the information have shifted dramatically. Prior to the invention and widespread adoption of the World Wide Web, the most obvious examples of IAs are libraries (Caldwell, 2020a): institutions that collected information (in the form of written books) and organized it according to a taxonomy (i.e., Dewey Decimal System, Library of Congress) that supported findability. This aligns with the definition of an IA. However, due to the physical form associated with this information, it was only available to access in-person, which limited the information's accessibility to those who had the means to travel to the library, were literate, and depending on the time period, other physical, social, or economic individual factors. When it came to the organization of these information spaces, the locus of control was firmly out of the hands of members of the general public.

2.7.2 Traditional IA Structure

First, the general structure of an IA will be described; this consists of four key systems: organization, labeling, navigation, and searching (Rosenfeld et al., 2015, pp. 82-83). Organization structures present information to the users, while navigation mechanisms support the users in maneuvering through the content to find relevant information. Search functionality provides users with a means to search through the content, often using keywords to generate a selection of possibly relevant content. Finally, labeling frameworks refer to the meaningful taxonomies that allow users to identify important information. Designers can approach creating an IA from the top-down (consider prospective users' questions and structure the content to answer them) or bottom-up (consider the structure of the content first and then provide context to address questions).

Information Structures. Information structures (or organization systems in the literature) come with a few critical considerations and challenges. One of the most important of these challenges is the heterogeneity-homogeneity of the content. For more homogeneous content, a highly structured information structure may provide an effective solution. However, with highly heterogeneous content (most digital content), it is crucial to move away from a single, highly structured organization approach (Rosenfeld et al., 2015). There are a number of ways to organize information, some exact (i.e., alphabetical) and some more ambiguous (i.e., topical). Ambiguous organization schemes are challenging to design and maintain and can be challenging to use. However, they are often more useful and important to the users performing tasks than exact organization schemes. This raises one of the significant challenges of information structures: they have an inherent level of ambiguity in that a term may mean two completely different things to two different people, or even just in two different contexts (Rosenfeld et al., 2015). Hierarchical information structures are often critical elements of the overall organization scheme, as they are relatively familiar to most users. Items within a hierarchy should be primarily (but not entirely) categorized into mutually exclusive elements, and there should be a balance between the breadth and depth of the content. It is also important to recognize where hierarchies may not be ideal: database structures function well for relatively homogeneous sub-elements, and non-hierarchical and heterogeneous information structures provide a non-sequential means of linking information. These non-sequential information structures will be further discussed later. A good information structure consists of a hybrid of all of these. When considering design for understandability, it is critical to incorporate a consistent design and structure so that users know that they are on the same website and roughly where they are within it. For example, headings and overviews are known to support text comprehension, particularly for long or complex text passages (Potelle & Rouet, 2003), and should be used to support user understanding.

Labeling frameworks. Labeling frameworks differ from information structures in that information structures group content, and labeling frameworks apply a name (i.e., a label) to the content (Rosenfeld et al., 2015). Labels should be designed with the users of the system (not the designers) in mind, using language that is familiar to them. Though iconic labels can be utilized in some situations, textual labels are significantly more common because they more directly support user understanding of the label's meaning. Labeling frameworks should emphasize consistent style, presentation, syntax, granularity, comprehensiveness, and audience. Labeling frameworks for new information spaces can be created through content analysis or by consulting with content authors, other subject-matter experts, or the users themselves.

Navigation mechanisms. Navigation mechanisms allow the user to move through the information environment that can be defined at several levels. Global navigation structures are present throughout the entire environment, with local navigation structures only present in their relevant sub-modules (Rosenfeld et al., 2015). Contextual navigation mechanisms, especially in the form of hypertext, offer an alternative means of moving through the digital environment. However, these can become problematic if they are critical to the content, since it has been shown that users often ignore them (Rosenfeld et al., 2015, p. 189). Additional supplemental navigation mechanisms include sitemaps, indexes, and guides, which can provide users with useful information and navigation pathways outside of the global, local, and contextual navigation mechanisms.

Searching functions. One of the most critical considerations of searching mechanisms is whether the IA truly needs one (Rosenfeld et al., 2015). The answer to this question depends on the amount of content, the usefulness of other navigation mechanisms, and user preferences. Searching can be an incredibly powerful tool for navigating large information spaces, both to optimize directed searches for specific information and to meet user expectations. However, it is poor practice for a designer to overwhelm users with too many results from the full information space. When a search mechanism is important to meeting information needs, designers may include specific search zones to narrow the amount of content being searched by the algorithm and provide users with the most relevant results for their search need. Additionally, it is essential to choose what to index (make searchable) from the information environment; this will vary based on the users' information needs.

Finally, elements such as metadata, controlled vocabularies, and thesauri are increasingly becoming critical elements of good information architectures. Metadata is the data about the content itself – this might include the type of file, publication date, author, and other relevant information (Rosenfeld et al., 2015, p. 270). This can enhance navigation and retrieval of information and be particularly useful in searching functions. A controlled vocabulary is a subset of natural language that refers to a list of equivalent or preferred terms for use within the IA (Rosenfeld et al., 2015, p. 271). Controlled vocabularies can be useful when it comes to defining relationships between terms or concepts and narrowing the possible search terms. Like labels, controlled vocabularies should consist of terminology that the user base is familiar with. In this context, a thesaurus is a special case of a controlled vocabulary where equivalence, associative, and hierarchical relationships between terms are identified to improve indexing and searching behaviors (Rosenfeld et al., 2015, p. 282).

2.7.3 Non-Sequential Information Structures (NSISs)

The terms multimedia, hypertext, and hypermedia have been attributed to a number of sometimes conflicting definitions throughout the literature. Therefore, establishing clear and explicit definitions of these terms is critical to a shared understanding.

Multimedia is any piece of media that offers information presented over multiple formats. Specifically, multimedia tends to include both verbal and pictorial content. Verbal content here may refer to either the written or spoken word, and pictorial content may be static or dynamic representations. The information conveyed by multimedia may also span multiple modalities, usually visual and audio. However, this is not strictly a requirement. For example, the combination of text and a silent animation would be considered as multimedia even though it only engages the visual modality.

Hypertext can be defined as a computer-based means of presenting textual information in a non-sequential network structure that emphasizes the association between topics. The nodes in the network structure represent the textual segments, and the links represent a semantic relationship between the nodes, as shown in Figure 8. Hypertext environments are generally considered to contain information only in the form of text, though some will argue that the term also encompasses static images and diagrams (Tolhurst, 1995). Hypermedia can be considered as a marriage of hypertext and multimedia. Hypermedia makes use of the same non-sequential network structure as hypertext, allowing users to control the sequence of the information being presented. At the same time, hypermedia emphasizes the incorporation of information presented in multiple modalities (i.e., audio, video, animation).

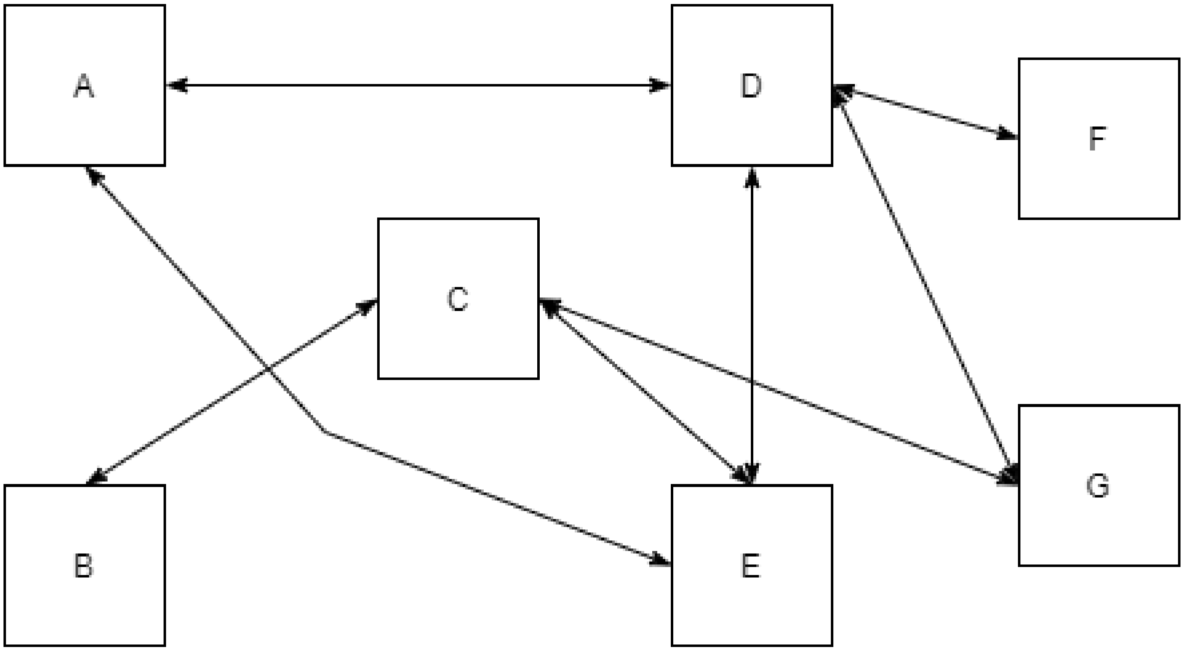

Figure 8: Example of a hypertext of NSIS network structure. Unique content files are represented by boxes containing letters to differentiate them. Image adapted from Rosenfeld et al. (2015).

It is clear that different considerations need to be made in hypermedia environments compared to hypertext environments. The inclusion and emphasis of the time dimension as a variable of interest highlights this need. However, in many cases, when describing the dynamics of the non-sequential environment and its organization independent of the type of content it presents, it is useful to have an umbrella term to apply to hypertext and hypermedia environments. Therefore, a non-sequential information structure (NSIS) is a computer-based presentation of information through a network of interrelated information nodes.

Benefits and Challenges

The prospective benefits and observed challenges of utilizing NSISs are often directly related. That is, the same underlying characteristics that evoke the benefit are also responsible for the drawback if implemented inappropriately. These benefits and challenges are listed in Table 5 and further described below. Additionally, the benefits and drawbacks associated with two specific user characteristics (prior domain knowledge/expertise and self-regulation) will be discussed.

Table 5: Benefits and challenges of utilizing NSISs

Benefits	**Challenges**
Mimicking of associative linking within knowledge structures in the brain	Cognitive overload
High learner control	Disorientation
Diversity of options to appeal to a range of interests	Distraction

One of the primary initial motivations behind implementing NSIS systems in educational resources was the way the associative links mimicked the way that schema theory described human knowledge organization (Lawless & Brown, 1997). The emergence of CFT (Cognitive Flexibility Theory) only further serves to highlight the potential of NSISs in learning. CFT emphasizes that the ability to explore an information space from multiple different perspectives will result in a richer, more holistic understanding (Niederhauser et al., 2000). The non-sequential nature of these environments facilitates this exploration, allowing users to move through the information landscape from several different entry points and highlighting connections between content.

Multi-point access and navigation of an information landscape can be helpful for some learning tasks but can also contribute to cognitive load. A higher cognitive load is not inherently problematic (low levels of cognitive load can result in a lack of engagement with the material), but cognitive loads that are too high result in cognitive overload, as discussed in relation to CLT (Cognitive Load Theory). Cognitive overload occurs when the cognitive demand on a learner is greater than the capacity of their working memory, ultimately resulting in impaired performance. NSISs are frequently cognitively demanding in a way that linear information presentation is not, demanding higher degrees of self-regulated learning (including self-monitoring of goals, navigation decisions, and orientation) from the learner. The load placed on the learner can be characterized as either germane (associated with learning) or extraneous (caused by design flaws) depending on the current learning goal. For example, if a learner is simply trying to understand the material at a surface level, the load imposed by an NSIS might be considered extraneous. However, if the learner's goal is to understand how different topics in a domain connect to one another, then the NSIS may impose a germane cognitive load that is critical to learner success.

Another major benefit of hyperspace navigation mechanisms is the high degree of learner control (Lawless & Brown, 1997). Learner control refers to the degree of control learners have to alter multiple representations within an environment and have multiple means of interacting with the representations. These may include deciding the order in which they access information, what content they access, how content should be displayed (i.e., audio-visually, textually, pictorially), and the pacing of the information presentation (Scheiter & Gerjets, 2007). Higher degrees of learner control are generally linked to positive outcomes such as increased motivation, engagement, and positive attitudes, as well as a decreased anxiety level (Yildirim et al., 2001). Among these outcomes, higher engagement especially is shown to relate to greater ability to determine the relevance of information, integrate new information into existing knowledge structures, and self-monitor comprehension of the content (Nolen, 1988).

While high learner control has benefits for some learners in some contexts, learners with low domain knowledge especially may be ill-equipped to handle the complete removal of the directed, scaffolded instructional design that permeates traditional instructional approaches. Disorientation in NSISs occurs when learners are not able to construct a mental map of the information space, including where they currently are, where they came from, and how to get to some other node within the network (Müller-Kalthoff & Möller, 2006). Disorientation may lead to declines in performance, especially when learners need to make navigation decisions, and to users missing information that they did not realize was within the information space or relevant to them (McDonald & Stevenson, 1998). However, disorientation can also increase extraneous cognitive load and contribute to cognitive overload (Amadieu et al., 2009), as the user must expend effort to try to (re)orient themselves. The phenomenon of disorientation is common within NSISs,[2] and its impact on domain novices especially should be considered during IA design.

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[2] Anecdotal evidence may suggest that disorientation may occur in a broad range of undirected, unscaffolded instructional environments, particularly in cases where the interface is unfamiliar, even if the user is "experienced" as a learner (upper-level undergraduate) though not in the specific domain of the content. The cognitive mechanisms and details of this disorientation are beyond the scope of this thesis.

NSISs provide learners with additional flexibility to explore an information space according to their interests (Scheiter & Gerjets, 2007). Allowing learners to explore information related to their personal interests boosts engagement and motivation, similarly to higher learning control. This approach may also allow learners to see the applicability of what they are learning to their own lives and careers. On the other hand, the flexibility afforded by NSISs can result in user distraction. Distraction can occur due to the learner either getting caught up in the features of the NSIS environment itself (Lawless & Brown, 1997) or as a result of encountering information that piques learner interest but is not relevant to the current learning task (Scheiter & Gerjets, 2007). Though providing information relevant to interests can be a benefit, it can also result in learners failing to engage with other information that may be critical for their understanding. There may be a higher risk for distraction if it is difficult for the learner to discriminate important information from supporting, less critical information, either due to content design or learner-based metacognitive challenges.

The challenges and benefits described above do not impact all learners equally. Several individual differences impact the severity of the challenges associated with NSISs. These include level of prior knowledge, self-regulatory skills, cognitive styles, and attitudes toward learning (Scheiter & Gerjets, 2007). In particular, those with high prior knowledge and high self-regulatory skills seem to be better equipped to handle to demands of NSISs.

Domain experts are able to mitigate their cognitive load by relying on knowledge structures from long-term memory rather than information that only exists in working memory. They are also less likely to become “lost” in an information space and are more likely to reap the prospective benefits of high learner control (Lawless & Brown, 1997). Navigational aids, such as hierarchical maps, content maps, graphical overviews, and alphabetical indices, can support these users in orienting themselves within hyperspace, identifying important information, and accessing it (Bezdan et al., 2013; Müller-Kalthoff & Möller, 2006; Puntambekar & Goldstein, 2007; Vörös et al., 2011). However, graphical overviews that are too complex may not be ideal, though other navigation support may be highly beneficial (DeStefano & LeFevre, 2007). Additionally, when it comes to the organization of the material, it is commonly found that a more restricted information space or hierarchical structuring can be beneficial to those with low prior knowledge (Shin et al., 1994). Critically, it is worth noting that these interventions, particularly the hierarchical content structure, that are critical for novices, can actually be detrimental for experts, as noted by the expertise-reversal effect.

Self-regulation, or an individual's ability to self-monitor and manage behaviors or emotions, also impacts the probability of disorientation. However, self-regulation is often discussed as imposing an additional cognitive load on an existing task, so even a learner who has extensive self-regulation skills may struggle in cases where the intrinsic load is high. Relatively few studies have emphasized self-regulatory skills (Scheiter & Gerjets, 2007), but there is evidence that a learner's level of self-regulation influences how they react to differences in locus of control (Young, 1996). There is a greater performance disparity between users with low and high levels of self-regulation in a learner-controlled environment than in a program-controlled environment. There are design interventions that can support self-regulation, primarily self-regulation prompts within the hyperspace environment itself that encourages learners to effectively regulate their cognitive, metacognitive, motivational, and behavioral processes in order to learn (Bannert & Reimann, 2012; Müller & Seufert, 2018). These, too, are subject to the expertise-reversal effect, so configuring these prompts as adaptive scaffolds would support the evolution of student learning.

Literature Limitations

There are some critical limitations of the general NSIS literature that should be acknowledged here. Even early in the NSIS literature, Chen & Rada (1996) identified that many of the experiments occurring within the research field varied drastically in terms of experimental design and the particular NSIS being used. This made it difficult to compare results across studies or accurately see emerging patterns. A more recent literature review identified small sample sizes, confounded experimental variables, and a lack of consideration of individual differences and their role in the experience of NSISs as some major limitations affecting reported findings (Scheiter & Gerjets, 2007). One of the frequently used measures to measure cognitive load in educational science (including within the NSIS literature) is a one-item self-report measure developed by Paas et al. (1992). This measure has garnered some criticism because the scale (1) measures cognitive load unidimensionally rather than considering extrinsic, intrinsic, and germane cognitive load separately, (2) relies on participants to be able to estimate their cognitive load accurately, and (3) has inconsistent and poor anchoring (de Jong, 2009).

In some experiments regarding NSISs, it is unclear whether the results are due to the hyperspatial navigation style or more specific information presentation issues. For example, Niederhauser et al. (2000) provided an NSIS environment meant to teach participants two distinct cognitive science models of how people learn. The information associated with this was broken up into parallel segments with identical sub-headings under the hierarchical structures of the two models. The NSIS element was a compare and contrast feature that allowed participants to navigate from a given subtopic (i.e., view of knowledge) in the branch of one model to the parallel subtopic in the branch of the other model. The study concluded that this feature impeded learning. However, it is not clear whether the impediment was due to the compare and contrast tool's NSIS nature or simply due to poor implementation of such a tool. This information may have been more clearly presented in a table that allowed for direct comparison between the two approaches, rather than requiring navigation between two different pages that increased the load on working memory to retain the content from the separate screen.

Finally, most studies within the educational NSIS domain emphasize a highly time-constrained context for interacting with the hyperspace environment. While this may make sense in terms of experimental design and control, this represents a rather severe lack of fidelity to a real-world educational context, especially in higher education. It may not be reasonable to assume learners would have to explore an NSIS environment for the first time in an extremely short period of time and immediately show learning outcomes. Experimental designs may also account for some of the high levels of cognitive load associated with NSIS-related tasks. Under self-paced conditions and with the availability of outside resources to mitigate cognitive load (such as the ability to take notes), outcomes may be dramatically different. Further investigation into these higher-fidelity contexts would reveal how learners interact with NSISs "in the wild."

2.8 Summary

There are a variety of factors that should be considered in the design approach to an online, asynchronous learning environment for a systems engineering course. Different design models emphasize different factors, but there is a consistent underlying focus on the user (the learner), the tasks they may need to perform (learning and information-seeking tasks), the content being presented, and the learning environment context and ICT. In addition, interactions between these factors must also be considered.

A range of individual differences that relate to learning outcomes were described. However, only a subset of those identified are relevant to the design of the PoSE learning environment. These include preferences for instructional presentation (FSLSM learning styles), self-regulation skills, levels of prior knowledge, objective-related priorities, and access to appropriate bandwidth. These individual differences will be emphasized throughout the IA and UX case design.

In some cases, learner characteristics create conflicting design needs. For example, the expertise-reversal effect highlights the conditions under which the interventions that subject-matter novices need can be detrimental to learners with a higher level of prior domain knowledge. The opposite may also be true: design decisions that are helpful for more experienced users may impair learning for novices. That is, the appropriate level of scaffolding is not constant across a learner-base with a distribution of prior domain knowledge. Similarly, instructional approach preference varies across learners, and a single instructional delivery approach along any of the four dimensions will fail to consider some learners. (Visual-verbal information presentation and sequential-global understanding are particularly relevant to PoSE.) One potential solution to these instances of conflicting learner needs is to utilize dynamic user experiences to transcend a "one-size-fits-all" design approach. This can be done through either adaptable (locus of control with the user) or adaptive (locus of control with the ICT automation) interfaces.

Self-regulation relates to a learner's ability to adapt and learn effectively in a self-directed (rather than instructor-directed) learning environment. Self-directed learning is a major characteristic of online learning environments. Other factors to consider in online environments include the nature of asynchronous communication and information availability across communication media.

Both prior knowledge and self-regulation skills are important to consider in the IA design of information structures and navigation mechanisms. NSISs have benefits to learners, including emphasizing connections within complex material, providing higher learner control, and allowing learners to explore their interests. However, challenges include cognitive overload, disorientation, and distraction. These benefits and challenges affect different types of learners to differing degrees. Specifically, learners with high prior domain knowledge or self-regulation skills are more likely to experience the benefits and less likely to experience the challenges in an NSIS environment compared to other types of learners. This is particularly critical to keep in mind for the PoSE course context.

The delivery of the content is also relevant to learner outcomes. For example, learners experience more knowledge transfer when the content is modularized and when the representation modality varies. Universal design considerations also provide recommendations regarding content delivery design, as well as out-of-scope considerations like learner-instructor interactions, content design, and course culture development. These principles will be further analyzed and considered in the next chapter.

3. METHODOLOGY (IA / UX DESIGN SPACE)

3.1 Introduction

This thesis emphasizes a case design approach to developing an online, asynchronous educational environment with the goal of supporting a variety of traditional and non-traditional learners with varied backgrounds, learning goals, and needs in learning highly interdisciplinary material. The case design considers the case of a graduate-level systems engineering course (PoSE). The scope of the case design is limited to understanding the characteristics, needs, and tasks of the users, information architecture (IA) design, and user experience (UX) design. This scope does not extend to the "at-the-screen" user interface (UI) design or the implementation or evaluation of the UX or UI designs.

Several approaches were utilized to define the required features and functions associated with the IA and UX design of the PoSE learning environment. This will follow the organization of content-person-task-context because, in this case, it is critical to understand the initial content before the personal factors are discussed. First, the initial state of available PoSE material was reviewed to establish the content available for use in the case design. Principles were extracted from the universal design literature connected to the content design associated with initial materials and the requirements for the learning environment design. Then, a task analysis was performed on the learner tasks associated with the PoSE content. The learning environment should support the completion of both learning tasks and information-seeking tasks in order to successfully facilitate the activities that learners need to complete in order to accomplish their individual goals, both within and beyond the boundaries of the PoSE course. Finally, the design tasks that must be performed (in part on the content) in order to describe a prototype learning environment for PoSE include the development of user personae, lecture captioning, IA design, and UX design. The full extent of these tasks will be expanded on later in this chapter.

3.2 Initial State of PoSE Material

Prior to addressing the methods applied to design the IA and UX of the PoSE learning environment, the existing material available for use should be described. The initial state of the material for the PoSE course is based on a synchronous, hybrid delivery model with both co-located and distributed cohorts. The cohorts were made up of traditional residential students (both graduate and undergraduate) and working professionals. The material available included paragraph-style and slide-style lecture notes, assigned readings, and recorded lecture videos. The recorded lectures were captured both for the Fall 2017 and Fall 2019 semesters, with some variation in the coverage of material between them. These lectures used a professional-style shift between the lecturer, document camera, and computer screen but were not otherwise edited during the semester of delivery. The recordings from Fall 2017 were not captioned, but those from Fall 2019 were captioned by an automated captioning system during the Fall 2019 semester. Additionally, four case studies had already been developed for lecture presentation, some from the public domain (e.g., NASA) and others specifically developed for PoSE. These were included within the initial course design to provide learners with a way to apply their knowledge to a real-world problem context.

The scoping of the PoSE project, as described in Chapter 1 and depicted in Figure 9, is the highest level of modularization of the content: the course as taught at Purdue University can be broken into three parts. The first covers the five systems languages, the second involves applying this knowledge to engineering case studies, and the third is a group-based project (which is out of the scope of this thesis). In the original lecture presentation, one week was allocated to each of the SE languages, which allows the material to be allocated to the corresponding modules.

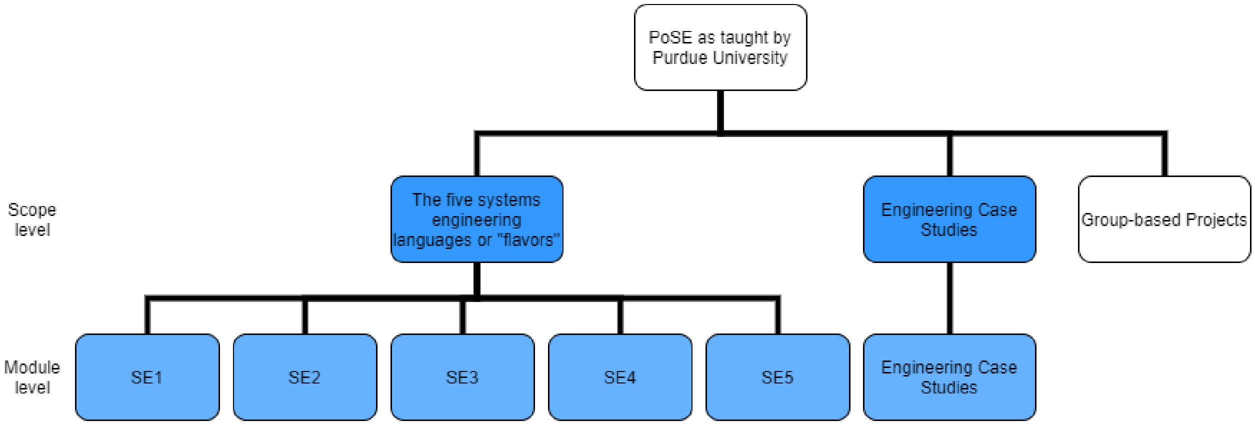


Figure 9: Scope and modules associated with the existing PoSE content

3.3 A Universal Design Perspective

User-centered design (or a design for all approach) is critical when it comes to the design of any online environment. In order to design an effective tool of any sort, the people that will be using the tool must be considered throughout the design process, both “at-the-screen” (user interface) and “beyond-the-screen” (information architecture and user experience; Caldwell & Rogers, 2000). Especially for the learner population enrolling in PoSE, there is the important consideration of a broader distribution of user types than would be expected in a more traditional, on-campus delivery of a specialty course in a single discipline. Thus, principles of universal design should be considered at every level of the design process. Though discussing the “at-the-screen” elements of the UI design is out of scope for this project, it is important to consider designing for a diverse distribution of users in the context of the IA and UX design process. Universal design offers an alternative approach to designing for the average user, resulting in design solutions that are more accessible and usable. Though initially developed as a means to support learners with disabilities, limited language fluency, or gaps in knowledge, the application of universal design in education ultimately benefits all learners (Burgstahler, 2009a; Rogers-Shaw et al., 2017). Three frameworks are associated with universal design as it applies to the education domain: Universal Design for Learning (UDL), Universal Design of Instruction (UDI), and Universal Instructional Design (UID). An analysis of the core principles associated with these frameworks is presented below.

3.3.1 Aggregated Principles for Effective Instruction

The principles of UDL, UDI, and UID discussed in Chapter 2 were applied to the context of the asynchronous, online PoSE learning environment. There was a significant overlap between the principles identified by the UDL, UDI, and UID frameworks. Therefore, those principles with the same fundamental meaning that appeared across the three frameworks were combined into one aggregated principle shown in .

Table 6 to clearly identify areas where specific aspects of universal design must be utilized. Several of these principles are addressed by the nature of the existing content itself, while others need to be addressed through the design of the learning environment context. These are the principles that are relevant to the PoSE case (and shown in italics in Table 6). Others, however, are features of the individual instructional support teams behind the course offering or need to be addressed through the development of supplemental (introductory) content. These principles will not inform the design of the learning environment. Principles within the table that fall into each of these categories will be identified below.

Table 6: Aggregated Principles from UDL, UID, and UDI approaches. The principles that are relevant to this case design are identified in italics.

Aggregated Principles	Original Principles
Principle 1: *An instructional environment should provide multiple, accessible means of representing the course information*	**UDL**: Multiple means of representation
	UDI: Utilize multiple, accessible means of content delivery
	UDI: All course materials should be accessible, engaging, and flexible
	UDI: All materials should be physically accessible and usable by all learners
	UID: Consider a distribution of learner individual differences
Principle 2: An instructional environment should provide learners with multiple means of expressing their learning	**UDL**: Multiple means of expression
	UDI: Learner progress should be regularly assessed through multiple methods of tools and should inform instruction
	UID: Provide multiple ways for learners to demonstrate their knowledge
	UID: Consider a distribution of learner individual differences
Principle 3: *An instructional environment should support multiple means of engaging learners with the material*	**UDL**: Multiple means of engagement
	UID: Consider a distribution of learner individual differences

Table 6 continued

Principle 4: *An instructional environment should provide a diverse, inclusive, welcoming climate*	**UDI**: Diverse and inclusive class climate
	UID: Create welcoming classrooms
	UID: Consider a distribution of learner individual differences
Principle 5: Instructors should encourage regular learner-instructor interaction	**UDI**: Accessible communication methods to facilitate regular, effective learner-instructor interactions
	UID: Encourage learner-instructor interaction
Principle 6: Learners should receive regular and constructive feedback on their performance	**UDI**: Provide regular and specific feedback
	UID: Provide learners with timely and constructive feedback
Principle 7: Instructors should clearly communicate their expectations to learners	**UID**: Communicate clear expectations to the learners
Principle 8: *An instructional environment should utilize natural learning supports*	**UID**: Consider and integrate the use of natural learning supports, including technology
	UID: Consider a distribution of learner individual differences
Principle 9: *Instructors should identify essential course components*	**UID**: Identify the course's essential components
Principle 10: Instructors should be flexible with accommodations that are not addressed by the instructional design	**UDI**: Plan for additional accommodations that are not met through instructional design
	UID: Consider a distribution of learner individual differences

Principle 1 relates both to the nature of the content and the learning environment. Multiple representations of course materials utilizing different modalities are a requirement of the content design (which is out of scope). However, the available existing material has already addressed this principle, as course content is presented through paragraph-style and slide-style lecture notes, assigned readings, and recorded video lectures from two different semesters. The presentation and accessibility of this content are a function of the learning environment design and are therefore highly relevant to the PoSE case design. Principles 1, 3, 4, 8, and 9 are most directly addressed with the PoSE case design emphasis of this thesis.

Principle 2 concerns the expression of learner knowledge through multiple means, essentially indicating that a variety of assessment methods should be used. This principle is associated with content design, as assessments are part of the course content. Although content design is not in scope, it is worth noting that the PoSE learning environment utilizes two different means of assessing learner knowledge: multiple-choice quizzes and free response-style case study position papers.

Principle 3 is relevant primarily to the design of the learning environment, as it emphasizes supporting multiple ways to engage with the material. This engagement might relate back to Principle 1's diverse presentation modalities or include elements such as the information structure and navigation mechanisms in the learning environment that are used to access and move between pieces of content. This principle addresses the importance of learner control, which can be associated with positive learning outcomes when provided to appropriately prepared learners (Yildirim et al., 2001).

Principle 4 recognizes the importance of diverse, inclusive, and welcoming learning environments. This principle is primarily a function of the individual instructional team supporting the PoSE learning environment. However, learning environment design decisions that consider a variety of users rather than applying a "one size fits all" design can partially address inclusivity.

Principle 5 regards the encouragement of learner-instructor interactions. This relates primarily to the instructional team responsible for the PoSE learning environment. Interaction could be encouraged within additional introductory course material, but this would consist of content design rather than learning environment design. The learning environment design can transform content in terms of structure, presentation, and interconnections, but the content generation itself is considered out of scope.

Principle 6 addresses the nature of the feedback learners should receive on their performance. This can be addressed through assessment design and learning environment design in the case of the multiple-choice quizzes to provide immediate feedback utilizing machine-grading and helpful recommendations. However, the case study position papers must be graded by an instructor, as there is nuance present that does not lend itself to machine-grading. Thus, the nature of the feedback is dependent on the individual instructional team and therefore out of the scope of the analysis.

Principle 7 describes the value of expectation clarity. The clarity regarding expectations is a function of the (additional introductory) content and the instructional team, rather than the learning environment design itself. The learning environment can offer scaffolding pertaining to the learning process but cannot address instructor expectations.

Principle 8 references the utilization of natural learning supports. This directly relates to the design of the learning environment, which should provide appropriate levels of scaffolding to support the learners.

Principle 9 states that essential course components should be identified. Similarly to principle 7, the identification of essential components is primarily a function of the content. However, there are aspects of the learning environment design (such as labels) that may serve as indicators of a topic's importance.

Principle 10, by definition, deals with flexibility regarding accommodations not addressed by the content or learning environment design. As such, this principle can only be considered in relation to the instructional team and is considered out of scope.

In summary, principles 1, 3, 4, 8, and 9 are relevant to the PoSE learning environment IA and UX design. These principles address functions that the learning environment may address, including providing multiple different content representations, multiple means of engagement with the material, an inclusive experience, appropriate levels of scaffolding, and an accurate reflection of important course components. Therefore, for the purpose of this case design, these five principles are considered to be relevant to the design process. All other principles are either primarily associated with content design (including both existing and additional content) or the instructional team responsible for the PoSE environment at any given time.

Finally, an additional outcome of the analysis described in .

Table 6 is that one original principle from the UID framework was identified as relating to six of the aggregated principles. No other original principles were associated with more than one of the aggregated principles, indicating that the repeated principle is worthy of additional attention. The principle states that a range of learner individual differences must be considered. This further emphasizes the importance of considering a variety of prospective users with different backgrounds, goals, preferences, and learning needs. One approach to establishing the diversity of the user base is through the use of user personae.

3.4 Learner Tasks within the Learning Environment

In considering learner-centered design, it is important to consider the goals of the prospective users, as well as the tasks and behaviors that stem from those goals. There are two primary goals: to learn the content and to locate (or re-locate) relevant information in the environment. This second goal may serve as a sub-goal in learning-related tasks. However, there are additional contexts outside of learning tasks in which information-seeking tasks may be performed. Therefore, in the PoSE learning environment, two primary task categories are relevant: learning tasks and information-seeking tasks. The PoSE learning environment must consider both learning and information-seeking tasks in order to facilitate and support learners in completing these tasks.

3.4.1 Learning Tasks

The design of the learning tasks themselves is drawn from the existing course material and past iterations of PoSE. However, the nature of these tasks must be defined and described in order to ensure that the design of the learning environment supports the completion of the learning tasks. These learning tasks are critical to a major goal of the PoSE course: to support the communication of SE knowledge to the learner. Learning tasks are the tasks that users perform that are related to accumulating or expressing knowledge by integrating information into the knowledge structures in the mind. Examples of learning tasks might include watching a lecture video, reading lecture notes or assigned readings, taking notes, reviewing content, and taking assessments. There are two types of learning assessments associated with the PoSE learning environment. Multiple-choice quizzes are associated with each of the SE languages, while two free-response-style case study position papers are related to the engineering case studies module. Figure 10 depicts these learning tasks and subtasks for the PoSE course in more detail in the form of a hierarchical task analysis (HTA).

Different users may have different goal motivations and needs associated with performing these learning tasks. For example, novices may emphasize simply learning the material initially, while more experienced users may initially want to learn through exploring connections amongst the material. Different motivational factors may also influence the depth of learning that is occurring. Suppose a learner is primarily preoccupied with earning a credit, for example. In that case, they may not engage with the material on the same level as if they were learning the material to apply to their current job.

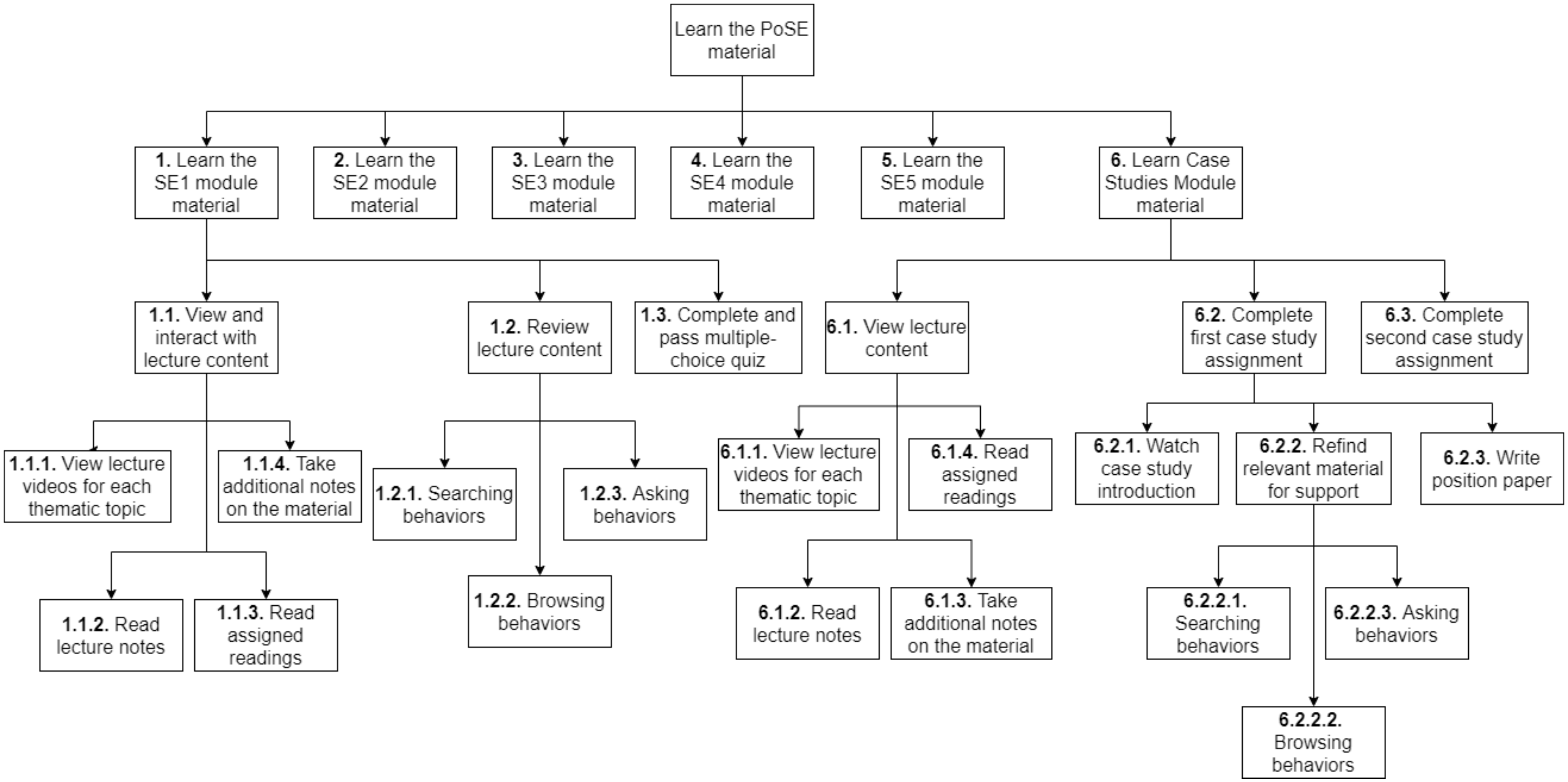


Figure 10: HTA of learning tasks within the PoSE course, as defined by the PoSE syllabus and graded exercises. Note that tasks 2-5 are accomplished identically to task 1, and so these details were omitted for readability. Similarly, task 6.3 is associated with identical subtasks as task 6.2, and so these too were omitted for the sake of readability.

3.4.2 Information-seeking tasks

Information-seeking tasks involve using strategies to find information to satisfy a need, which may vary according to the learner’s context. That is, trying to find information to utilize as support in the workplace may have different requirements and constraints compared to finding information to study for a quiz. Similarly, the information-seeking task associated with refinding material to support the completion of a case study is different from either of the aforementioned tasks. As previously mentioned, information-seeking tasks can, but do not have to be, associated with learning tasks such as reviewing material or completing assessments. Information-seeking tasks may also be related to tasks that occur outside of the scope of the course, such as those the learner performs in the workplace or as a part of their research. This variety makes it difficult to describe a single information need or behavior that is associated with these tasks, so a variety of need profiles and information-seeking behaviors will be considered.

Searching, browsing, and asking are the three major information-seeking behaviors that may be integrated or iterated upon to meet an information need (Rosenfeld et al., 2015, p. 46). Searching is the direct strategy of entering queries into a search mechanism. For example, typing “information architectures” into Google Scholar to find important IA articles is a searching behavior. In the case of PoSE, this may include searching for references to the “beer game” (for example) utilizing a search function that considers the indexed terms associated with each file in the information space. Browsing involves moving from link to link while looking for information. An example within the PoSE learning environment might be clicking through different files associated with an SE language or utilizing contextual navigation to explore more detail associated with a specific term or topic. Asking is an information search behavior that involves requesting help from another human. An example of this would be asking an organization’s librarian for support in finding information about a topic, which might be accomplished through email, chat, or another interface. In the case of PoSE, asking behaviors may include interacting with the instructional staff in order to locate information or clarify a learner’s understanding. A user might first browse an environment to explore its contents and determine whether it meets their need and then shift into a more goal-directed search pattern.

Information findability considers four distinct information need profiles, each with its own goals, conditions, and behavioral patterns: known-item, exploratory, exhaustive, and refinding

(Rosenfeld et al., 2015). Known-item seeking refers to when the user knows what they are looking for, where to find it, and what terms to use to support that process. Known-item seeking is likely to utilize searching techniques due to the sufficient background knowledge the user has pertaining to their search. In exploratory seeking, the user is not yet sure of what they are looking for and are instead engaging in browsing behavior to acquire some knowledge, usually pertaining to what they are looking for. Exhaustive research is when the user wants to consider everything available in relation to a topic. In this case, there are usually multiple ways that the user might phrase their information request, and they will likely utilize searching, browsing, and even possibly asking behaviors to support meeting their information need. Finally, refinding refers to when the user goes through the process of rediscovering a piece of information that they had previous exposure to but either forgot about or could not attend to at the time. Refinding may be accomplished through a combination of browsing, searching, and asking depending on what information the learner remembers about the context of the information they are trying to locate.

3.5 Designer Tasks

There are a number of tasks that must be completed by the course designer (in this case, the author) as a part of the IA and UX design effort. These tasks are meant to result in a design that ensures the development of a robust learning environment that considers the backgrounds, goals, and needs of a range of traditional and non-traditional learners. This process is described in the flowchart depicted in Figure 11. These tasks include the development of user personae, as previously discussed. Additionally, content modularization and captioning activities should be performed. Design decisions associated with the information structure inform the design of the supporting navigation mechanism. That is, the means of organization has a clear impact on how users can navigate through the content: a purely non-sequential (or hypertext-style) information structure is ill-suited for a highly structured, purely hierarchical navigation process. In the case of non-sequential or hybrid information structures, candidate terms for contextual navigation (or tags) must be identified. Regardless of the information structure, indexing terms should also be determined to inform the searching function. A design decision must be made regarding utilizing an adaptable (where the locus of control is with the user) or an adaptive (where the locus of control is with the automated system) interface in order to provide two distinct dynamic user experiences.

The first dynamic experience is meant to alter the information structure and primary navigation mechanism presented to the user. The second dynamic interface should alter the information presentation modality through which information is initially presented to the user.

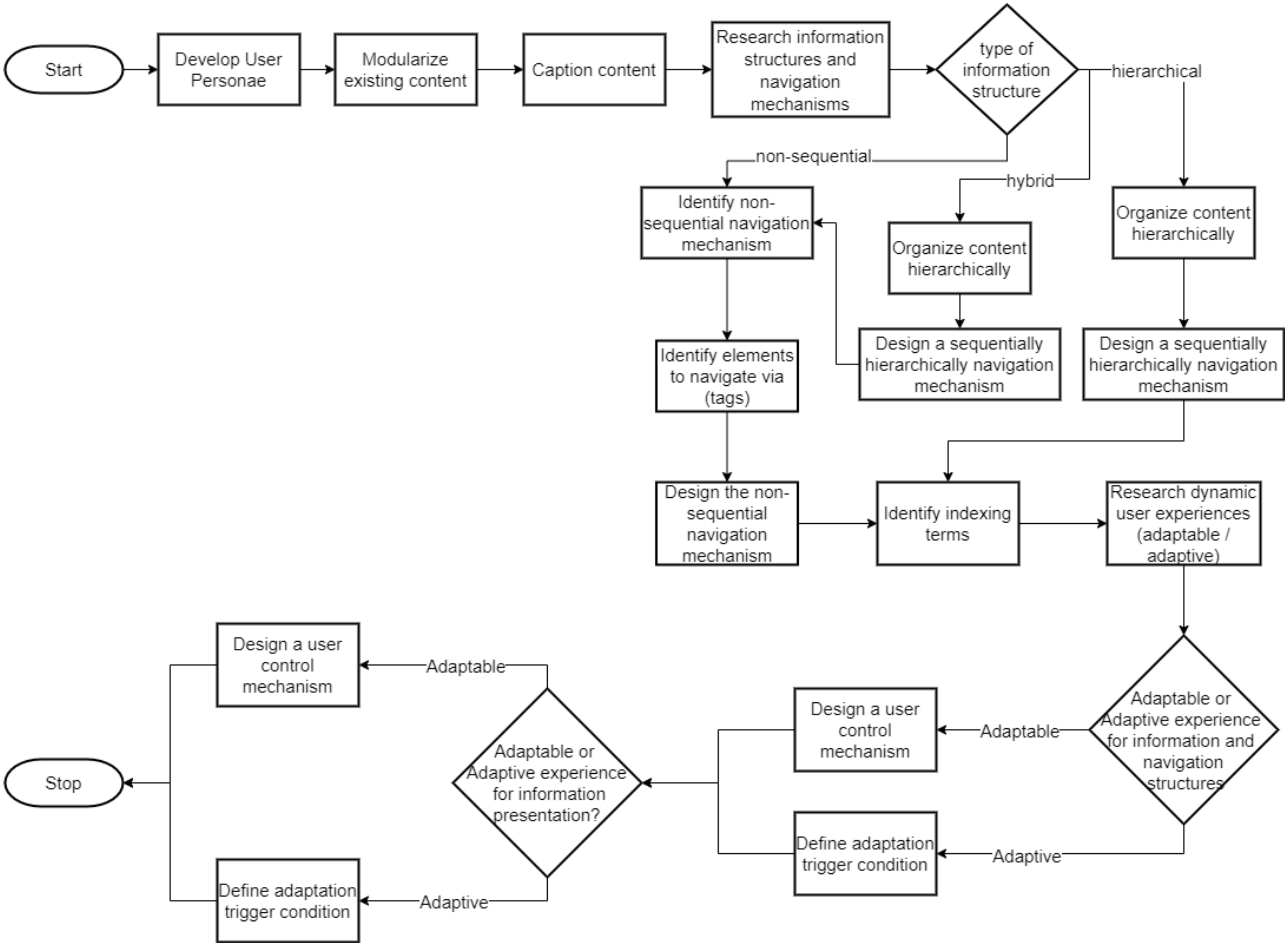


Figure 11: A flowchart of the tasks that the designer must complete in order to design the IA and UX associated with a learning environment for the PoSE course

3.5.1 Persona Development

In order to understand the needs and priorities of prospective users, it is important to identify the characteristics of those who are likely to interact with the online educational resource. Persona development is an approach where one or more fictional example users are created through user research or the experience of subject-matter experts to represent the majority of these prospective users. When more than one persona is used, each persona reflects the behaviors, skills, and attitudes of a typical user from within their sub-category. Personae support the designer(s) by providing a concrete example of a user, facilitating the prioritization of user needs, desires, and expectations throughout the design process.

For the adaptation of PoSE to a purely online, asynchronous format, overarching persona development was done through a collaborative discussion between three subject-matter experts (one of whom was the author) who were able to represent various perspectives and groups, including students, professors, and industry representatives. Three roles associated with personae were developed: the (traditional) career student, the working professional, and the senior executive. Each persona was created as an amalgam of several actual students who took PoSE in the 2017 or 2019 sessions, addressing their goals and priorities for taking the class as self-reported in a “What’s Your System” discussion board assignment. The roles were developed based on known characteristics of students enrolled in PoSE, plus additional feedback from a retired professional with a history of complex engineering project management experience. Further critical variable characteristics were identified based on the relevant individual differences identified in Chapter 2, including preferences for instructional delivery (reflected within FSLSM learning styles), objective prioritization, self-regulation skills, level of prior domain knowledge, and bandwidth availability.

3.5.2 Lecture Captioning

Providing lecture captioning is a further recommendation of the universal design literature in addition to being referenced in relation to accessible content representations. To provide support for a diverse range of individuals, some of whom may struggle with processing purely auditory information, accurate captioning is critical. However, as mentioned above, assisting learners with disabilities is not the only benefit of universal design. Captioning can benefit learners for whom

English is not their primary language and those who are situationally disabled due to studying in crowded or noisy areas. Additionally, they can potentially benefit all learners when a speaker's accent or audio quality issues make the lecturer's meaning difficult to discern. Providing accurate closed captioning to learners allows for effective information processing of the content being presented, which ultimately supports the completion of learning activities.

There are additional advantages to the designer associated with the completion of the captioning process. The output of this process is a textual representation of the material within the recorded lecture videos in the form of a closed captioning .SRT file. These files can be utilized to perform text-based content analyses, which are valuable to the design process. Content analysis can support the identification of indexing terms to inform search functions, as well as tags to support contextual navigation mechanisms. The process associated with this will be discussed further later in the chapter.

Two alternatives for generating captions were considered: algorithmic generation via machine learning and manual generation via an external, professional captioning provider. The original captioning available for the Fall 2019 semester was algorithmically machine-generated. This captioning was subject to a preliminary review, which resulted in the discovery of meaningful errors. For example, phrases like "metadata structure," a critical concept in the presentation of SE5, were captioned as "method data structure." This error could lead to learner confusion and obstruct the identification of relevant keywords within the content. Therefore, it was concluded that machine-generated captioning is prone to significant, meaningful errors described above and requires significant edits to reach a high level of accuracy. On the other hand, human captioners can use additional context from the slides within the video to mitigate these issues. As such, professional closed captioning for all videos was completed using an external provider (Rev.com). The process from the designer's perspective is described by Figure 12.

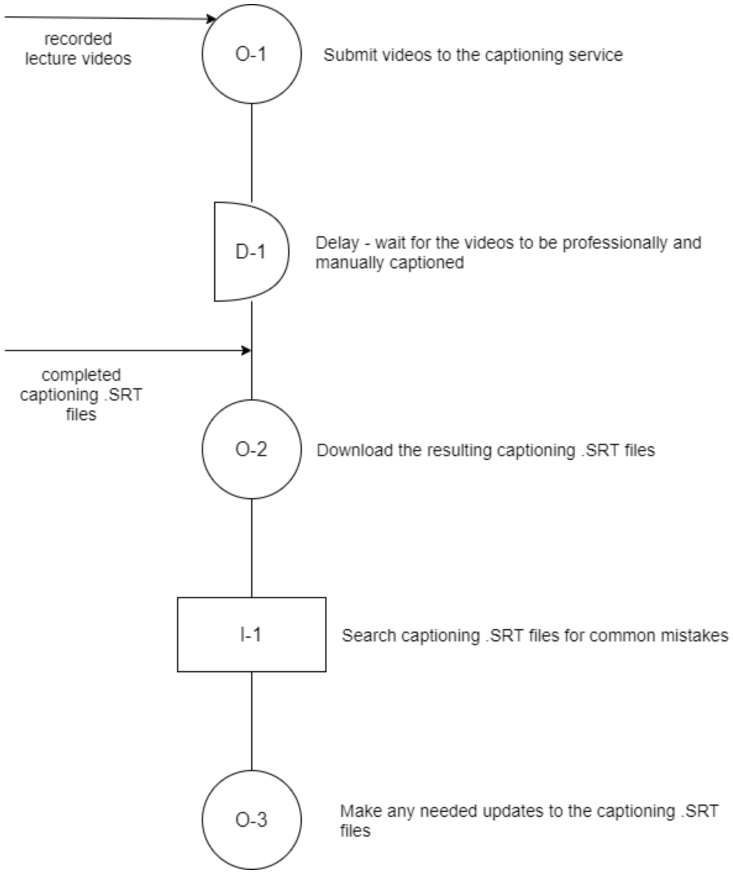


Figure 12: Operations process chart for the closed captioning process utilizing a professional, external provider

3.5.3 Designing the Information Architecture

The IA design for the PoSE course can be considered in relation to the four sub-components of an information architecture: information structures, navigation mechanisms, labeling frameworks, and searching functions (Rosenfeld et al., 2015). The design tasks associated with this effort are depicted in an HTA given in Figure 13. The information structure and navigation components are highly interrelated, in that the navigation mechanism must align with the type of information structure. A hierarchical navigation approach would be ill-suited for a “pure” NSIS, and a primarily contextual navigation mechanism may be inappropriate for a hierarchical structure (Rosenfeld et al., 2015).

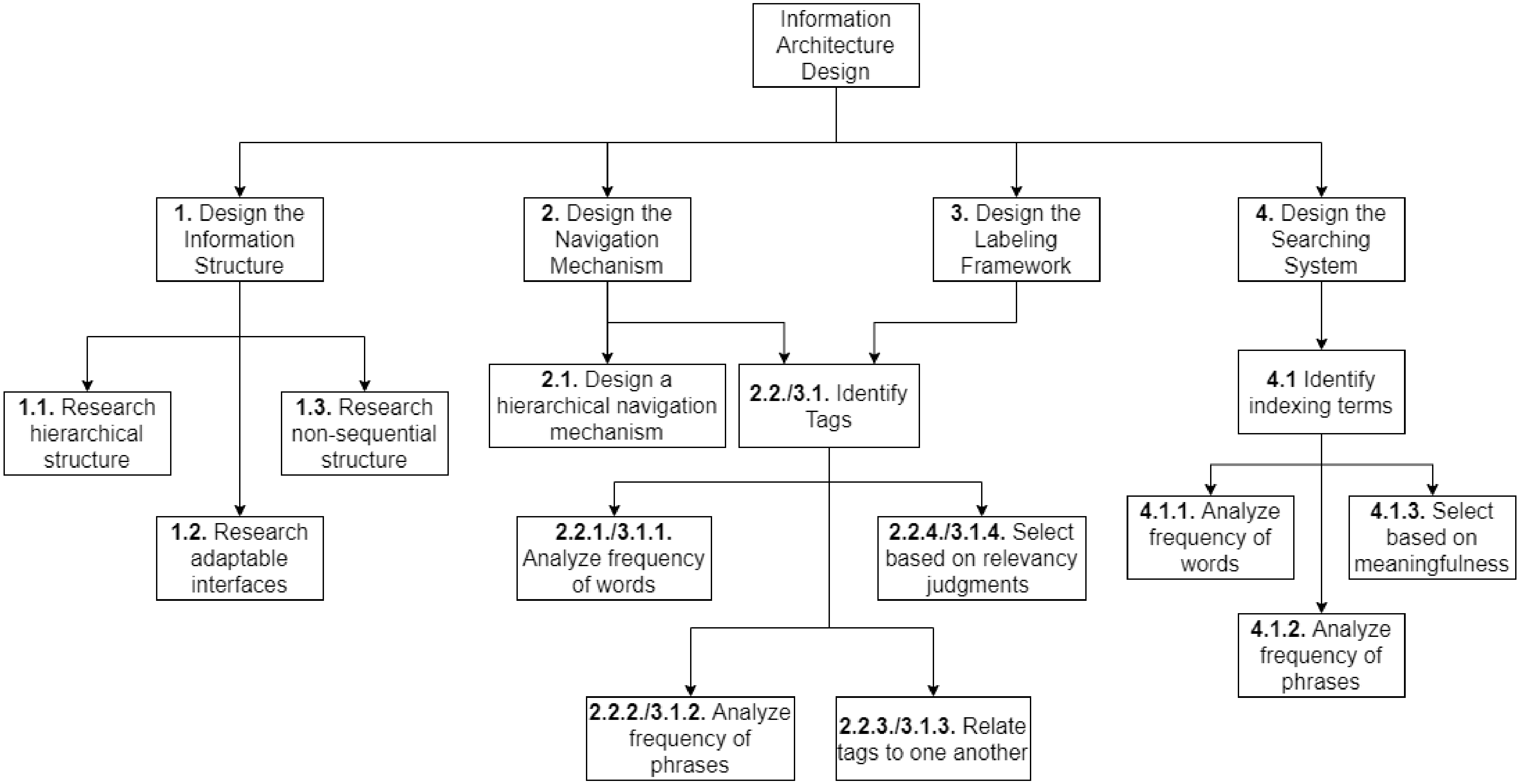


Figure 13: HTA for the tasks associated with the design of an information architecture for PoSE

Literature related to both information and navigation mechanisms that support the traversal of the information structure was explored through the initial identification of HyperCard as an initial application of interest (though it did not ultimately resemble the final outcome). From there, the keywords “hypertext” and “hyperspace” allowed for the identification of further literature that primarily emphasized the comparison of an NSIS on learner performance in an educational context. NSISs were of interest because their structuring, according to cognitive flexibility theory (CFT), facilitates understanding of highly complex, interconnected, and poorly structured information spaces (Spiro et al., 1988). NSISs are thought to foster a deeper understanding of the material through allowing exploration of the information space from multiple perspectives (Niederhauser et al., 2000), and this deeper learning is more likely to result in the development of “SE disease.” This literature was then utilized to further expand the literature database through identifying relevant papers cited in the articles’ literature reviews. Refined searching for more specific elements outside of the literature reviews was also completed periodically to fill in any elements that were missing.

The navigation mechanism, along with the labeling framework and searching function, was additionally informed by the outputs of a content analysis performed on the initial PoSE material. The content analysis considered the paragraph-style lecture notes, PowerPoint presentations, and captioning files for the videos. Analysis was performed at both the level of the whole course and at the module (i.e., systems languages and engineering case studies) level. There are a variety of content analysis approaches that support both qualitative and quantitative analyses. Both qualitative and quantitative analysis approaches will be utilized to inform the identification of keywords that support navigation, labeling, and searching as is appropriate for the design need. Qualitative approaches will be used to determine whether longer readings will bias the quantitative analysis, including usage of word and phrase frequency lists. These frequency lists will be utilized, along with further qualitative judgment by the author, in order to identify a subset of the keywords that may inform an NSIS navigation mechanism.

For PoSE, an initial qualitative analysis in the form of generating word clouds was performed to serve as representations of the information space. The word clouds are processed through the use of stop lists to remove irrelevant “words” such as numbers and meaningless strings of alphanumeric characters or special characters. Additionally, parts of speech that do not provide insight into the actual content, such as verbs, adverbs, and many general adverbs, are also removed to provide a clearer representation of the core content. These described the content of each module and were performed both with the inclusion and exclusion of the relevant external readings, which enabled the identification of any bias from the readings (which could be extensive) in future analyses.

Additional quantitative analyses took the form of word and phrase frequency lists. These lists were generated at the module level and contained every word or set of 2-4 words that occurred more than once in or across any of the files associated with that module. Similarly to the word clouds, extensive stop lists were utilized to limit the number of words and phrases to review manually. This included removal of all phrases beginning with a preposition, conjunction, or article, for example, since the meaningful word(s) within them would be captured either by another phrase or by the single word frequency list.

The contextual navigation mechanism and labeling framework should be informed by the content analysis; a sub-set of the identified keywords can be utilized to determine what words or phrases are candidates for contextual navigation. Similarly to the labeling approach, meaningful terms from the content analysis were identified by a subject-matter expert (the author) and were then analyzed for frequency and recurrence. If a meaningful term only occurred in a single, relatively short document, then it may not be worth utilizing it within the contextual navigation mechanism. However, if a keyword occurs across too many documents (for example, "systems engineering"), it loses its value as a navigational tool. Keywords that are meaningful and valuable for navigating (directly or indirectly) will be called tags. Tag identification is a process that can be done by reviewing the word and phrase frequency lists and comparing the entries to the criteria defined for a tag.

Search systems are a major element of IA that predominantly supports known-item information-seeking tasks, though other information-seeking tasks may utilize a combination of both searching and browsing. First, it is important to establish that there is a need for a searching function, as simply assuming that this need exists is ill-advised within the IA design literature (Rosenfeld et al., 2015). The amount of content being presented is considerable, with over 1,200 minutes of video content relating to describing the SE languages alone. This amount of content would be difficult and frustrating to navigate through via browsing, especially for learners performing known-item searches or more granular exhaustive searches, without a searching function to narrow the scope of their search. This searching function would best operate based on indexing terms that represent the meaningful content within a given document or video. These indexing terms can be considered a sub-set of all keywords identified in the content analysis but with fewer requirements compared to a tag. Indexing terms do not need to directly or indirectly support contextual navigation. So all meaningful keywords and phrases identified by the content analysis (specifically the word and phrase frequency lists) should be considered indexing terms. Because there is overlap between these indexing terms and the tags, there should be some alert to the user when search terms align with one of the tags to allow users to optionally but easily explore the tag more directly to hone in on the information they are trying to find. It may also be beneficial to provide users with a means of restricting their search to a specific subset of the information space (e.g., one of the SE languages).

3.5.4 Designing the User Experience

The user experience design of the PoSE educational environment is critical to consider in order to support users in performing both learning tasks and information search tasks. UX design differs from IA design in that IA design emphasizes the structure and findability of the content. Additionally, UX design does not focus on the human-computer interaction that occurs at the "at-the-screen" level of button-clicks or the aesthetics of the design, both of which are characteristics of UI design that are considered out of scope for this project. UX considers primarily how users will interact with and experience the environment and how it can support their completion of tasks, emphasizing tasks and processes that occur "beyond-the-screen." This section will present the methods associated with components of the UX design, including modularization of the existing content, adaptation of the UX design based on user needs and characteristics, and wireframing.

Content Modularization

The COVID-19 pandemic does not necessarily represent the context of the PoSE educational environment, in that it is not being developed in response to the pandemic for use only within the pandemic's environmental constraints. However, the closure of education institutions and subsequent mass migration to online learning have exposed several challenges of online, distributed learning that are worth considering in the PoSE environment design. These include difficulty maintaining attention through long recorded lectures (Villasenor, 2020) and difficulties accessing reliable network connections with appropriate bandwidth (Bao, 2020). There is also a well-established disruption to primary task performance that occurs when complex tasks are interrupted, and the more time the task requires, the more likely it is to get interrupted. Finally, content modularization is one recommendation for fostering learning transfer, which is a critical element of developing "SE disease" or application of SE concepts to current organizational settings, one of the goals associated with the PoSE course.

A potential solution to these issues is to provide shorter lecture video units. For example, instead of presenting the original, 75-minute lecture in its entirety, it could be broken down into segments based on the "thematic topic" being discussed. This is an example of topic-based modularization where the content must be analyzed in order to identify what topics are emphasized or signaled to be important. In addition to this topic-based modularization, further modularization can be performed to create a set of videos that are shorter than a maximum length. This time-based modularization can address some of the issues of attention, time, and bandwidth constraints. For example, instead of presenting the full 40 minutes associated with a certain thematic topic in a single video, this material could be segmented into two to three related but self-contained lecture videos. A high-level task analysis of the content modularization process is provided in Figure 14.

The identification of initial, high-level modules (the systems languages and engineering case studies) shown in Figure 9 can be considered content modularization at a coarser grain size. Therefore, the implementation of both topic-based and time-based modularization can be considered an extension of the division of the material into distinct sections during which a different high-level topic was the primary focus. This division was inherent to the structuring of the course, whereas the identification of thematic topic-based and time-based modularization required a more detailed analysis of the existing content. Figure 14 provides an initial overview of this structure; a more in-depth elaboration of the full process will be described as an output in Chapter 4.

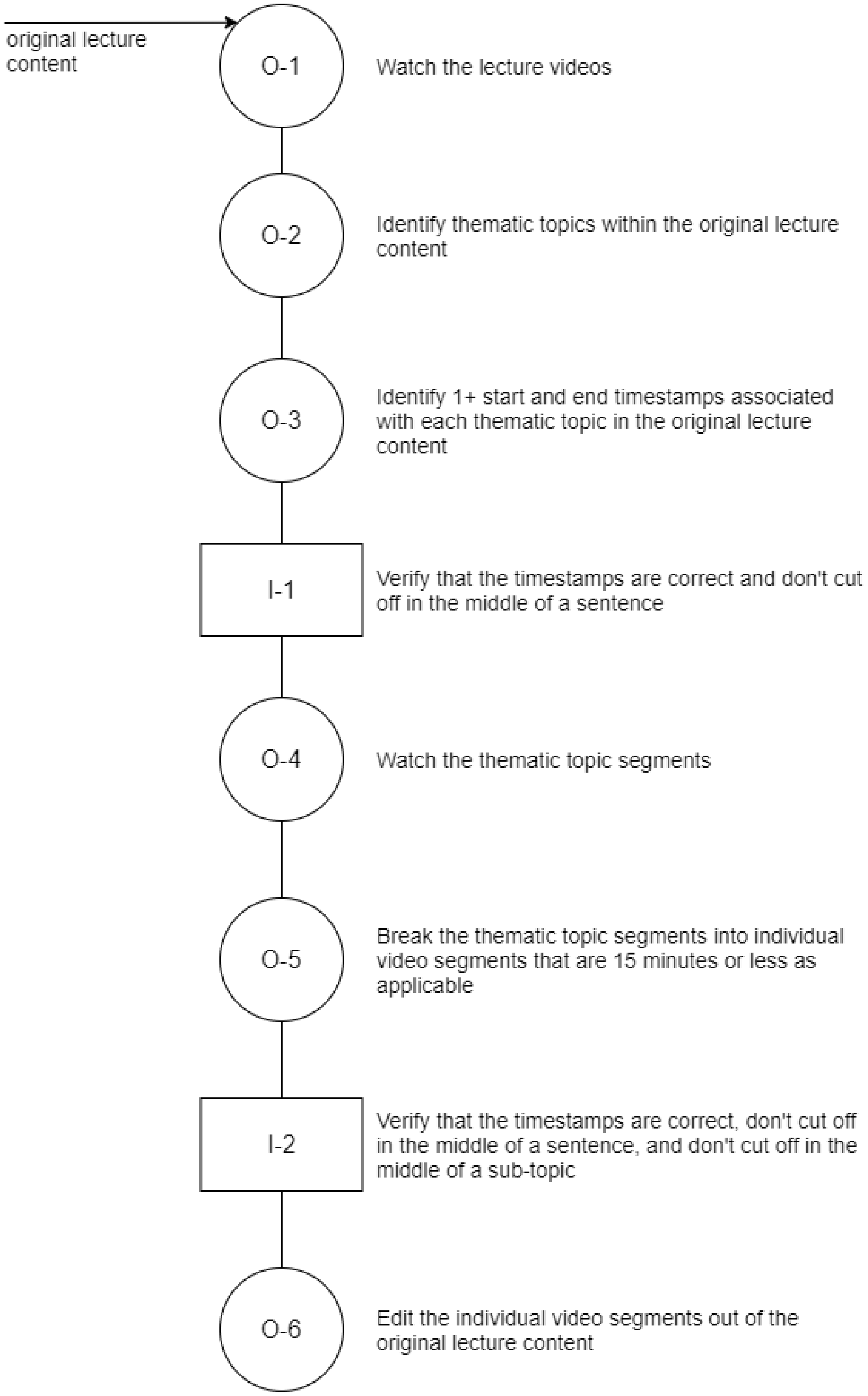


Figure 14: Operations process chart for the content modularization process

Dynamic User Experiences: Adaptation to Support a Variety of Users

There are three independent elements of the user experience that would benefit from a customizable or personalized approach. A static user experience configuration would only address the characteristics, goals, or needs of a subset of the learner population or only during a subset of their interactions with the material. When different learners can have conflicting or evolving needs that suggest different learning environment designs, then the associated design choices should be evaluated as a dynamic user experience opportunity. The first relates to the use of NSIS compared to a more structured, hierarchical organizational approach. The second is in reference to the primary medium being initially presented to the user when they interact with the interface. Finally, the order in which the learner explores the content based on their prior knowledge should be considered. All of these will be addressed, but the former is more highly related to individual differences and task demands, whereas the latter may be better construed as a product of user preference.

The design method used in this thesis to reinforce this emphasis on the variety of user characteristics included the development of user personae, or simplified descriptions of the familiarity, learning goals, and professional experience of students taking the PoSE course. The list of personae developed was based on an amalgamation of students who actually took PoSE during the two semesters utilized for this case design (Fall 2017 and 2019). Students self-reported experience and learning goals in a “What’s Your System” online discussion exercise assigned by the course instructor. Additional input to the development of user personae was provided by a retired engineer who considered possible learners who might benefit from PoSE material from the perspective of supporting ongoing corporate projects or standing up a new, multidisciplinary corporate initiative (both of which the engineer had relevant industry experience). Responses to the “What’s Your System” exercise helped illuminate differences in which SE language was most familiar to various students (on-campus undergraduates or graduate students across multiple engineering degree programs; online students who were full-time working professionals pursuing a Master’s degree or Systems graduate certificate) taking the course in 2017 or 2019.

The use of hierarchical or non-sequential information structures is an opportunity for a dynamic user experience because the value of such structures is not uniform across all learners. For example, learners with high prior domain knowledge and high self-regulatory skills were significantly more equipped to handle the demands of NSISs (Scheiter & Gerjets, 2007). Experienced learners are able to benefit from using NSISs, and the higher learner control may increase their motivation to engage with the material (Jones, 2009) and allow them to explore topics according to their specific interests. On the other hand, users with low prior domain knowledge are particularly susceptible to the negative impacts of NSISs, including cognitive overload and disorientation (McDonald & Stevenson, 1998; Scheiter & Gerjets, 2007). Instead, subject-matter novice learners benefit from the additional scaffolding associated with hierarchical information structures (Amadieu et al., 2009; Shin et al., 1994; Vörös et al., 2011). These disparities in outcomes based on user characteristics suggest that a more flexible experience may be desirable. This could come in the form of either (1) a hybrid information structure and navigation mechanism design, where information can be navigated linearly in a hierarchy or nonlinearly in a less structured information space or (2) an adaptable or adaptive interface that allows the primary information structure and navigation mechanisms presented to the user to be dynamic. One major disadvantage to a hybrid configuration is that, in the presence of other navigational tools, hyperlinks (which serve as the means of contextual navigation) are often ignored by users (Rosenfeld et al., 2015). Therefore, a dynamic user experience would offer another means of addressing the strengths and needs of both types of learners.

In addition to the differences between learners with different levels of domain knowledge, the types of tasks being performed by a learner may also influence the relative value of hierarchical versus non-sequential information structures and navigation mechanisms. These tasks vary in relation to the learner's current level of domain knowledge. For example, a learner with limited domain knowledge is more likely to have a goal of exploring the material and learning the content, likely through relatively exhaustive information-seeking behaviors. As mentioned previously, learners with newer, more limited domain knowledge who are primarily performing learning tasks in relation to content that is new to them benefit from more clearly structured information presentation. On the other hand, learners with more extensive domain knowledge may be utilizing the information space for a few reasons, including (1) learning more about a specific topic they already have some familiarity with, (2) understanding the connections within the information landscape to get a more holistic sense of how the material is interrelated and deepen their understanding, or (3) refinding information they have already encountered to reinforce learning or support their perspective. These tasks may best be accomplished through the provision of a searching interface as well as the NSIS system to support understanding the interconnectedness of the information landscape.

The second opportunity for customization or personalization comes in the form of the medium through which the information is initially presented to the user. Much of the initial PoSE material is "parallel." That is, the lecture recordings present and expand on the material in the paragraph-style lecture notes. Therefore, the different material within each thematic unit is not independent, and the lecture notes, 2017 videos, and 2019 videos do not have a straightforward linear ordering between them. Considering this, it could be valuable to consider learner preference for information presentation when selecting which medium to initially provide when they navigate to a thematic unit. For example, some users may learn better via or have a preference for watching audiovisual media, and therefore presenting the videos first would provide the most cohesive user experience. In contrast, other learners may learn more effectively or have a preference for reading the text, and presenting the lecture notes initially would facilitate their performance of the learning task.

The final dynamic user experience opportunity is the order in which the learners interact with the content. Different learners may have different levels of prior knowledge or experience with one or more of the systems languages (or may have no identifiable previous experience). Higher levels of prior knowledge with one of the systems languages indicate that the material associated with the corresponding module would be the most accessible for that learner. A higher level of prior knowledge may also indicate existing learner interest in that sub-domain of systems engineering. Ensuring that lessons build on previous knowledge (Gregory, 1886), are accessible to learners (Al-Azawei et al., 2016; Burgstahler, 2009b; Fox et al., 2003), and are interesting (Scheiter & Gerjets, 2007) support positive learning outcomes. As such, a dynamic user experience that allows for different "entry points" into the PoSE content should be considered.

Literature on adaptable and adaptive interfaces was utilized in order to determine what type of interface would be most appropriate for the opportunities described above. Adaptable and adaptive interfaces both allow for a dynamic user experience that may be beneficial if the primary navigation mechanisms differ depending on individual differences. When it comes to these designing dynamic user experiences, it is important to determine the locus of control for the adaptation behavior as either with the human user or with the interface system (Opperman et al., 1997). These design decisions have significant consequences on the user experience and thus should be informed by the nature of the individual differences that are being accommodated, as well as principles of good adaptable or adaptive interface design, as given by the literature. For example, literature on adaptive interfaces (which have a system-based locus of control, often with adaptation occurring within sessions) emphasizes that changes in the user interface, especially those that are not transparent and easily reversible, may ultimately reduce usability and increase confusion (Rathnayake et al., 2019). Additionally, it is worth noting that it is usually considered good practice to provide the user with some control over the adaptation (Gullà et al., 2015).

The adaptation trigger consists of a condition that, when met, should cause a change in the user experience or interface (the adaptation behavior). The availability and accessibility of these triggers are particularly relevant in adaptable interfaces due to the emphasis on user control. Triggers associated with settings that act more like constants may be hidden and available only on demand, but triggers associated with settings that a user may wish to change multiple times over the course of a session or where the adaptation is time-sensitive should be more easily accessible. The dynamic information structure (hierarchical or non-sequential) component falls into the latter category, as users may become "lost" or cognitively overwhelmed in the NSIS and wish to quickly revert back to the hierarchical structure throughout the course of a learning session. Conversely, the information presentation modality customization is more likely to operate as a constant. These factors must be considered during the design process.

Wireframing

Wireframing is a UX design process that emphasizes the development of skeletal representations of screens that should appear within a software application. Wireframing should be performed as an element of designing the IA and UX elements associated with the PoSE learning environment. These wireframes should especially emphasize critical "at-the-screen" components that the user must interact with in order to perform learning or information-seeking tasks. Wireframes provide an example of what the screens that the user encounters may look like without being functional prototypes. Wireframing for the PoSE learning environment was accomplished through first developing physical sketches and then revising the design during the transition into a digital format. These wireframes were developed for user interaction tasks associated with the major IA and UX design elements identified previously and therefore did not address every possible or necessary screen that should or would need to appear in the PoSE learning environment once it is developed. Notes associated with the functionality of components were also included where relevant. Critically, these wireframes will not be subject to any user testing. This is considered outside the scope of this project, so instead, the initial prototype wireframes will be presented.

4. RESULTS (IA / UX CASE PRESENTATION)

4.1 Introduction

The goal and purpose of this thesis is to develop a case design, emphasizing information architecture (IA) and user experience (UX) design elements, to address teaching a highly interdisciplinary subject matter to a variety of learners with different backgrounds, learning goals and needs. The asynchronous and online (distributed) elements of the design are not design decisions made to support this purpose but instead constraints on the case design. Similarly, the use of existing content acts as an additional constraint on the resulting design. The emphasis of the case design is on understanding the prospective user base and developing distinct IA and UX elements to support teaching a graduate-level systems engineering course (PoSE) to a range of different learners.

This chapter will present the prototype case design and is organized in accordance with the person-content-context model. The prototype design elements all transcend the boundary of a single element of the person-content-context model. For example, content modularization is an operation done on the content for the benefit of the users interacting with it. Content modularization also supports its presentation in the context of an online educational environment. Results in this chapter are organized according to their respective primary element of focus within the person-content-context model.

First, the development of user personae is presented. The user personae primarily concern personal factors and describe the range of prospective users that must be considered during the design process. Next, the content modularization is described in terms of necessary design characteristics, the developed process, key takeaways from performing the process, and outputs of the process. This content modularization interacts with the diversity of the user personae and user needs to inform the non-sequential organization of the different modules. Content modularization and non-sequential module organization both transform the presentation of the content, which is relevant to the design of the context. The identification of tags and keywords is described in terms of design characteristics, the keyword and tag identification process, key takeaways from that process, and outputs of the process. The tag and keyword identification are informed by the content but are highly relevant to the design of the online educational environment (context). Finally, two adaptable interfaces alter the delivery of the content and are therefore relevant to the learning environment (context) design. The first adaptable interface allows for changes in the information structure and navigation mechanisms. This IA and UX design adaptation is described in terms of the adaptation trigger and both of the possible information structure and navigation configurations (scaffolded and unscaffolded settings). The second adaptable interface alters the initial information presentation modality (i.e., text versus video) associated with a given user. The adaptation trigger and resulting behavior are both discussed.

4.2 User Personae

Five distinct user personae were developed in order to inform the design of the online, asynchronous learning environment. Each of the personae represents a type of prospective user that the learning environment should accommodate by building on composite examples of actual students who have taken the course in the past. For the purposes of this case design, the users of the online learning environment are the learners. The case design does not consider the design of the interface to directly support instructors.

Prospective learners can be described on two dimensions: their current role and the systems language with which they are most familiar (as students explicitly reported in the "What's Your System" assignment during actual PoSE online discussions). This is illustrated by the blank matrix in Figure 15. This description emphasizes that each prospective user primarily relates to one current role value and one most familiar SE language value. The learner's current role can be used to describe the learner as either a traditional (an undergraduate or full-time graduate student) or non-traditional (a working professional or executive) student learner. Each different type of learner may be characterized by different goal emphases and needs when it comes to interacting with course content within an online learning environment.

While many high-level goals associated with the course are present across these roles, the degree of emphasis, motivations, or desired outcome associated with achieving the goal may vary. These high-level goals include learning the material, earning credit toward a degree or certificate, and receiving a good grade. These goals are not mutually exclusive within a given individual user, nor among a role (student, working professional, or executive). However, the relative emphasis that users place on each goal may vary as a result of the priorities supplied by the user's context or environment, which is influenced by the user's role.

The traditional student may be either an advanced undergraduate (most commonly a senior) or a graduate student. This role is characterized by the user's primary focus on their education without other competing full-time work responsibilities. Students may come from a number of different disciplinary backgrounds, both with and without formal engineering training. Undergraduate student users may have some work experience, but it would generally be limited to temporary employment. Graduate student users may be direct (entered graduate school directly following the completion of their undergraduate program) or returning (entered the workforce following the completion of their undergraduate program and later entered graduate school). Those with more limited work experience may need more vivid descriptions of real-world examples and applications, as they may struggle to view their immediate surroundings as relevant to their coursework. These students may face additional environmental pressure to emphasize earning credits toward their degree or systems certificate, especially when time constraints become relevant. However, students may also be eager to learn the material in order to apply it in their current research or to their future careers.

The working professional is a part-time graduate student who is taking academic courses while still being active in the workforce. These users may be degree or non-degree seeking, depending on the scope and focus of their educational goals. Some of these users are part of a program through their company that offers tuition remission and other benefits for taking classes or completing their master's degree. Therefore, there may be pressure for working professionals to earn a good grade in a course in order to exhibit their value to their employer and validate the company's investment in them. There may be some emphasis on the goals of earning credits toward a degree or certificate, but working professionals would also be expected to apply their new knowledge and perspectives to current and future projects. Non-degree seeking students may simply want to take certain courses that are highly relevant to them without needing to fulfill degree requirements. This incentivizes deep learning in order to build a strong understanding of the information space. Depending upon their familiarity with the unique classroom environment and culture of the university, working professionals may need additional scaffolding compared to full-time students when it comes to the educational environment, processes, and expectations.

Additionally, higher levels of flexibility may be required to accommodate both their full-time jobs as well as their course load.

The executive is not a degree-seeking graduate student, but instead a member of upper management in a company. These users would interact with a course like PoSE in order to understand the systems languages and apply that understanding within their organization. Goals of earning credit toward a degree or certificate or receiving a good grade are emphasized less within this role. Executives are more removed from the educational demands of course requirements and structured assignments, so they will need additional scaffolding compared to students when it comes to the educational environment, processes, and expectations. The time limitations faced by executives may be significantly higher than those faced by working professionals, so flexibility and high-level overviews are useful for these users. The value of these users' time is also higher when measured as a function of their compensation levels or hourly rates.

Most Familiar SE Language Dimension. The most familiar systems language to a learner similarly offers insight into that individual's background and initial understanding of systems engineering before interacting with the course material. This dimension may reflect current or past work positions or educational backgrounds. For example, learners who work in manufacturing or are formally trained in manufacturing engineering may be most familiar with the SE3 component-whole relationships emphasis. Prospective users with no formal or practical backgrounds in any particular SE language will be considered to be most proficient in SE1, as a non-quantitative approach of "systems thinking" is the most widely accessible language, particularly for non-STEM majors or professionals.

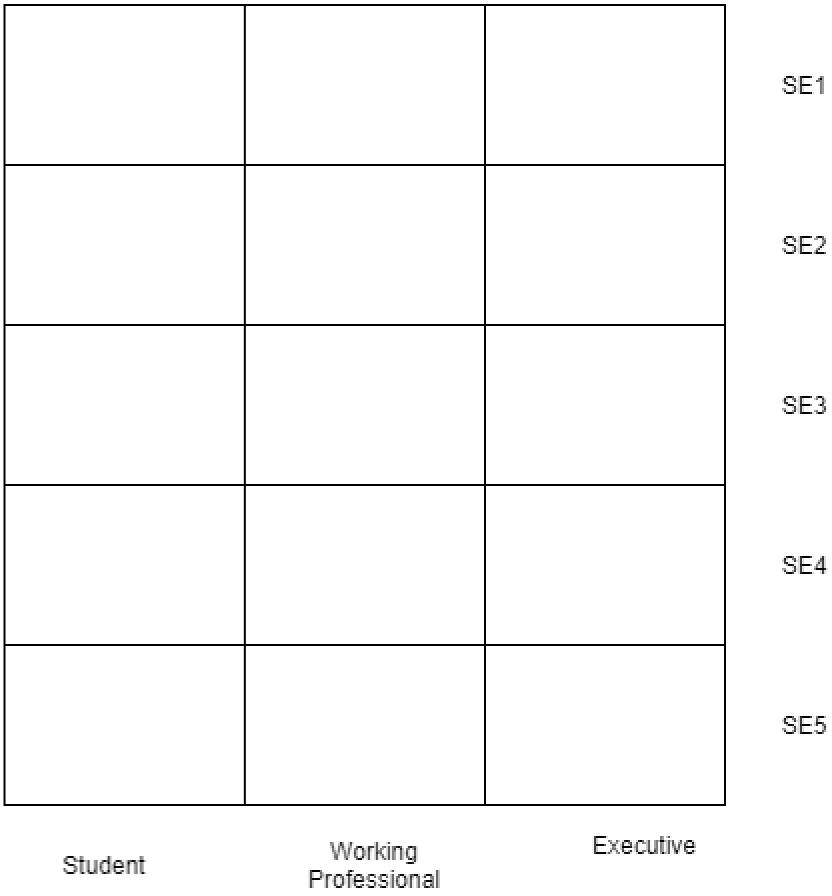


Figure 15: Two-dimensional description of prospective users

This two-dimensional description of users makes a critical assumption that users are best described by considering only the systems language that they are most familiar with. Some learners may be familiar with multiple systems languages, though to varying degrees. Additionally, this two-dimensional model cannot differentiate between users with varying levels of proficiency in a given systems language. A three-dimensional model can address these issues and more wholly describe prospective users in terms of SE experience and learner role context (but not in terms of learning styles or other individual learner attributes). This is shown in Figure 16. The dimension of the learner's current role has been retained. However, the SE languages dimension no longer constrains the description of users to a single, primary systems language. Instead, the addition of the proficiency dimension allows for the user's full SE languages proficiencies to be depicted along this dimension. That is, users with proficiencies in multiple SE languages can be described in terms of their level of proficiency with each language. This model also allows for the description of true SE language novices (with no meaningful proficiency in any language) without assuming a given language is the most familiar. Instead, their characterization with a low proficiency across the SE languages will more accurately reflect their initial status.

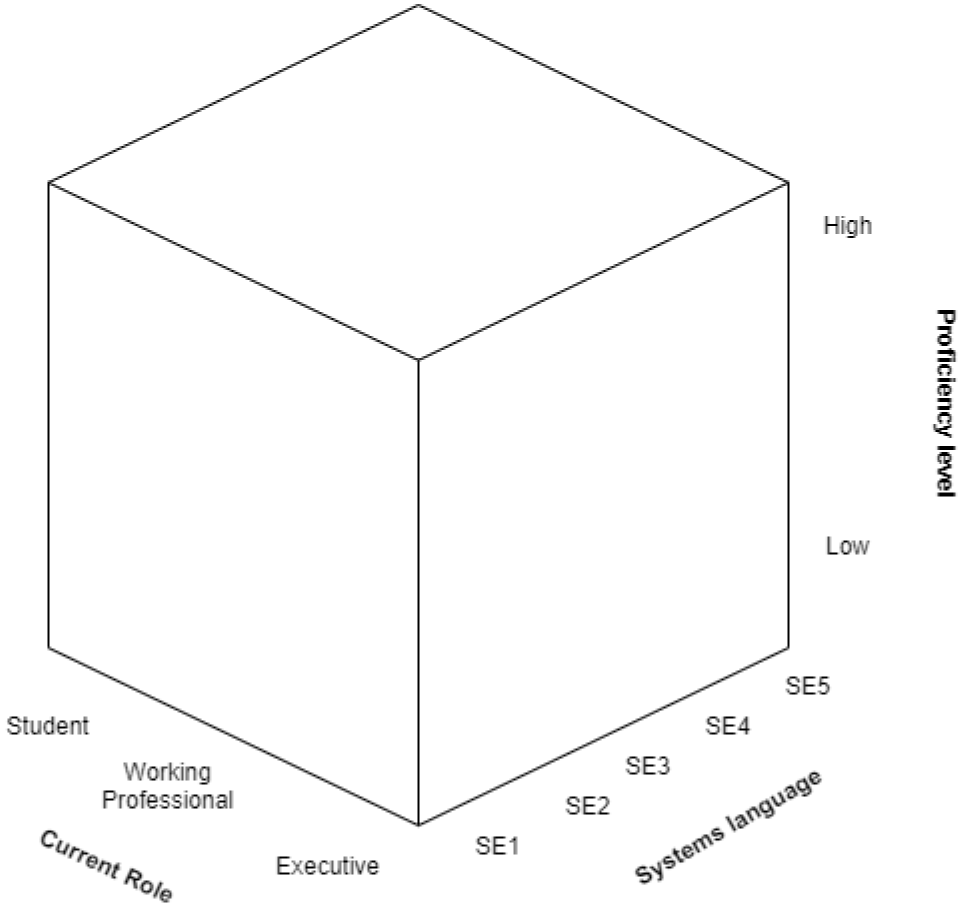


Figure 16: Three-dimensional description of prospective users

The five user personae that were developed will be presented below. These descriptions primarily emphasize information relevant to the case design, including learner backgrounds, goals, motivations, and needs.

4.2.1 Adrian

The first user persona is Adrian. Figure 17 describes Adrian on the three dimensions identified above. They currently act as a project manager at a consumer-facing product manufacturing company and are pursuing their master's degree part-time. Therefore, they are considered to be a working professional. Their project management experience results in a high proficiency for SE4, but their exposure to manufacturing provides some insight into SE3. Adrian is part of a management rotation program that provides tuition remission and upward mobility for the successful completion of a systems certificate and their degree. They are thus motivated to earn the credit toward their degree and certificate, but also want to learn about the different systems languages in order to apply them to their current work. As a working professional, Adrian may need additional flexibility at times and takes all their classes online and asynchronously. Their experience as a project manager has allowed Adrian to significantly refine their self-regulation skills; however, these skills can be impaired when they are overworked or overwhelmed. Adrian needs to be able to accommodate frequent interruptions to their learning experience due to work calls and family obligations. Being able to re-find information is also imperative to Adrian so that they can confirm and support their understanding before discussing the material with their coworkers, and they have a preference for a verbal information presentation. Finally, Adrian had access to high-bandwidth internet connections both at work and at home.

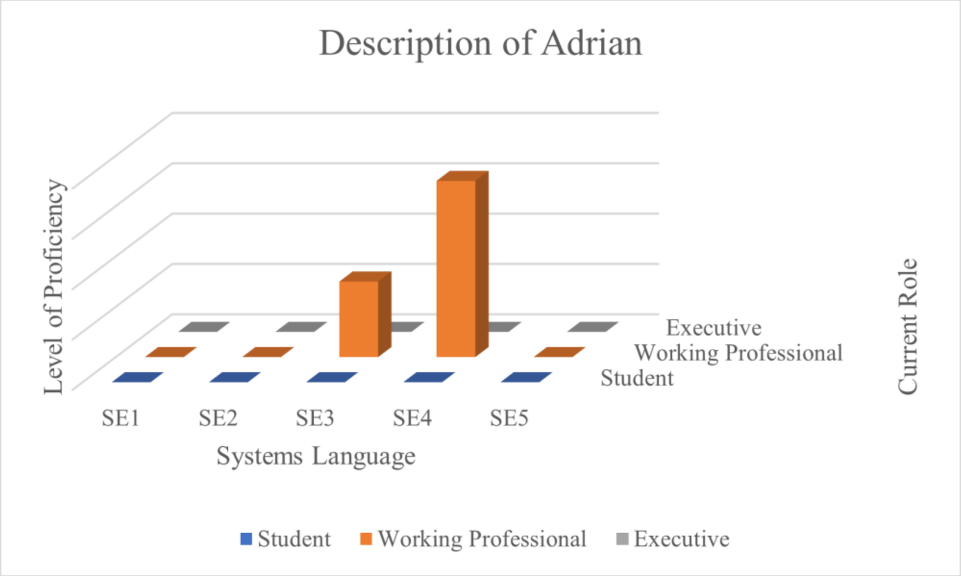


Figure 17: Dimensional description of the user persona Adrian

4.2.2 Bailey

The second user persona, described in Figure 18, is Bailey. Bailey is a senior in their undergraduate degree program studying aeronautical and astronautical engineering. They have had two summer internship experiences with NASA and have already accepted a mission operations position with a commercial space provider. Their responsibilities will emphasize satellite coordination and timing needs for cislunar operations. Bailey is primarily aware of the NASA engineering deployment process sub-domain of systems engineering (SE4). However, their strong mathematical background and engineering courses have also given them exposure to SE2 analyses. Their objectives associated with taking PoSE include applying the material to their future career and achieving a good grade in the course to maintain their GPA. Bailey learns best when provided with clear, accessible examples presented visually and is accustomed to highly structured learning environments. As such, they have lower self-regulation skills. Bailey lives on-campus, and therefore has consistent access to appropriate levels of bandwidth throughout their day.

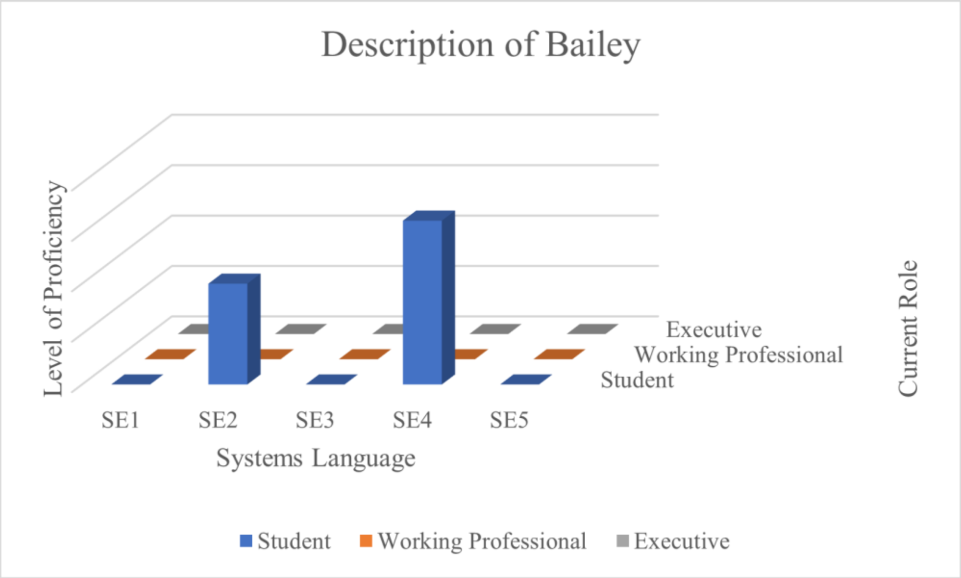


Figure 18: Dimensional description of the user persona Bailey

4.2.3 Casey

Casey is the third user persona and is described in Figure 19. Casey is a full-time on-campus student pursuing a master's degree in interdisciplinary engineering. Their undergraduate background is in mechanical engineering, and they returned to graduate school after working in industry for three years at a company struggling due to supply chain issues. During their time in industry, they developed an interest in secure supply chain infrastructure and are looking to combine industrial engineering, computer engineering, and cybersecurity emphases in their master's studies. Casey has some experience in systems thinking (SE1) and component-whole relationships (SE3) from their previous job. They also have currently limited but growing exposure to information architectures (SE5). However, Casey would not necessarily consider all of these to be languages associated with systems engineering. Casey is motivated to take the PoSE course in order to apply the knowledge they will gain to projects in their future career. Casey enjoys reflecting on course material and making connections between different disciplines to further their knowledge and understanding of a topic. They prefer visual information presentations and have adequate self-regulation skills to support online learning. Lastly, Casey lives off-campus and thus can experience low bandwidth situations at home, though they do have reliable bandwidth on campus.

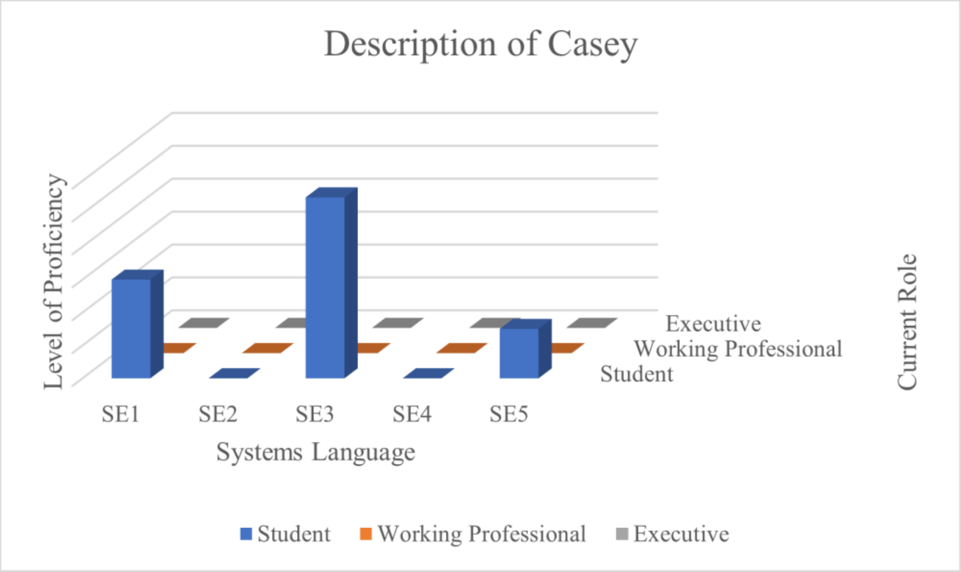


Figure 19: Dimensional description of the user persona Casey

4.2.4 Devin

Devin is the fourth user persona and is shown in Figure 20. Devin is a second-year on-campus PhD student in industrial engineering. Devin entered graduate school directly after completing their undergraduate degree, which was also in industrial engineering. Their undergraduate degree primarily emphasized stochastic optimization and cybernetic mathematical analysis (SE2) with minor elements of project management (SE4). However, during the first two years of their graduate program, Devin has discovered a passion for human factors and is interested in learning more about sociotechnical systems as a part of their PhD research. Devin is taking the PoSE course in order to apply the information to their current (and future) research. Due to their limited past work experience, Devin may need more vivid descriptions of real-world examples, and they prefer a visual presentation style. Devin has high self-regulation skills, which are rarely impaired regardless of their other academic and personal commitments. They have sufficient bandwidth on-campus and at their apartment but regularly visit their parents in rural Indiana. Thus, they may experience intermittent low-bandwidth situations.

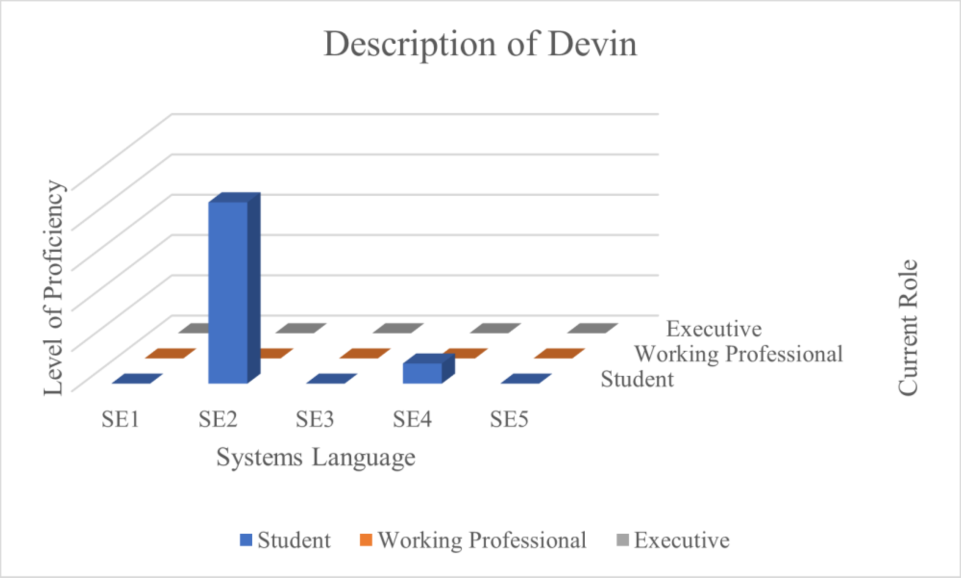


Figure 20: Dimensional description of the user persona Devin

4.2.5 Eli

Eli is the fifth and final user persona and is described in Figure 21. They are the Chief Information Officer at a Fortune 500 company and are categorized as an executive. Eli's educational background includes an undergraduate and master's degree in computer science, which results in a high familiarity with digital and information architectures (SE5). Eli also engages in systems thinking (SE1) to inform organizational strategy and project management (SE4) to manage the people and processes within the company. However, they would not necessarily consider systems thinking and project management as being systems engineering. Eli wants to better understand how to talk to a variety of people within the company about systems engineering and understand how it can help the organization going forward. However, they have extremely limited time due to their responsibilities and need a high level of flexibility, especially since emergencies may arise in their workplace that require their immediate attention. Eli's self-regulation skills are high, but frequently overwhelmed by the magnitude of their workplace responsibilities. Their access to bandwidth can fluctuate due to frequent travel and the regular need to work from hotel rooms, which may or may not have high-bandwidth network connections.

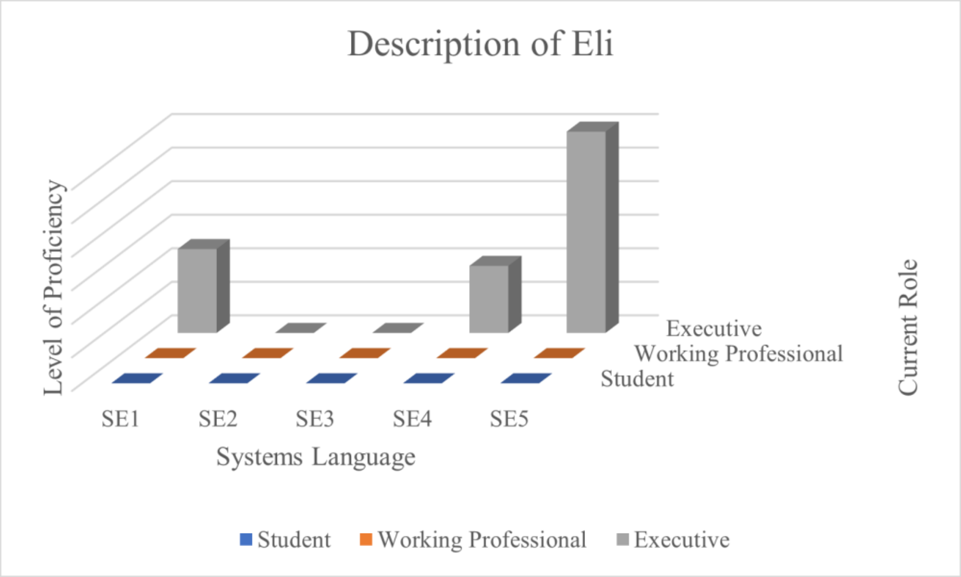


Figure 21: Dimensional description of the user persona Eli

4.3 Content Modularization: Thematic Topics and Video Segments

As mentioned previously, content modularization occurs at a number of levels, as shown in Figure 22. Modularization at the scope and module levels was inherent to the PoSE course structure as taught at Purdue University as a hybrid course. The material was already organized into distinct weeks of lecture material that were dedicated to each of the systems languages as well as the engineering case studies. However, the design requirements and process for segmentation at a thematic and segmented video level had to be developed as an element of the design. Thematic topic modularization sought to establish major topics within each of the modules and identify segments of the existing recorded lecture material that related to that topic. Within each of these topics are individual videos that address those topics as a major emphasis. This section will primarily emphasize the modularization that occurs at the thematic topic and individual video segment levels.

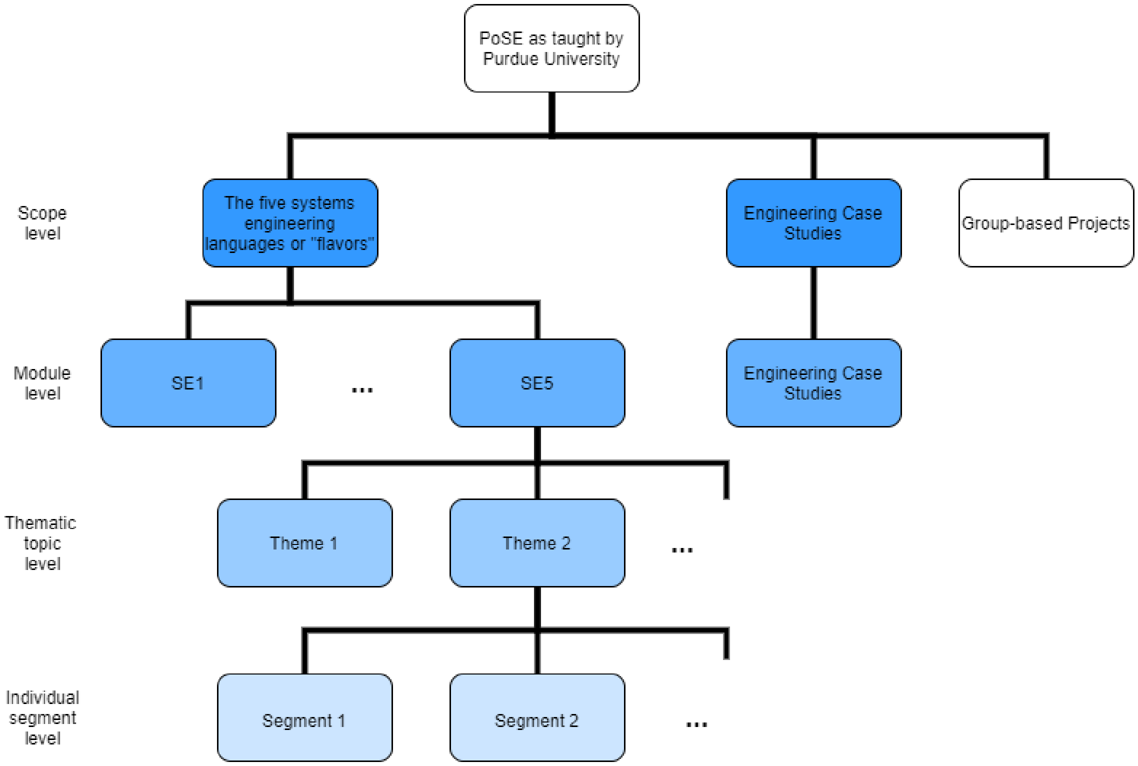


Figure 22: Diagram of the levels on which modularization occurs

The modularization approach was applied to the recorded lecture videos, but these videos do relate to other content presentations that were also categorized at the module level. Both the paragraph-style and PowerPoint-style lecture notes connect to the individual videos, which cover the content presented within them. Frequently, assigned readings can also connect to the individual readings in a similar way. These text-based presentations differ in terms of the level of detail that they contain and the available context to orient the information within the learner's understanding of the information landscape of the course. For example, the PowerPoint-style notes provide, on average, less detail and less context (fewer words, less concept linkage than paragraph-style lecture notes) when viewed independently of their associated lecture video segments. The medium constrains the amount of text that can be presented without overwhelming learners while emphasizing the use of visualizations as supports to an oral presentation. The assigned readings may be detailed on their own, but the context of how they connect to the wider course material may not be entirely self-evident. Finally, the paragraph-style lecture notes provide a higher level of both detail and context. Documents that fit the description of each of these three textual presentations can be related to one or more lecture videos.

4.3.1 Modularization Design Characteristics

There are several specific design characteristics or requirements that are relevant to content modularization. The thematic topics should be directly identified and accessible in order to support non-sequential information structuring and navigation. This means that thematic topics should not necessarily need to be viewed in the order they appeared in the original, 75-minute lecture recordings. Critically, this design characteristic does not imply that all references to the material presented outside of the topic should be removed. Instead, thematic topics should be defined in such a way that any information that must be presented sequentially to support learner understanding is contained within a single topic.

The length of individual video segments is another relevant design characteristic. There has been a persistent assertion in the literature that learner attention decreases over the course of lectures, even in in-person course configurations, though these claims have been challenged (Wilson & Korn, 2007). More recently, a claim has gained traction that learner attention in an online environment decreases sharply after only six minutes due to learners only passively watching and attending to the video (Geri et al., 2017). However, since then, these conclusions have been challenged (Geri et al., 2017; Lagerstrom et al., 2015). While these studies do not strictly conclude that shorter lecture videos are ineffective for maintaining attention, they do argue that attention can be maintained for longer than six minutes, particularly with additional interventions. The inclusion of interactive assessment and feedback elements within the online lecture video has been shown to further increase the learner's attention span (Geri et al., 2017). The exact recommendation for lecture video length varies slightly among researchers. Lagerstrom et al.

(2015) recommends a maximum video length of 12-20 minutes, but other recommendations include 10-15 minutes and 9-12 minutes (Robal et al., 2018).

Access to internet connections that are both reliable and have appropriate bandwidth is clearly important in an online, asynchronous course. However, simply recommending that learners have access to a high-speed internet connection does not present a robust solution, and there are a variety of operating conditions where learners may need to rely on their existing home internet. The bandwidth available on these channels varies widely based on location and plan (which may relate to financial status), so designing with lower-bandwidth learners in mind allows for the environment to be more accessible. Pre-recorded video is considered to be a high bandwidth and low immediacy tool (Stanford, 2020), but the amount of bandwidth required varies as a function of file size. Files can be compressed either by decreasing the quality or the length of the video. The former may be less than ideal in an educational context when clear video and audio may be critical to learner understanding. Therefore, limiting the length of any individual lecture segment can contribute to a design that is robust to varying bandwidth levels.

Task interruptions and their impact on task performance are another reason why shorter lecture videos can be ideal for learners. Virtual-based learning takes place in a variety of physical contexts, including both the home and the workplace, that are full of distractions and potential interruptions. These interruptions can have disruptive influences on primary task performance, including resumption lag, needing to restart the task, or becoming confused about whether a step had been completed yet (Trafton & Monk, 2007). The impact of interruptions is characterized by interruption complexity, the similarity of the interruption to the primary task, availability of retrieval cues to support the resumption of the primary task, and the human’s control over attending to the interruption (Trafton & Monk, 2007). Interruptions can be particularly disruptive to cognitive tasks (such as learning), especially if the interruption is also a cognitive task, as opposed to a skill-based task that does not require much cognitive effort (Lee & Duffy, 2015). Interruptions are more likely to occur as the length of a learning task increases, especially in the context of remote learning, where the learner’s immediate physical environment cannot be controlled. Therefore, providing shorter individual learning tasks (via shorter lecture videos) can help decrease the number of potential interruptions compared to a significantly longer lecture presentation.

Ultimately, a maximum limit of 15 minutes was placed on each individual lecture video segment, with an exception being allowed when the video is between 15 and 16 minutes. Videos within this one-minute time frame are not significantly over the 15-minute mark such that they would have an additional negative impact on learner attention or bandwidth. Further breaking these videos down would not provide sufficient value to the learners, and so they may be exempted from the general rule of a maximum of 15 minutes. Therefore, within the design case presented in this thesis, all individual video segments must be less than 16 minutes, with the majority being less than 15 minutes.

Modularization of the individual video segments within a thematic topic provides additional guidance that each video should also be reasonably self-contained. These segments (as described above) may have an inherent sequence and that sequencing does not need to be removed. However, at a minimum, video segments should not be cut such that the instructor is in the middle of a sentence. The individual videos should be segmented at a transition point between sub-topics within the thematic topics. Next, the process through which these requirements were met will be discussed.

4.3.2 Developed Process

In order to satisfy the design characteristics, a process for content modularization was developed. Initially, segments that can be easily identified as being thematic topics without an in-depth review of the lecture material should be identified and removed from the remainder of the content. These segments are summarized in Table 7. The PoSE case primarily consisted of initial overviews presented at the beginning of each module. These overviews were meant to give a high-level summary of the module-level topic (i.e., each of the systems languages or engineering case studies) in approximately 10 minutes. The self-contained nature of these overviews suggested that they should make up their own thematic (and segmented) topics. The individual case study introductions were modularized similarly, as their presentation was also generally self-contained and easily identifiable.

The remaining content was not as easily modularized, and so a more detailed segmentation process was developed and is described here. This process was applied to the remaining content in all modules, which represented the remaining approximately 17 hours of the existing content that would ultimately be modularized. First, an initial watch-through of the content presentation from one semester should be performed. During this process, high-level notes should be taken by the designer regarding is the information being covered in the lecture, when major transitions to or from notes, slides, or readings occur, and when the instructor is addressing logistical issues specific to that particular semester. From these initial notes, it was possible to begin to identify potential thematic topics. The individual performing this task (the author) was able to discard the video where the instructor is addressing semester-specific logistics. From here, the process depends on whether there are multiple semesters of recorded material that are roughly parallel. This may be evidenced by the use of the same or similar notes, slides, and readings. However, it is rare that the material will be presented identically across the two semesters. The sequence of the presentation and the depth of the information provided may vary widely.

Table 7: Quantitative summary of overview and case study introduction segments

	Number of videos	**Total length of content (hh:mm:ss)**
SE1 overview	2	00:22:55
SE2 overview	2	00:22:36
SE3 overview	2	00:17:31
SE4 overview	1	00:12:09
SE5 overview	1	00:12:12
Engineering Case Studies overview	1	00:11:28
Case Study introductions	14	03:06:02
Total	23	04:44:53

For those modules where there is only one available semester of content, the content was reviewed with the thematic topics in mind. During this secondary watch-through, the transitions between the thematic topics were identified, and their associated timestamps were recorded by the author. Attempts to identify these transitions in some cases led to iteration on what thematic topics are presented. There may be content associated with a thematic topic that is temporally separated from the initial thematic segment within the same or a different lecture. In this case, multiple sets of timestamps must be recorded. It is also possible that there may be some overlap in the timestamps associated with different thematic topics in order to meet the non-sequential thematic topics design characteristic. However, this should be kept to the minimum necessary. By the end of the second watch-through, the thematic topics should be identified and each associated with at least one set of timestamps denoting its beginning and end. The modules that fell into this category in the PoSE case were SE4 and SE5.

For modules with more than one available semester of content, the lecture videos from the other semester(s) should be viewed, and high-level notes should be taken, with a special focus on noting where the preliminary thematic topics are discussed. This watch-through will help capture any additional thematic topics that were not addressed as strongly or at all in the previously viewed semester. With the support of the notes, all lectures associated with the module should be opened in order to match up thematic topic segments across semesters. It is critical to note that thematic topics may not occur in the same order or be discussed at the same level of depth across semesters. When multiple lectures are associated with each semester, a thematic topic that occurs in the chronologically first lecture of one semester may be discussed in the second lecture of another semester. The thematic topic segments must be found within the lecture material, and their association should be noted. Additionally, as with the modules with a single semester of content, the timestamps relating to the transitions between thematic topics must be identified. The start and end timestamps associated with each segment of each thematic topic must be recorded. These segments may be temporally separated within the same lecture or across lectures. Overlap between thematic topics may exist but should be minimized as possible. The modules that fell into this category in the PoSE case were SE1, SE2, SE3, and Engineering Case Study.

Regardless of the number of semesters of content available, there is a final series of activities that must be done for content modularization that occurs at the individual video segment level. The following process must be repeated for all thematic topics. First, each set of timestamps associated with a thematic topic must be analyzed. If the resulting segment described by the set of timestamps is greater than 5 minutes in length and less than 15 minutes, then it can be considered an individual video segment. If the resulting segment is longer than 15 minutes, then the segment will be reviewed on its own, and potential transition points within it will be identified. These may include the instructor taking natural pauses, transitioning between documents, or asking for questions. If the segment is less than 5 minutes (a “short segment”), then the other segments associated with the thematic topic from the same lecture should be considered. The goal of this analysis is to identify whether there is another segment from the same original lecture presentation that is under the 15-minute maximum limit by at least the length of the short segment. If and only if these conditions are met, then the two segments can be reviewed together to determine whether the transition between them is jarring or confusing. If this is not the case, then the two segments may be combined. Otherwise, the short segment should remain a separate video. Finally, the timestamps associated with each segment should be confirmed through watching the segments independently. This full process is also depicted in Figure 23.

Notes were kept throughout the implementation of this process on the PoSE content. An example of these notes is provided in Appendix A.

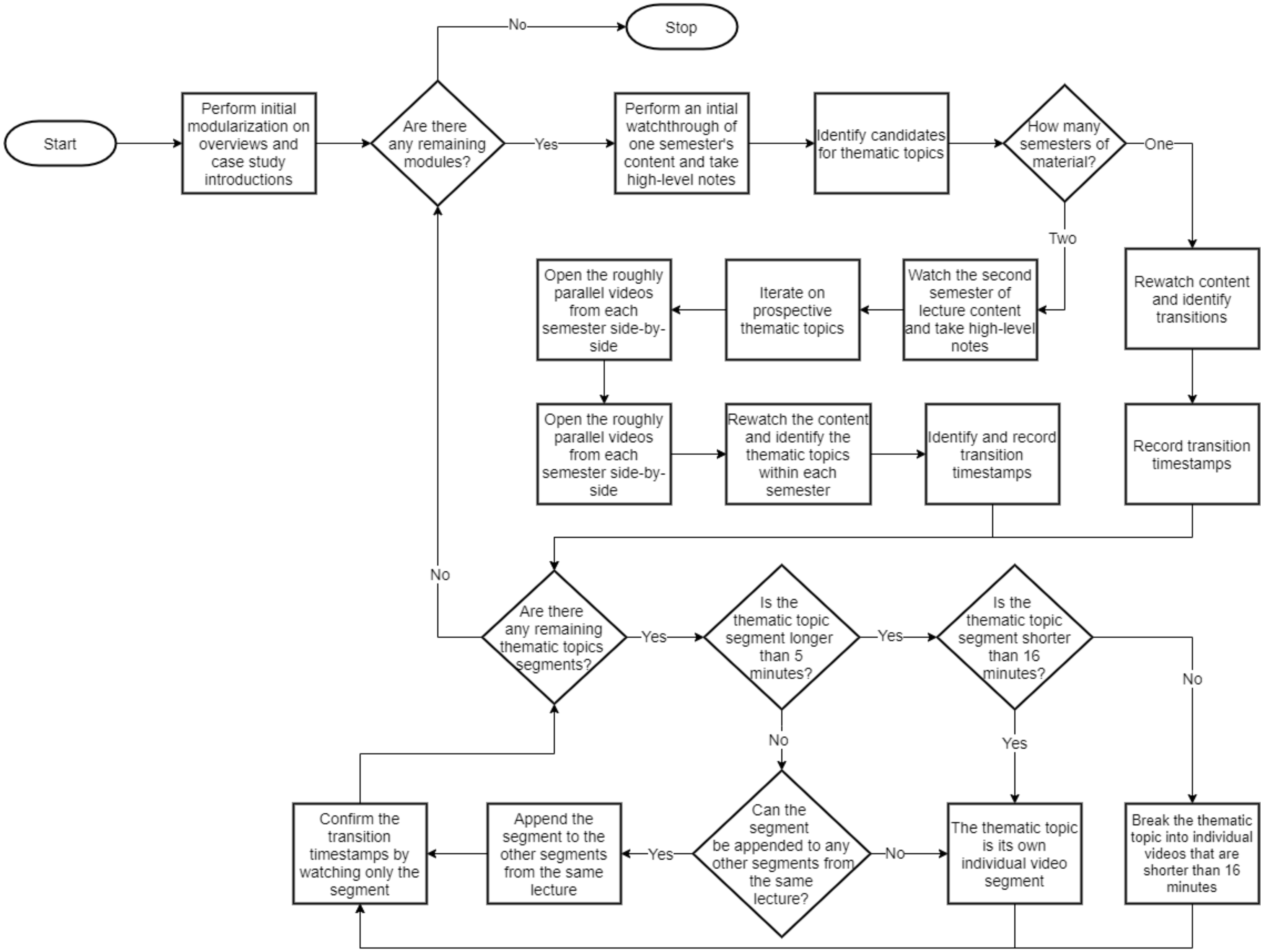


Figure 23: Flow diagram of the UX / IA content modularization process completed for this design

4.3.3 Content Modularization Outcomes: Key Takeaways

There were a number of key takeaways from performing this process which are relevant to report. Firstly, there was a significant time requirement associated with performing the process described above, in part due to the length of the original lecture videos (for PoSE, 75 minutes each). SE1 and SE2 contained four of these lecture videos, SE3 contained three, and SE4 and SE5 both contained two. The engineering case study module was created mostly through the initial identification of easily parsed segments. This is because the relevant material was largely contained within specific case study introductions and discussions, rather than the surrounding full lecture context. However, there was one full lecture that introduced the historical context and process associated with case studies that was modularized as well. The full modularization process for the SE1 module took approximately 8 hours total, with the identification of thematic topics and their corresponding timestamps requiring about 5 hours and the individual video segmentation adjustments requiring 3 hours. SE2 was similarly an approximately 7-hour time commitment, SE3 required about 5 hours, and SE4 and SE5 took under 4 hours. It is worth noting that the process did become increasingly efficient as the author's experience with modularization increased.

In addition to the time requirements, the cognitive load imposed on the designer (the author) by the task was high in some situations. The SE1 and SE2 modules were the most complex due to the number of lectures and an inconsistent presentation sequence of material pertaining to the same thematic topics across semesters. The SE3 module was less complex despite still having lecture videos from two semesters because there was a higher degree of consistent sequentiality. The consistent sequentiality was related to the significant emphasis on using paragraph-style lecture notes to structure the original lectures. SE4 and SE5 were both more straightforward, owing to the existence of only one semester of lectures. Especially in the more complex configurations, notes should be used throughout the process to manage the cognitive workload as much as possible.

The identification of thematic topics and the transitions between them is a highly subjective matter, especially if the lecturer utilizes a more conversational lecture style. It is possible that different viewers would identify different thematic topics and different points of transition. Critically, expertise with the subject matter (either in the form of taking the class or teaching it) is important to be able to effectively identify major and relevant thematic topics.

4.3.4 Outputs

The outputs of the content modularization process were the identification of the thematic topics within each module, which were then broken down into individual video segments that had links to the lecture notes and readings. Table 8 provides a description of the modules in terms of their content, thematic topics, and individual video segments. In total, 1293.72 minutes of content were modularized (excluding introductory lecture materials, which focused primarily on semester-specific course logistics). SE2 contained the most minutes of content, while SE4 contained the fewest. This is largely due to the number of semesters of lecture content that were available for each module. The number of thematic topics ranged from 7 to 10 for each module, for a total of 57 identified thematic topics. The average length of material associated with a thematic topic within each module ranged from 16.6 minutes to 29.65 minutes. The overall average length of a thematic topic was 23.9 minutes, with a maximum of 98.08 minutes (a thematic topic in SE2) and a minimum of 2.15 minutes (a single-video thematic topic also in SE2). There are a total of 138 individual video segments identified within this case design. The average video length is 9:22. The maximum video length is 15:45 minutes, which relates to a segment that introduces a case study. The minimum video length is 1:10, which describes a segment within the SE3 module. Of these videos, 66 of them were part of a sequential set, where one thematic topic segment was broken up into 2-5 parts, all of which are shorter than 15 minutes. There were 29 of these sequential sets in total across all modules.

A full list of the thematic topics and individual videos for each module can be found in Appendix A.

Table 8: Description of modules and their thematic topics and individual video segments

Module	Total length of content (min)	Number of Thematic Topics	Average Thematic Topic Length (mm:ss)	Number of Individual Video Segments	Average Video Segment Length (mm:ss)
SE1	275.92	10	27:36	30	09:12
SE2	296.47	10	29:39	38	07:48
SE3	206.82	9	22:59	22	09:24
SE4	116.20	7	16:36	12	09:41
SE5	152.10	8	19:01	15	10:08
Engineering Case Studies	246.22	10	24:37	21	11:43
Total	1293.72	54		138	

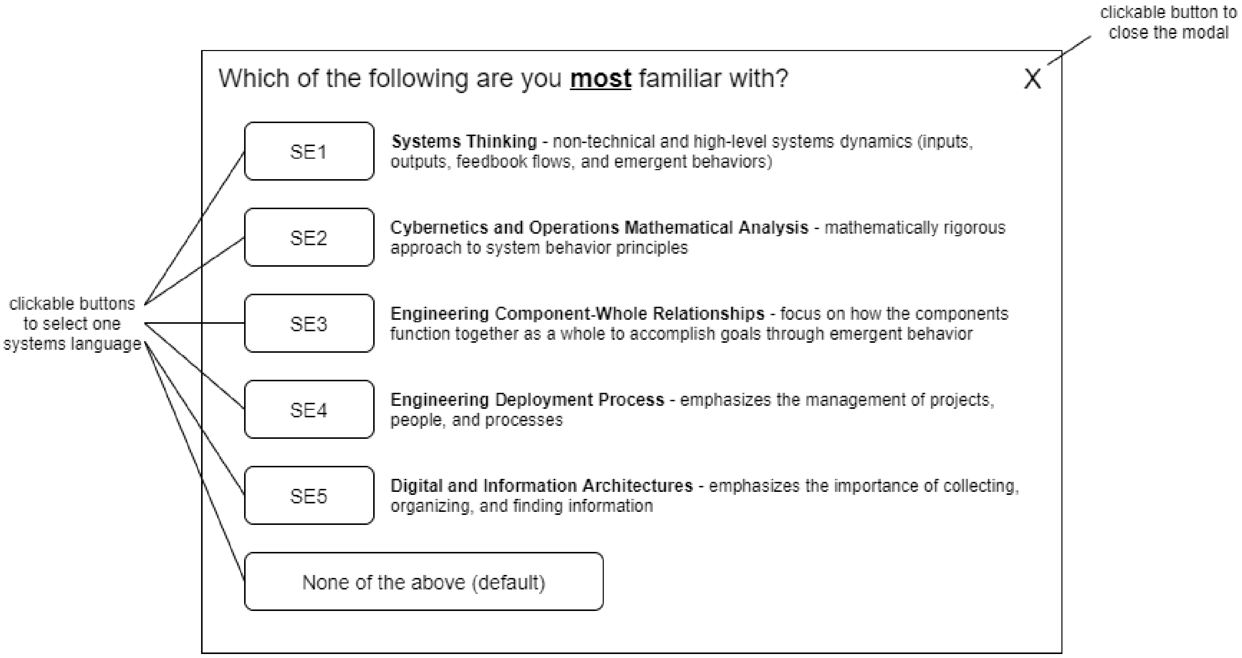
4.4 Non-Sequential Modules: Different Entry Points

The development of non-sequential modules emerged as an interaction between the development of the user personae and the higher levels of the content modularization process. The non-sequentiality of the modules is distinct from the non-sequential nature of thematic topics discussed as a design characteristic, as they occur at different levels. In this case, the emphasis is on the modules (i.e., SE1, SE2, etc.). However, there is one restriction: due to the nature of the material, the engineering case studies module cannot be accessed until after all systems languages have been completed.

The user personae reveal a variety of backgrounds that may result in different learners entering the course “speaking” different systems languages. Therefore, what information would be most familiar and accessible would vary significantly between learners. Providing learners with the material which is most familiar to them is one way to increase engagement and allow them to adjust to the learning environment. Therefore, users should be able to select which systems language they are initially most familiar with and subsequently begin learning with that module.

An example of what this might look like to the user is given in a wireframed modal (a dialogue or pop-up window) in Figure 24. This mechanism can be considered an opportunity for learners to customize their experience through an adaptable mechanism.

If a learner selects that they are not familiar with any of the systems languages based on the provided names and descriptions, then they will initially begin with SE1, as it is the most non-technical and widely accessible. Even in the case that a learner selects a systems language, an additional confirmation screen should provide them the opportunity to start at SE1 instead of that particular language. An example of this is shown in Figure 25. Ultimately, this functionality allows users to utilize different entry points into the material to access material that might be most relevant and familiar to them first.



clickable button to close the modal

clickable buttons to select one systems language

Which of the following are you **most** familiar with?

Systems Thinking - non-technical and high-level systems dynamics (inputs, outputs, feedbook flows, and emergent behaviors)

Cybernetics and Operations Mathematical Analysis - mathematically rigorous approach to system behavior principles

Engineering Component-Whole Relationships - focus on how the components function together as a whole to accomplish goals through emergent behavior

Engineering Deployment Process - emphasizes the management of projects, people, and processes

Digital and Information Architectures - emphasizes the importance of collecting, organizing, and finding information

Figure 24: Wireframing Modal for selecting a module, permitting adaptation of student access based on previous SE language familiarity

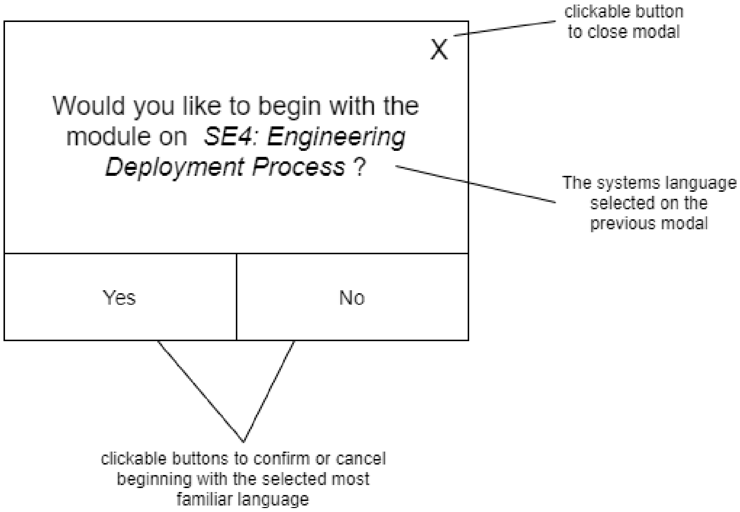


Figure 25: Wireframe for module selection confirmation modal

4.5 Tag and Indexing Term Identification

Tag and indexing term identification are methods that inform the design of the labeling framework, searching functions, and navigation mechanisms associated with organizing and accessing specific lecture videos, notes, and readings. Keyword is a broad umbrella term for the content within the PoSE course material. Keywords tend to be meaningful beyond common words utilized to structure information within a language (i.e., articles, prepositions, conjunctions, etc.). A subset of all keywords can be utilized to determine what words or phrases are candidates for contextual navigation. Meaningful terms from the content analysis were identified by the author, similar to the labeling approach, and then were analyzed for frequency and recurrence. If a meaningful term only occurred in a single, relatively short document, then it may not be worth utilizing it within the contextual navigation mechanism. However, if a keyword occurs across too many documents (for example, systems engineering), it loses its value as a navigational tool. Keywords matching this description will be called tags.

Indexing terms are critical to searching functions within a usable IA design. Index terms are informed by meaningful keywords within the content that were identified through the content analysis procedure. This set of keywords may be inclusive of the sub-set that were identified as tags, but this does not describe the full set of keywords used as index terms. This is because the process of identifying tags required consideration of the value of the terms to navigation. Some meaningful terms occurred too frequently or too infrequently to be valuable as contextual link labels. However, these terms can still inform the index terms that support the searching function and provide helpful insight into the contents of various media (text or video files) within the information environment.

The primary emphasis of this section is on the tagging process. Indexing terms are used for broad or deep searching by a range of learners. Therefore, all available and accurate keywords that can be identified may be of some use, especially since very little is known about how prospective users would go about searching the information space. First, the design characteristics associated with the tags and indexing terms will be described. Then, the process utilized to identify tags will be reported, followed by key takeaways from performing the process and outputs of the process.

4.5.1 Tagging Design Characteristics

There are several design characteristics that pertain to the identification of tags, with fewer relating to indexing terms. By their definition as keywords that support contextual navigation, tags must meaningfully allow navigation. The tag is a metadata structure that connects two or more individual instances of a keyword, allowing for navigation throughout the learning environment. These instances should be associated with a file and a location or timestamp. In order to meet this specification, tags must occur more than once throughout the six modules (SE1 – SE5; Engineering Cases) and must occur in more than one document. If both of these conditions are not met, the keyword is not considered to support navigation and therefore is not a tag.

However, just because a tag could support navigation does not mean it is ideal to do so. Some high-level tags may not be appropriate as a primary means of navigation, but instead be included to support the tagging relationships (discussed below). For example, “system” appears 5318 times throughout the full scope of the PoSE content (including recorded lectures, paragraph-style and slide-style notes, and assigned readings). It would not be reasonable to navigate utilizing “system” as a tag that supports navigation to all instances. At most, it may be useful to allow navigation to the initial definition of a system. However, it may be reasonable for learners to want to navigate from “system” to a lower-level tag like “system boundary” or “emergent capabilities.” Therefore, higher-level tags do not necessarily have to primarily support navigation throughout the content.

Tags must be consistently syntactically structured as nouns to follow labeling best practice within IA. Additionally, tags will have the relationships depicted in Figure 26, which is a variation on the semantic relationships for labels described in Rosenfeld et al. (2015, p. 283). The core tag, depicted in the center of the figure, may have hierarchical, equivalence, and associative relationships with other tags. Hierarchical relationships are associated with moving from the core tag to either a higher-level (broader) or lower-level (narrower) tag. Tags do not have to relate to either higher or lower-level tags, but if they do, there is no restriction on how many they may relate to. That is, a core tag may have zero or more hierarchical relationships. Tags that serve as examples for the core tag are considered to be a special case of a lower-level tag. For example, a "Dewey Decimal system" tag would be an example of a "taxonomy" tag. Tags may also have equivalence relationships with synonyms or other forms of the tag that appear within the content. For example, "living subsystems" would be considered a synonym for "living systems." Finally, an associative relationship may exist between the core tag and another tag that is related, but does not fall within any of the other relationship categorizations.

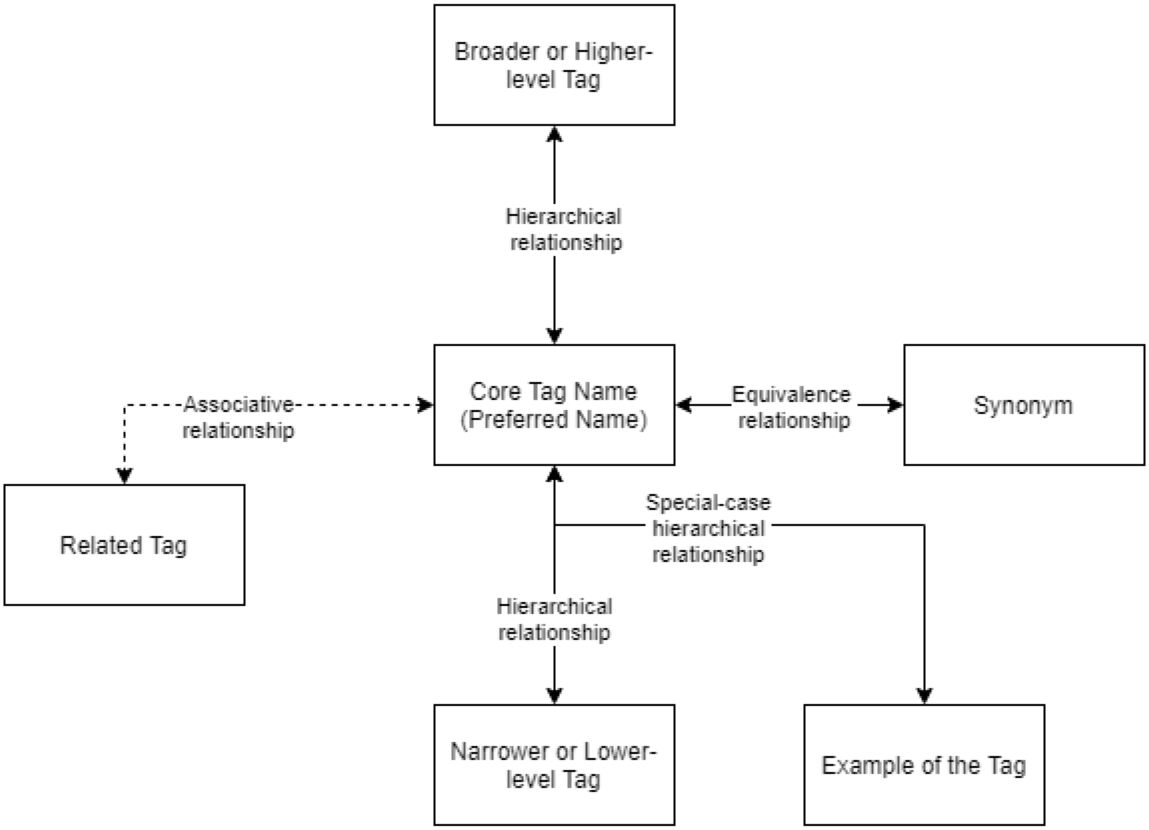


Figure 26: Visualization of the semantic relationships of tags. Figure and relationships are adapted from Rosenfeld et al. (2015).

Finally, instances within tags must have a specific relationship with other instances within the content that cover identical material in the same or a similar context. For example, a sub-topic may be discussed in lecture video content from both semesters and described in paragraph-style notes (or slides). In this case, accessing the tag through the instance that occurs in one of those materials should provide the user the opportunity to navigate to the "equivalent" material coverage in the other files.

As discussed above, indexing terms exist to support searching, so including as many keywords as possible with little a priori determination is beneficial. Little is known about how learners would try to search the learning environment or what information needs they would likely face. In fact, search patterns are highly unlikely to be uniform across the diversity of user personae described. Eli might be comfortable and accustomed to using specialized query languages with Boolean operators due to their computer science background. However, the same may not be true for Bailey, who may be more comfortable with natural language searches. Additionally, with the amount of content associated with PoSE, indexing the full learning environment would not result in an overwhelming number of results to most searches. Even keywords that occur at a high frequency are not so common that a search would be entirely overwhelming. For example, “system” occurs over 5000 times within the content and is present in 163 documents. However, this is only one of 14 terms that occur over 1000 times and one of 11 terms that occurs in over 100 documents. Therefore, the number of potential searches that could be considered overwhelming to the learner is minimal, suggesting that making all documents searchable is an appropriate and important design characteristic of the learning environment. Therefore, the following process, key takeaways, and outputs will emphasize tag identification over indexing term identification.

4.5.2 Process

The author’s process of tag identification was based on a content analysis performed on the modularized video lectures, paragraph and slide-style notes, and assigned readings. The full process is shown in Figure 27. After the author modularized the video segments, these segments were professionally captioned by a commercial captioning service (Rev.com) between January 25 and February 3, 2021. The choice to utilize professional, manual captioning services rather than automated caption generation was made after observing systemic issues with the existing automated captions from 2019. These issues included misinterpretations of meaningful content that could have resulted in significant misunderstandings if not corrected. The closed caption files (.SRT) for each lecture module were then imported, along with the notes documents and assigned readings for the associated SE lecture content, into MaxQDA. A breakdown of these files by the associated module is given in Table 9. It was ensured that the contents of the imported documents were readable by MaxQDA. When this was not the case upon initial import, the document was reformatted to be readable.

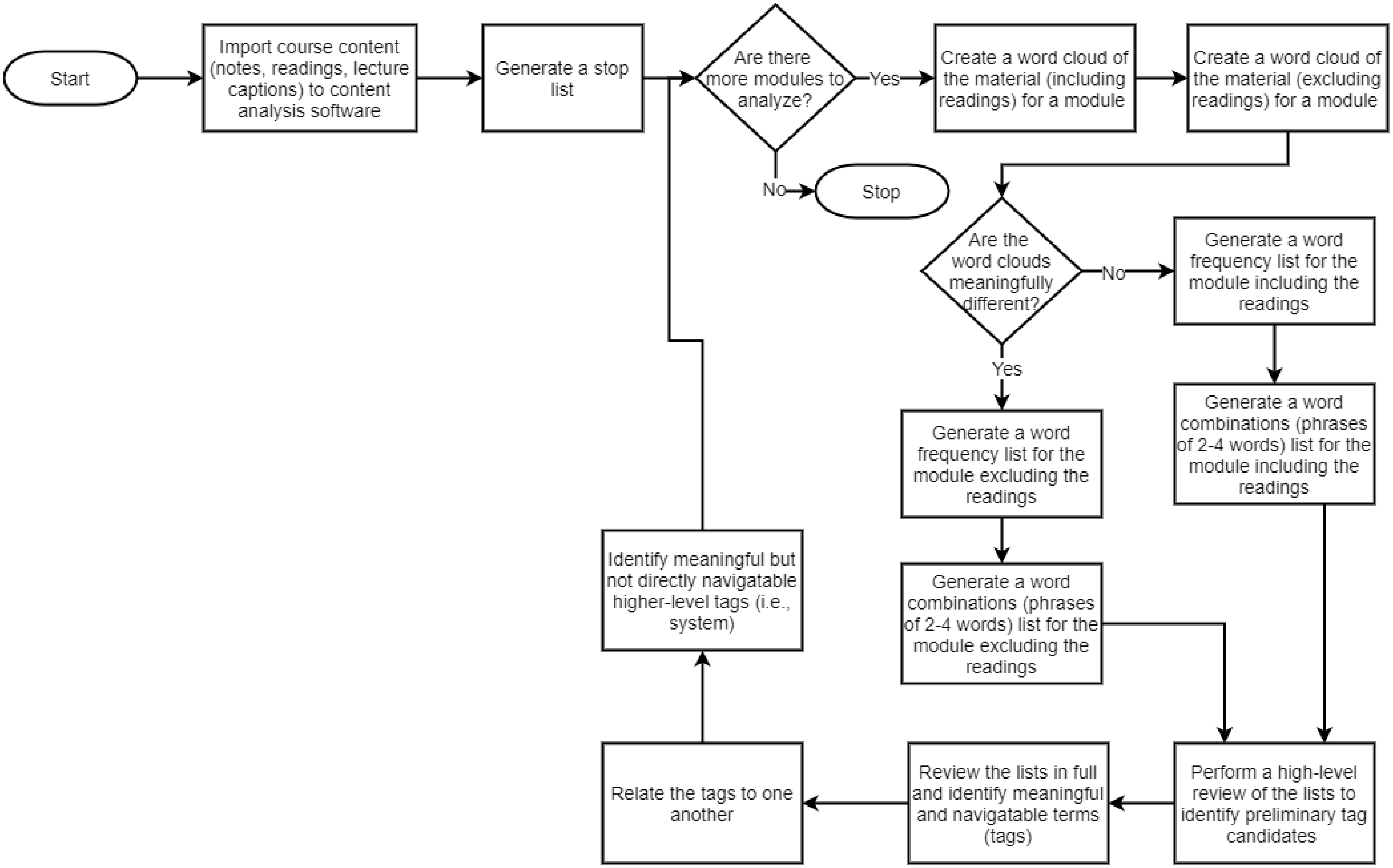


Figure 27: Flowchart describing the tag identification process

Table 9: Documents associated with the content analysis of author-created modularized content

	Number of individual videos (.SRT files)	**Number of notes documents**	**Number of assigned readings**
SE1	30	3	3
SE2	38	3	1
SE3	22	3	2
SE4	12	3	3
SE5	15	3	2
Engineering Case Study	21	6	6
Total	138	21	17

The content analysis performed on the materials included creating word clouds and utilizing the word frequencies and word combinations analyses to identify the full range of tags for each of the modules and also for all of the PoSE content. The word clouds were created both with and without the assigned readings included. The emphasis of the assigned outside readings could dramatically alter what content was being presented, particularly when readings were long. These analyses made use of the lemmatization function within MaxQDA, which combines syntactically related words. For example, the lemmatization function would combine "system" and "systems" into a single entry on the output word lists. Stop lists were also utilized to remove common English words, including articles, conjunctions, and prepositions, as well as meaningless phrases. These word clouds provide insight into candidates for high-level tags and additionally illustrate the different emphases present in each of the modules. The other analyses were also performed both at a module level and an overall content level. The following detailed example describes the tagging process at the level of detail of an individual module.

The word combinations analysis was set to consider combinations of 2-4 words that occur more than once within the selected content (module or all material). With a few exceptions, it was found that most four-word combinations were not useful, so this was considered to be the upper limit of the value of such an analysis. The word frequencies analysis considered a grain size of a single word. This analysis also made use of the lemmatization functionality and stop lists. Once the word lists containing combinations of 1-4 words were obtained, further manual selection processes were needed.

There were two stages of tag identification: the initial stage and the in-depth stage. The initial stage involved systematically searching through the word lists generated only for the PoSE lecture content (lecture video caption files and lecture notes) and extracting any clearly meaningful words or word combinations at the module level. These tag candidates were identified based on the author's familiarity with the subject matter and the material being covered in the lecture videos and notes and a special emphasis on direct (rather than indirect) navigability. Additionally, these candidates had to occur at least twice in at least two documents within the module. The order of this initial tagging process was applied to the modules, and the number of resulting tag candidates is given in Table 10.

The author then applied a more in-depth tag identification process. This tagging process still consisted of manually searching the word lists, but was much more thorough, requiring every entry in the list to be considered and marked as being relevant or irrelevant for inclusion. This judgment, unlike the previous judgment, included consideration of the tag relationships, and therefore captured a higher number of the high-level tags that had been dismissed from the initial identification process. In this case, even tags that only occurred in one document within a module could be considered if there were other instances within the full scope of the content. This provided a final list of tags; the number of these final tags in each module is also shown in Table 10, along with the order in which the modules were subjected to the tad identification process. The modules were not tagged in SE "language" order, to mitigate ordering biases that may interact with the amount of available content (both SE4 and SE5 have less content than the other modules). The average number of tags per module is 125.2 ($\sigma = 16.02$). The SE5 module has the lowest number of tags (94), and the SE2 module has the highest number of tags (148); both of these are within two standard deviations of the mean. There is no clear ordering effect in the final tag analysis. It is possible that the number of tags associated with SE5 is lower due to the total available content length, but SE4 has fewer minutes of content and more tags, so this is not the only factor at play.

Table 10: Description of tagging process outcomes

	Initial Tagging Stage Order	Number of Initial Tag Candidates	Secondary Tagging Stage Order	Number of Actual Tags Included in Module (including repeats)
SE1	2	52	2	130
SE2	1	71	3	148
SE3	5	39	1	124
SE4	4	24	4	130
SE5	3	29	5	94
Engineering Case Study	6	34	6	125

With the final list of tag candidates, the tags then must be related to each other. Tags should be identified as being either synonyms, higher-level, lower-level, examples, or related tags. These categorizations are treated as mutually independent. Finally, for each instance of the tags that are deemed fit to support navigation, equivalent instances must be identified and related to each other where they exist. When tagging instances in a video, a minimum of 10 seconds must be included in order to provide context to the instructor’s use of the tagged keyword. However, just because a tag instance occurs in one medium or file within a given module does not necessarily mean it will occur in others. For example, one lecture presentation may mention the tag “structural model.” Its presence in one lecture video does not guarantee its presence in a notes document or in the lecture segments modularized from another semester.

4.5.3 Tag Design Outcomes: Key Takeaways

There are several notable additional takeaways associated with completing the tagging process. First, the detailed implementation and tag specification process is more demanding than it may appear, even for a relatively small information space. Even with an extensive stop list and limiting the scope to a single module, the PoSE corpus reflects a substantial base of potential information tags. Effectively determining what is relevant and irrelevant requires the judgment of someone who is familiar not just with the domain, but with the content being presented within the course. The author met these requirements due to having already experienced the hybrid PoSE course, as well as taking and TAing for other systems-related courses and worked alongside the PoSE course designer and instructor. This expert judgment is also required in order to accurately identify relationships amongst the tags. It is worth noting that both judgments are somewhat subjective, and therefore different people may identify different tags and different relationships.

Table 11: Precision of initial tag identification process compared to the in-depth, secondary tag identification process

	Number of Initially Identified Tags that were also Final Tags	**Percentage of Initial Tags that were also Final Tags**	**Percentage of Final Tags that were Initial Tags**
SE1	40	76.92% (40 of 52)	30.76% (40 of 130)
SE2	62	87.32% (62 of 71)	41.89% (62 of 148)
SE3	35	89.74% (35 of 39)	28.23% (35 of 124)
SE4	22	91.67% (22 of 24)	16.92% (22 of 130)
SE5	27	93.10% (27 of 29)	28.72% (27 of 94)
Engineering Case Studies	27	79.41% (27 of 34)	21.60% (27 of 125)

The initial tagging process was effective at identifying only a subset of the final tags, as shown in Table 11. Of the tags identified for each module within the initial tagging process, emphasizing the lecture content and emphasized navigability, 76-93% appeared in the final tag list as well. This indicates that a majority of the tags that were identified were, in fact, later confirmed to be relevant. However, this initial tagging process resulted in “false positive” tags. Across all six modules, the tags identified in the initial tagging process never met or exceeded 50% of the final tags. That is, in the SE1 module, 40 tags that overlapped between the initial and in-depth phases made up only approximately 30% of the final tag list. Therefore, the in-depth tag identification phase that considers the readings (where they do not introduce significant bias), indirect navigation, and the relationships between tags are important to creating a full tagging environment. There is some iteration that may occur between relating the tags to one another and the identification of tags. The process of trying to relate tags may indicate the value of including a tag that had initially been judged as less relevant on previous iterations. From the author's experience, the process of relating the tags to one another is best done visually, but best recorded in a table, such as the one provided in Appendix B.

Finally, it is important to be vigilant around transcription errors in the captioning files. Failing to recognize these can result in a failure to identify instances of a tag. For example, one error observed was the use of "se four" rather than the expected term "SE4." Capturing and correcting or accounting for these inconsistencies is critical to a highly functional tagging system.

4.5.4 Tag Outputs

The outputs of the tagging process include visualizations of three different core tags and their relationships, the word clouds (both including and excluding the readings), and example wireframes for the user-facing tagging interface.

The three tag visualization examples provided below are all from the SE3 module. The full tag table associated with this module can be viewed in Appendix B. Figure 28 depicts the tag tree associated with the "assembly task" tag. It has two higher-level tags (assembly and task) and two lower-level tags. These lower-level tags are related to one another, and one of them has a synonym. Finally, the "assembly task" tag has an associative relationship with six other tags.

Figure 29 depicts "neuron" as the core tag. This tag has one synonymous tag and five lower-level tags that describe the sub-components of a neuron. There are two higher-level tags ("brain" and "cell"), and one of these higher-level tags is related to one of the core tag's lower-level tags ("nucleus").

Finally, Figure 30 shows the core tag "nonliving system" and its relationships to other tags. This tag has one higher-level tag and three synonymous terms. It also has an associative relationship with three other tags, one of which is "living system," the antonym of the core tag. This highlights the flexibility of the associative relationship.

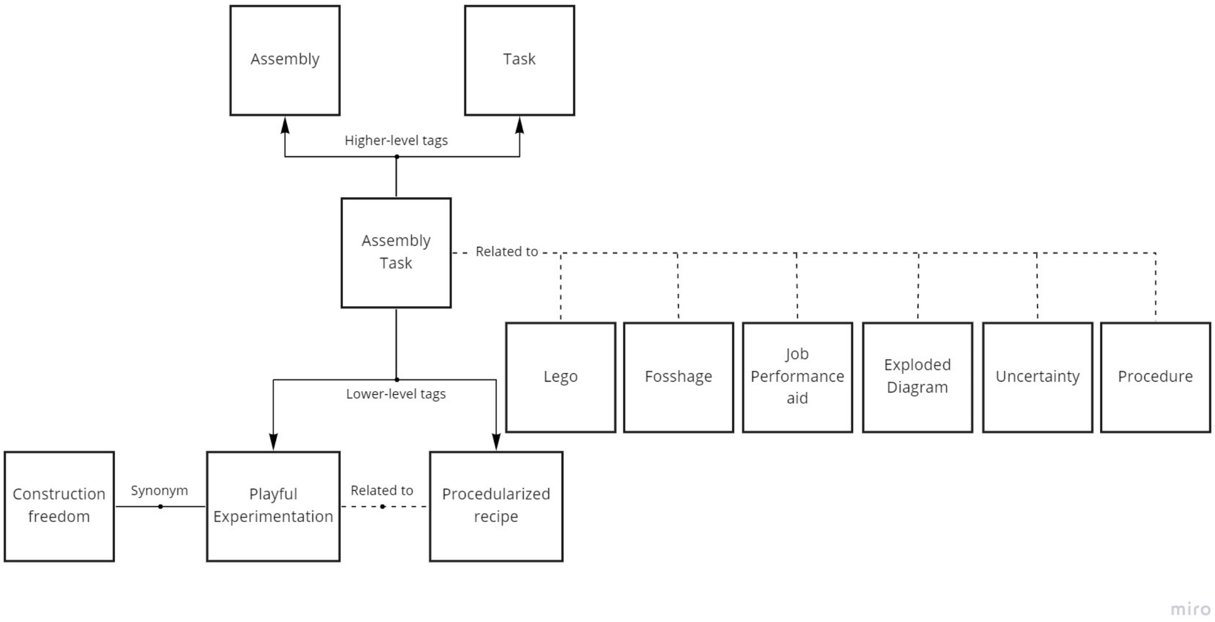


Figure 28: Tag Tree for "Assembly Task"

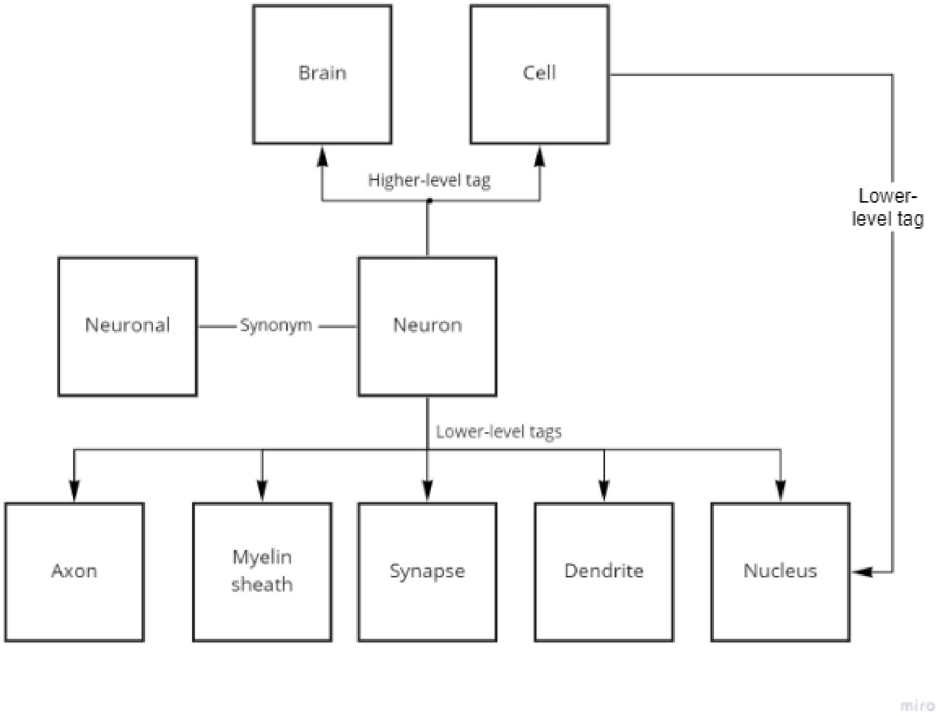


Figure 29: Tag Tree for "Neuron"

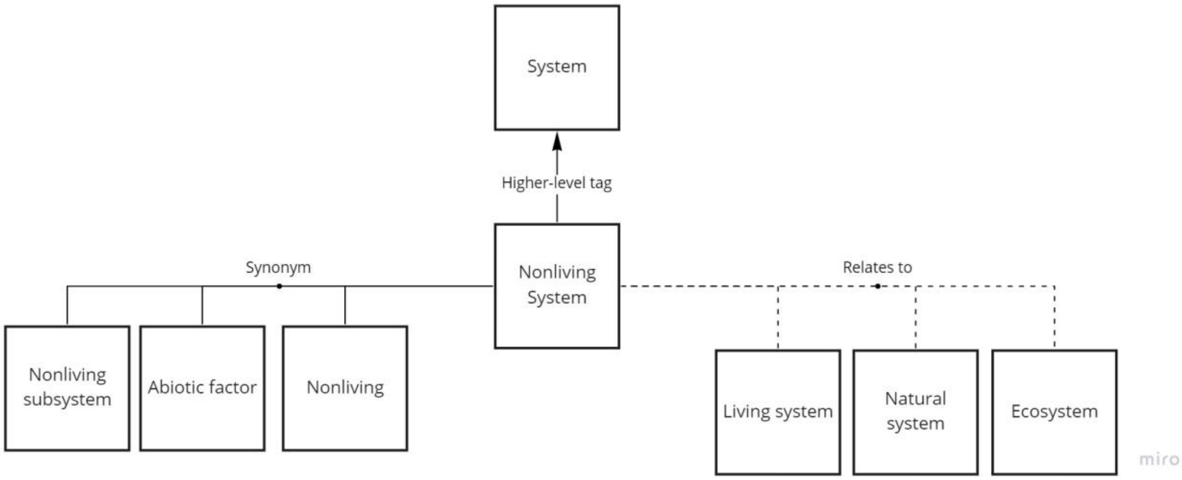
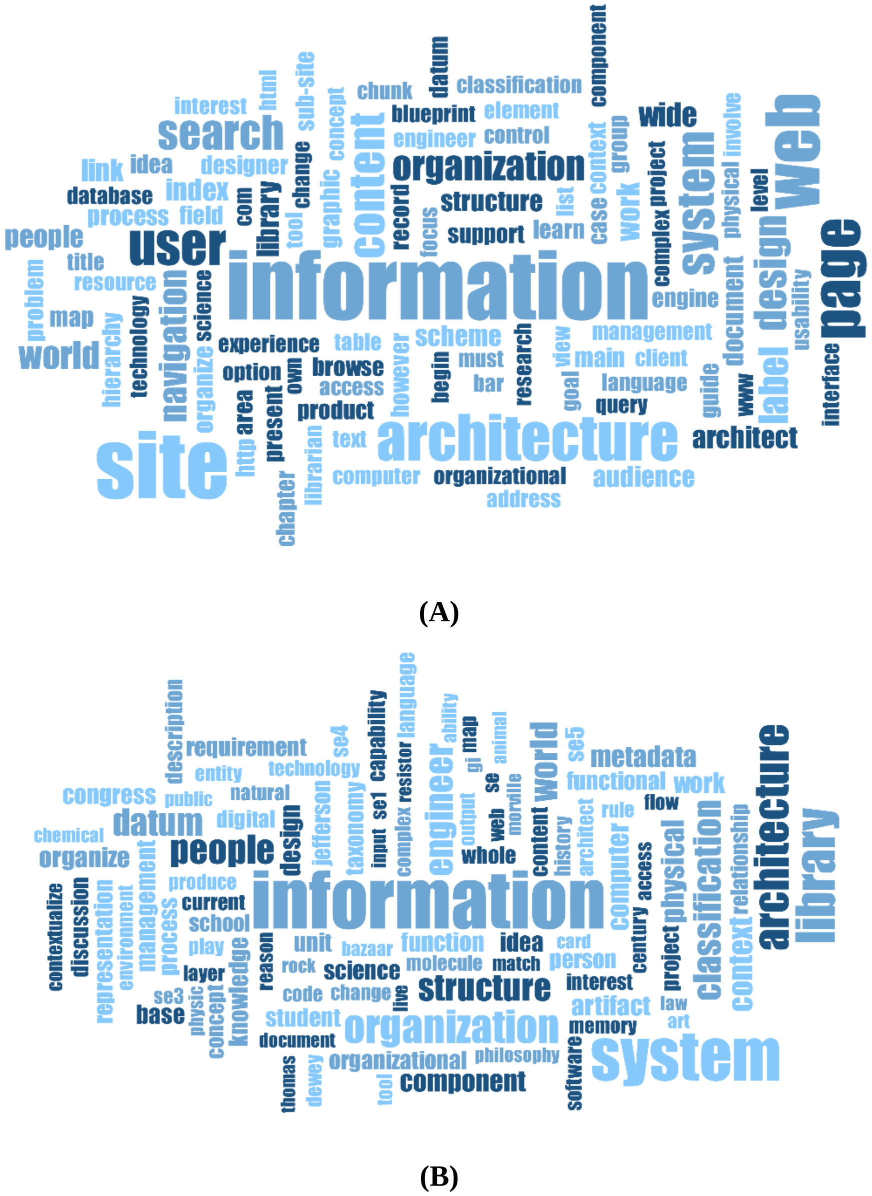


Figure 30: Tag Tree for "Nonliving System"

A set of word clouds associated with the SE5 module is presented in Figure 31. This module was chosen as an example because it is one of the modules where a longer assigned reading does result in substantial differences between the word cloud that includes the readings and the one that does not. In the word cloud generated with the readings, terms such as “site,” “web,” “page,” “content,” and “search” are heavily emphasized, but they are absent in the word cloud that excludes the readings. Similarly, many of the words present in the word cloud that only considers lecture material are strongly de-emphasized (i.e., “classification,” “library,” etc.) or entirely absent (i.e., “metadata,” “SE4,” “SE5,” etc.) in the word cloud analysis that includes the readings. This suggests a considerable influence of the readings on the word frequencies, which may result in certain tag candidates appearing to be more important than they truly are in the scope of the material as a whole.



(A)

(B)

Figure 31: Word clouds describing the SE5 module (A) excluding assigned readings and (B) including assigned readings

Finally, wireframes were developed to provide an example of how the user can interact with the tags. Figure 32 shows an example screen for viewing an individual lecture video segment. At the bottom of the screen, there are a few example tags: “grain size,” “assembly task,” and “constructivist learning.” The former two are active and clickable, whereas “constructivist learning” is inactive and not currently clickable. A tag being active means that it is associated with the current timestamp in the video. In order to access the tag interface, the learner would click on one of the active tags, such as “assembly task.” This will open the modal depicted in Figure 33.

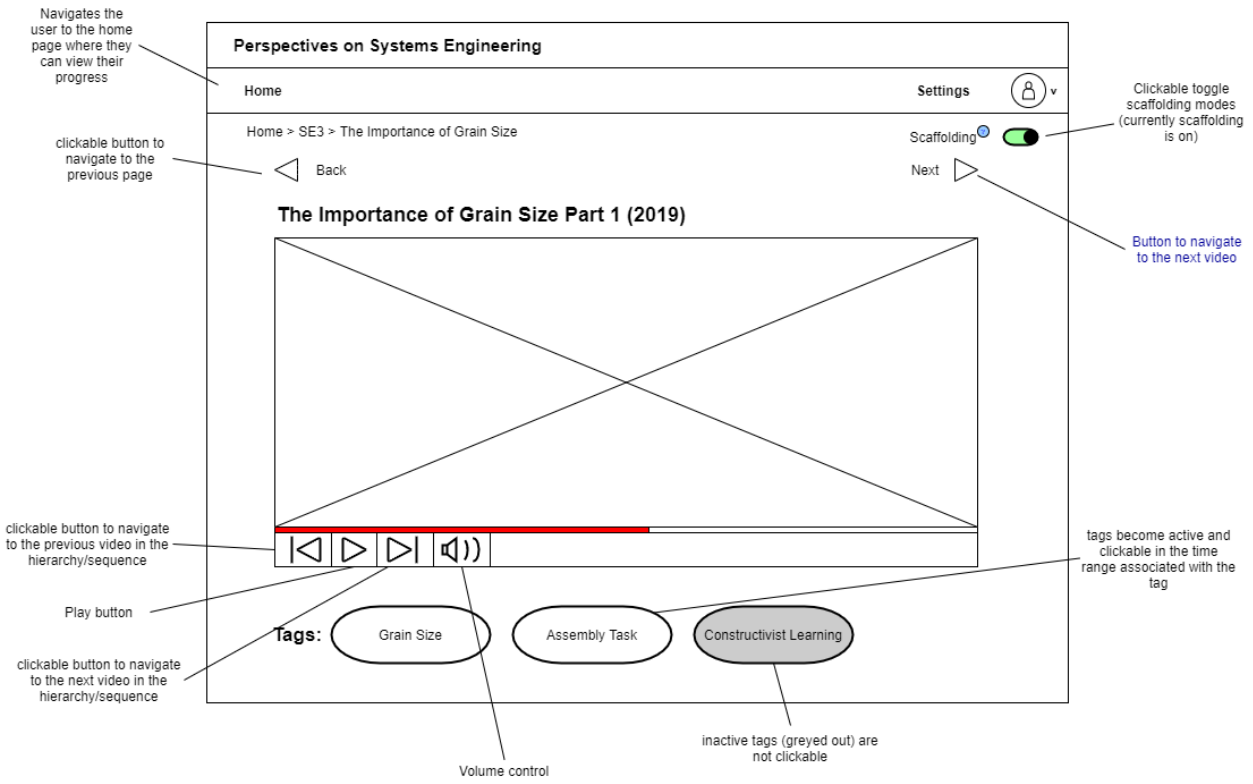


Figure 32: Wireframe for an example video screen, supporting user adaptation for tag use and video navigation

This modal provides the name of the tag as well as identifying where the learner has accessed the tag from (labeled "source"). If there is other material with similar or equivalent content (lecture notes, video material from either another semester, or a second reference to the content in the same semester), the user will be able to navigate to these in the notes or other lecture recording. Learners will be able to navigate from the core tag ("assembly task") to the other tags that are related to it through hierarchical or associative links. Finally, in tags meant to support navigation (not high-level tags), there should be an option to view all instances of the tag, but this should be information that is only presented when requested by the learner (through clicking a dropdown button, for example).

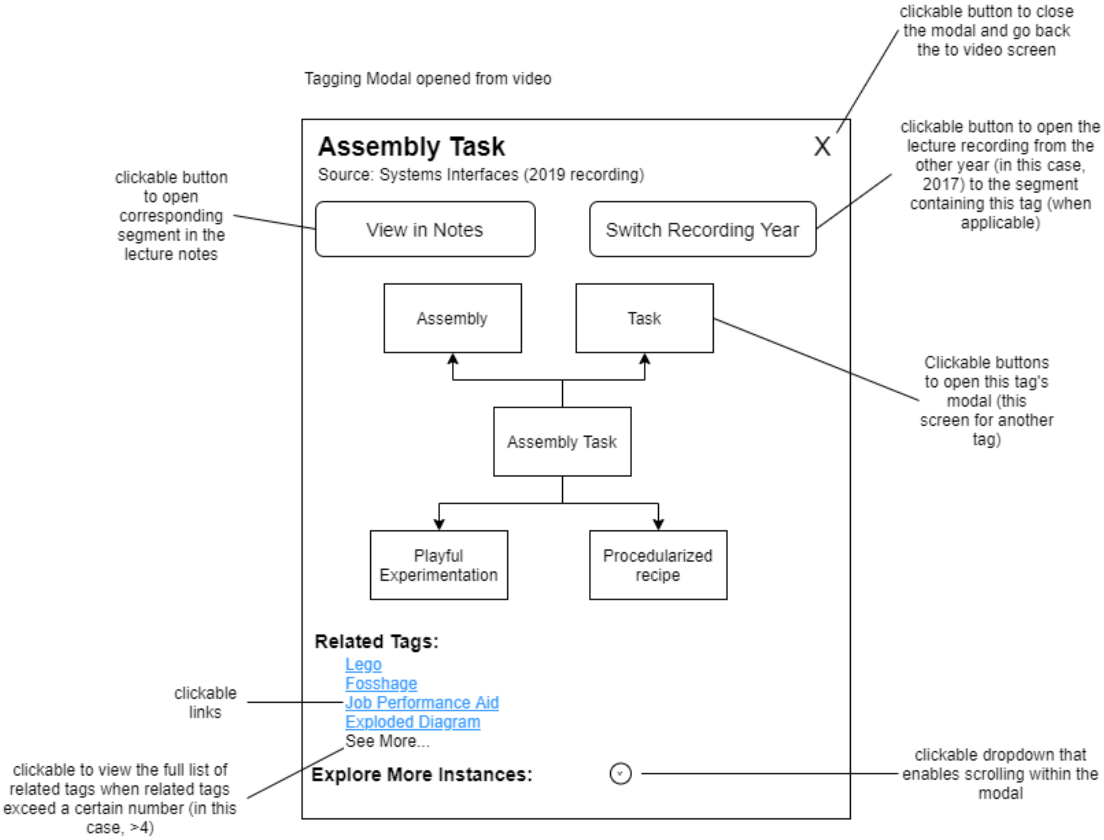
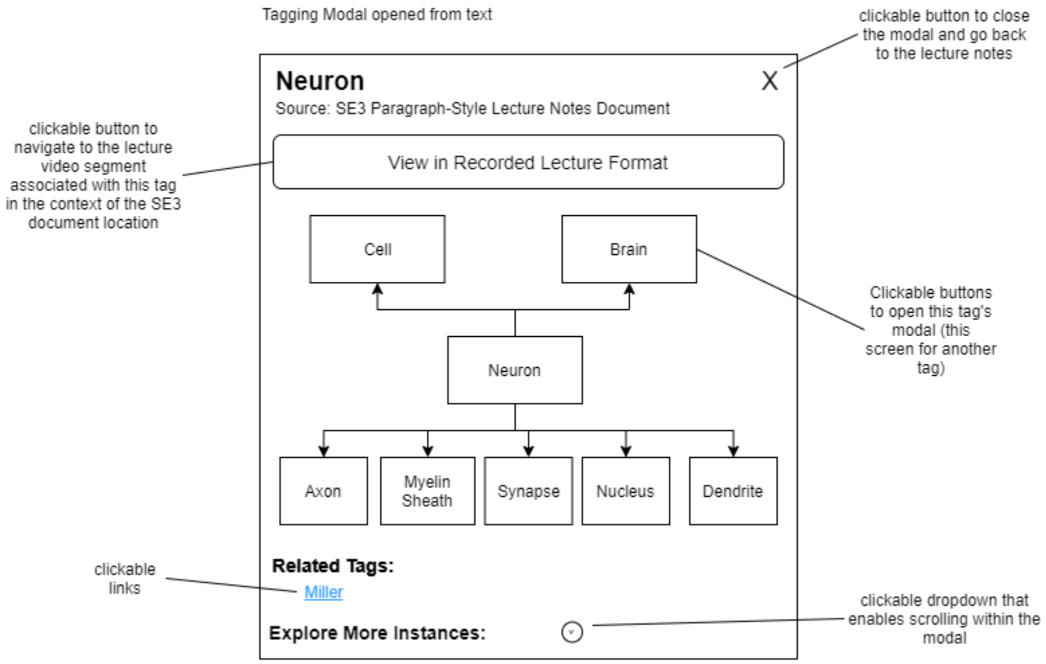


Figure 33: Wireframe for Tag Interface as opened from a video screen

Figure 34 similarly shows the tag modal interface, this time for a tag instance that was opened from the lecture notes. For this core tag ("neuron"), there is only one associated equivalent lecture presentation. Figure 35 provides an example of what it might look like when the learner does request to view all instances of a tag. The source instance is highlighted in red, and there are clickable links to navigate to the other instances.



clickable button to close the modal and go back to the lecture notes

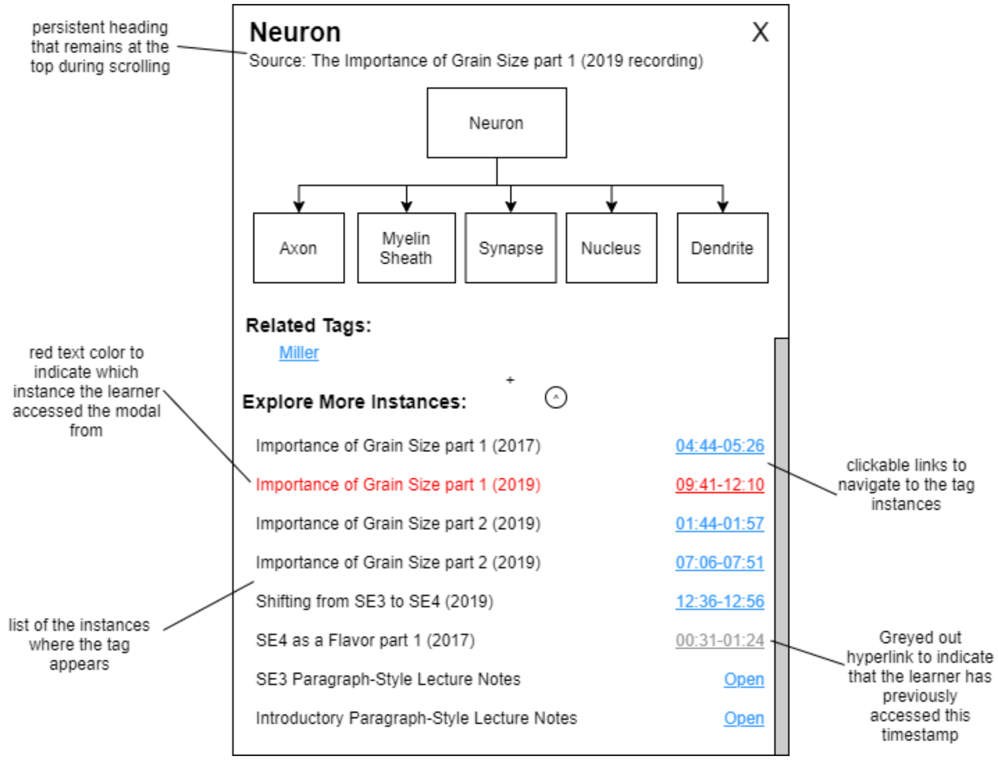
clickable button to navigate to the lecture video segment associated with this tag in the context of the SE3 document location

Clickable buttons to open this tag's modal (this screen for another tag)

clickable links

clickable dropdown that enables scrolling within the modal

Figure 34: Wireframe for Tag Interface as opened from the lecture notes document



Importance of Grain Size part 1 (2017)	04:44-05:26
Importance of Grain Size part 1 (2019)	09:41-12:10
Importance of Grain Size part 2 (2019)	01:44-01:57
Importance of Grain Size part 2 (2019)	07:06-07:51
Shifting from SE3 to SE4 (2019)	12:36-12:56
SE4 as a Flavor part 1 (2017)	00:31-01:24
SE3 Paragraph-Style Lecture Notes	Open
Introductory Paragraph-Style Lecture Notes	Open

persistent heading that remains at the top during scrolling

red text color to indicate which instance the learner accessed the modal from

list of the instances where the tag appears

clickable links to navigate to the tag instances

Greyed out hyperlink to indicate that the learner has previously accessed this timestamp

Figure 35: Wireframe of the Tag Interface with "Explore More Instances" expanded

4.6 Adaptable Information Structure and Navigation

The adaptable information structure and supporting navigation mechanism is an example of the learning environment being dynamic in order to respond to the diversity of learner needs and characteristics reflected by the user personae. Within an information architecture, the information structure organizes the content, and the navigation mechanisms allow users to move through the various pieces of content. Information structure and navigation are highly interdependent, as the types of navigation available are constrained by the organization of the material. There are two major configurations that are relevant to consider for this case design: the hierarchical structure and a non-sequential, thematically linked structure. More experienced learners (those with higher levels of prior knowledge) are able to utilize the non-sequential structure, but novices experience significant disorientation and negative learning outcomes (Amadieu et al., 2009; McDonald & Stevenson, 1998; Müller-Kalthoff & Möller, 2003). In contrast, the expertise-reversal effect can render the hierarchical structure that provides the needed scaffolding for novices as unnecessary or detrimental for the more experienced learners (Kalyuga, 2007; Kalyuga et al., 2003). In order to address the needs of both groups, dynamic information structures and navigation mechanisms must be utilized.

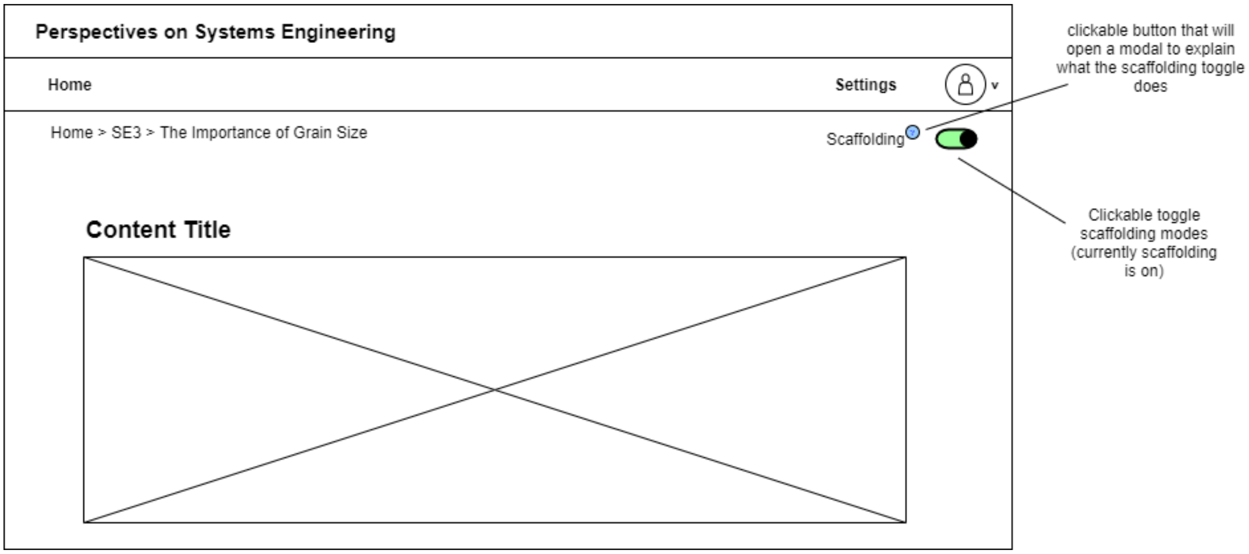
Navigation mechanisms are often hybrid systems, with different approaches applied at the varying navigational levels. Purely hierarchical navigation mechanisms only allow users to navigate up or down a level in the hierarchy (Rosenfeld et al., 2015). The restrictiveness of such an approach means that purely hierarchical navigation structures are rarely used. Global navigation mechanisms are available throughout the entire application, while local navigation mechanisms are available at a lower level and may vary across the full environment depending on which content module is being viewed. Additionally, contextual navigation supports NSISs through allowing users to navigate directly to another particular piece of content. As discussed above, non-sequential information presentation may have benefits for some users performing some types of tasks.

Adaptable and adaptive interfaces both allow for a dynamic user experience that may be beneficial if the primary navigation mechanisms may differ depending on individual differences. When it comes to these dynamic experiences, it is important to consider the locus of control for the adaptation behavior. Adaptable interfaces emphasize placing the locus of control with the user and generally interact with changes that do not occur frequently. Adaptive interfaces place the control primarily with the machine, and changes generally occur over the course of a session. In the case of the dynamic information structure and navigation mechanism, these features of an adaptable interface represent a better fit than an adaptive interface. It is critical to provide learners with control over the adaptation due to the significant influence the adaptation behavior has on their experience. The adaptation is not minor, instead influencing how they perceive the information to be organized and how they move through that information landscape. The learner would be in a better position to gauge their current level of expertise with the material, as well as their preferred cognitive load, in order to engage the non-sequential system only when they feel comfortable to do so. Additionally, keeping the control firmly in the learner's hands empowers them to switch back to the hierarchical presentation if they become overwhelmed or disoriented.

4.6.1 Adaptation Trigger

The adaptation trigger proposed for the current PoSE adaptable information structure and navigation mechanism is a means of self-selecting a scaffolded (hierarchical) presentation or an unscaffolded (non-sequential) presentation. This self-selection tool could take a number of forms: in Figure 36 and Figure 37, the tool is presented as a toggle which shows the scaffolding on and off settings respectively. It is critical that regardless of the exact mechanism, the adaptation trigger is always available to the learner so that they can easily switch between a scaffolded and an unscaffolded experience as needed.

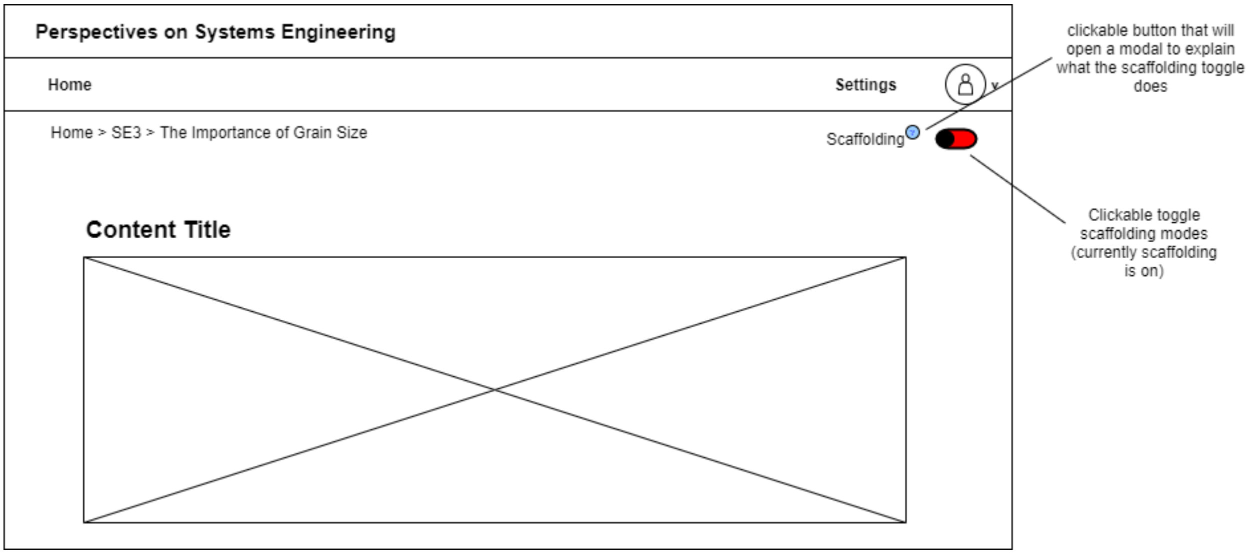
Additionally, information regarding the adaptation trigger and the behavior it controls should be available to the learners on demand. This is represented by the blue question mark button in Figure 36 and Figure 37, but the exact "at-the-screen" UI mechanism is not the emphasis of this thesis. An example of what this detailed explanation might look like is provided in Figure 38. This modal is primarily informational, rather than having a high level of functionality, and describes both settings. The learner is also informed about the availability of the adaptation trigger.



clickable button that will open a modal to explain what the scaffolding toggle does

Clickable toggle scaffolding modes (currently scaffolding is on)

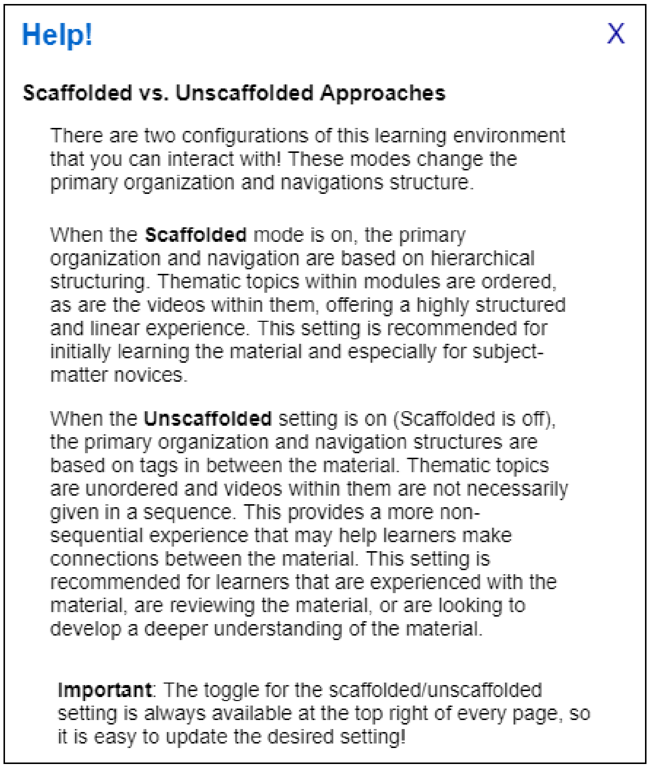
Figure 36: Wireframe of a content page with scaffolding setting on



clickable button that will open a modal to explain what the scaffolding toggle does

Clickable toggle scaffolding modes (currently scaffolding is on)

Figure 37: Wireframe of a content page with scaffolding setting off


Help!

Scaffolded vs. Unscaffolded Approaches

There are two configurations of this learning environment that you can interact with! These modes change the primary organization and navigations structure.

When the **Scaffolded** mode is on, the primary organization and navigation are based on hierarchical structuring. Thematic topics within modules are ordered, as are the videos within them, offering a highly structured and linear experience. This setting is recommended for initially learning the material and especially for subject-matter novices.

When the **Unscaffolded** setting is on (Scaffolded is off), the primary organization and navigation structures are based on tags in between the material. Thematic topics are unordered and videos within them are not necessarily given in a sequence. This provides a more non-sequential experience that may help learners make connections between the material. This setting is recommended for learners that are experienced with the material, are reviewing the material, or are looking to develop a deeper understanding of the material.

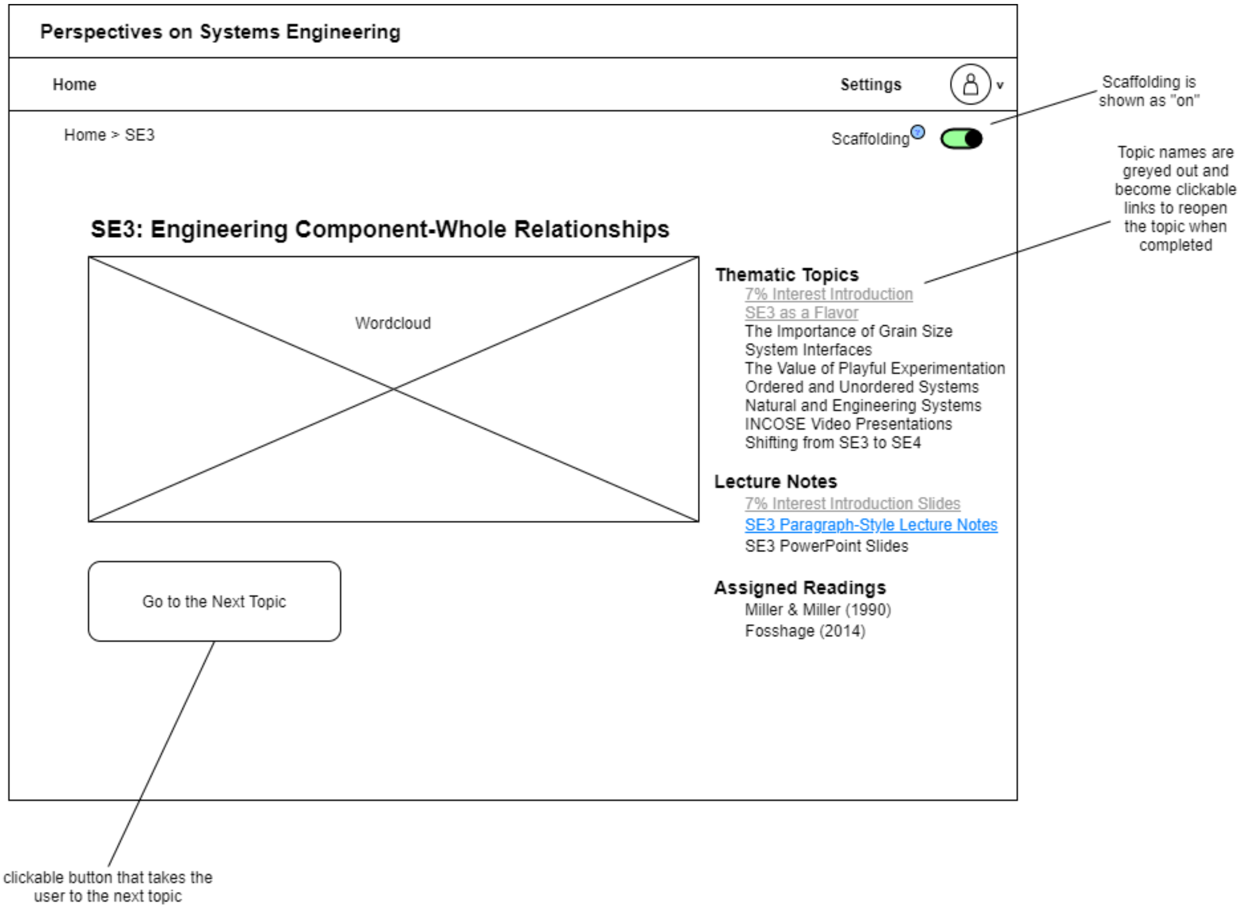
Important: The toggle for the scaffolded/unscaffolded setting is always available at the top right of every page, so it is easy to update the desired setting!

Figure 38: Wireframe of the help regarding scaffolded versus unscaffolded settings modal

4.6.2 Scaffolded Information Structure and Navigation

The scaffolded information structure and the supporting navigation mechanism are structured hierarchically to provide additional support for learners (especially those for whom the SE language content is not previously familiar). The hierarchical structure emphasizes a sequential route through the material within each module (though the modules may still be accessed in any order). The tags associated with the content still provide a non-sequential means of navigating to other content, resulting in a hybrid navigation structure. An example of what a module page might look like in the scaffolded configuration is given by Figure 39. This page only allows the learner to progress sequentially to the next thematic topic (e.g., The Importance of Grain Size) or return to previously completed thematic topics to support review activities. The notes associated with any of the completed or next video segments are available, and readings are always available. This scaffolded configuration was also exemplified above in Figure 32, as the only navigation options available to the user were to proceed or go back. The hierarchical structure of the material is exemplified for the SE3 module in Figure 40. This shows the recorded lecture videos as well as the notes and readings and provides more detailed insight into the hierarchical information structure.

Compared to domain experts, subject-matter novices are more likely to become “lost” in a non-sequential information space and are less likely to be benefited from being provided additional control over their learning experience (Lawless & Brown, 1997). In contrast, novices can benefit from more restricted learning environments and hierarchical information structures (DeStefano & LeFevre, 2007). This may be due to the fact that learners with higher levels of prior knowledge experience less cognitive load associated with processing the information, possibly due to their existing knowledge schemas and how they are accessed by working memory (Amadieu et al., 2017). NSISs are associated with cognitive load challenges such as cognitive overload and disorientation.



Scaffolding is shown as "on"

Topic names are greyed out and become clickable links to reopen the topic when completed

clickable button that takes the user to the next topic

Figure 39: Wireframe of systems language page with scaffolding on

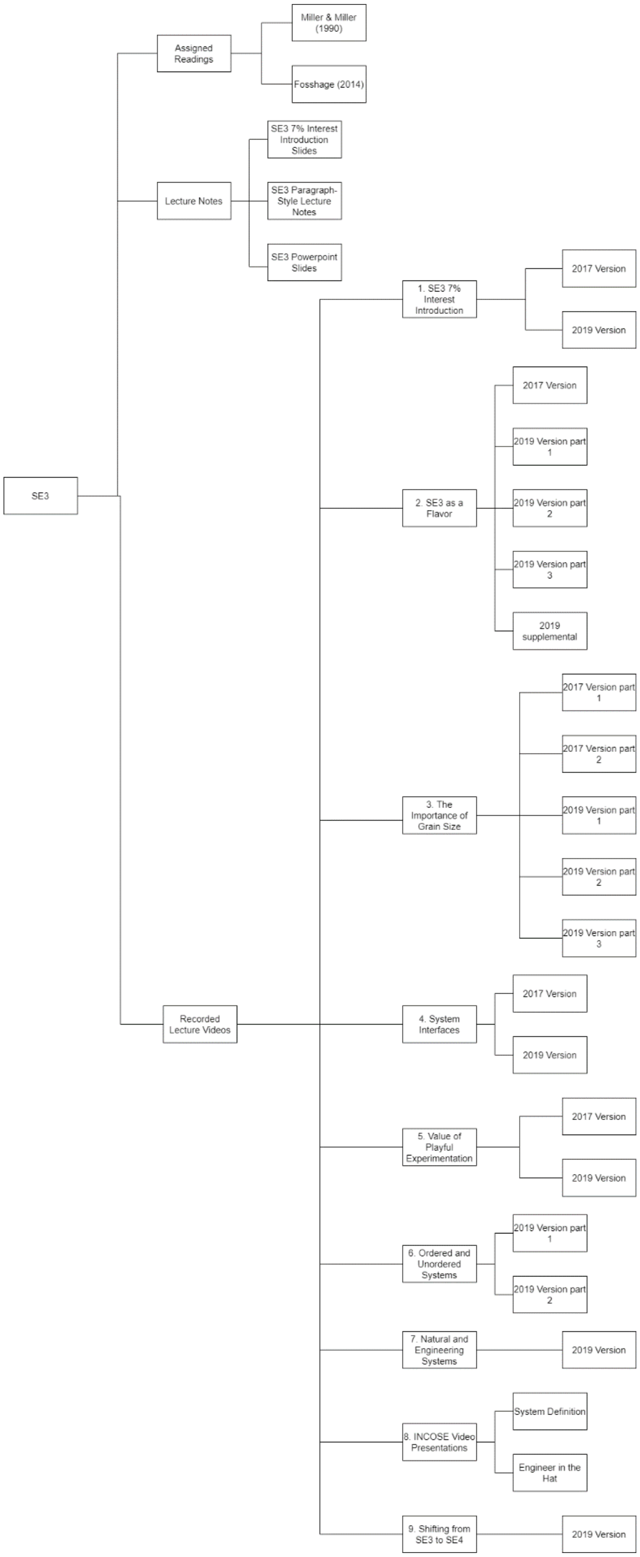
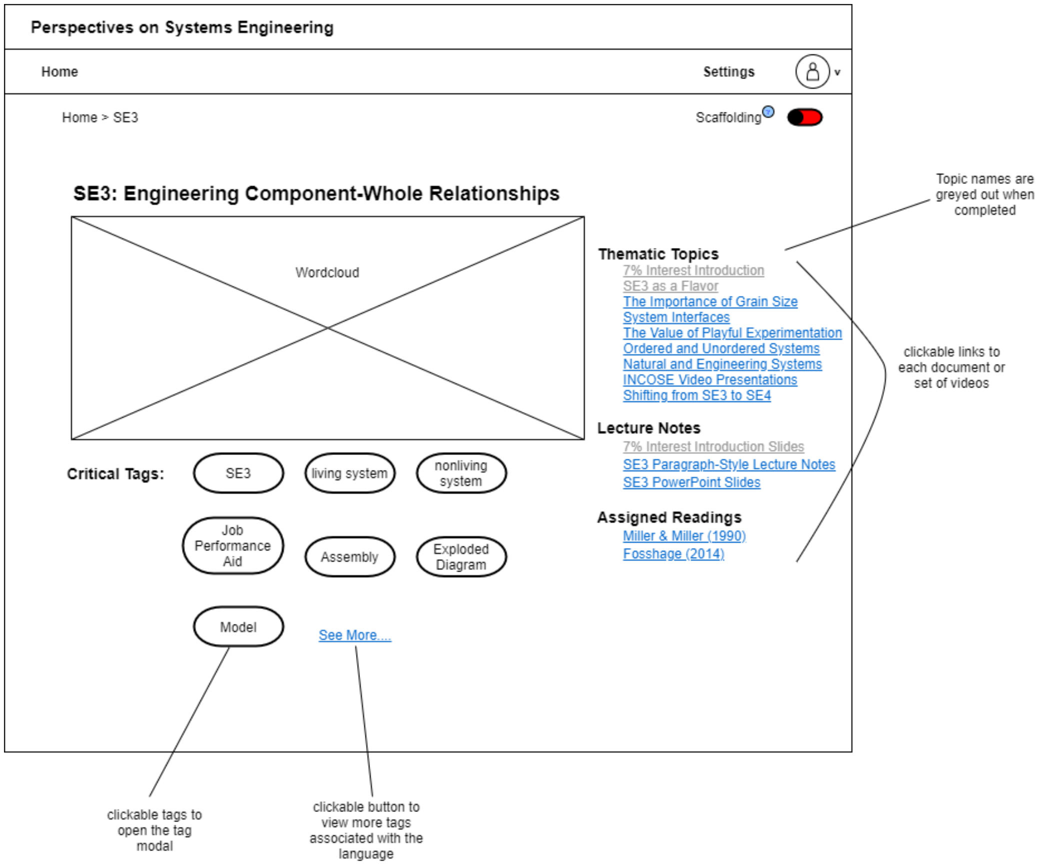


Figure 40: Hierarchical Structure of SE3

4.6.3 Unscaffolded Information Structure and Navigation

The unscaffolded information structure and navigation approach is characterized by a non-sequential information structure (NSIS) that relies heavily on the usage of tags for navigation, although some structure is still provided to support information findability as described in Rosenfeld et al. (2015). This allows learners (especially those with significant previous exposure to, and familiarity with, the SE language being presented) to move through the learning environment more freely, as there is no required sequence associated with thematic topics. An example of a systems language module page in the unscaffolded configuration is given by Figure 41. All the thematic topics are clickable. In addition, there are a number of "critical tags" associated with the systems language. These are clickable and would take the learner to the tag system interface described previously. As an additional contrast to the scaffolded configuration, Figure 42 depicts a sample video screen without the navigational supports to go back or onward to the next video. Instead, the tags are highlighted as a means to navigate the content. The structure of this NSIS is significantly more complex than a hierarchical information structure, and this is depicted in Figure 43. This diagram depicts all the possible navigation routes that can be taken between the lecture material (video segments, assigned readings, and paragraph-style and slide-style notes) in the SE3 module, using only tags to navigate non-sequentially among SE3 material. This excludes consideration of high-level tags that are not conducive to navigation, such as "system" and "component." There are only 34 of a possible 352 navigation pathways that were only characterized by a high-level tag, and only one where no linking tag between the segments was present.

Non-sequential information structures are thought to mirror the way that the human mind works through the use of associative links (Lawless & Brown, 1997). Exploring information spaces that are structured non-sequentially can allow for a more holistic understanding of the space by highlighting different perspectives and connections between material. Therefore, NSISs can be useful for deepening an existing understanding. However, as discussed previously, there are a number of challenges, including cognitive overload, disorientation, and distraction, that disproportionately impact subject-matter novices. In contrast, subject-matter experts (or even more experienced learners) are better able to manage their cognitive load and avoid becoming "lost" in the NSIS. Therefore, it is recommended that the unscaffolded setting be available so that as learners gain experience, they can take advantage of this system without experiencing its challenges as sharply.



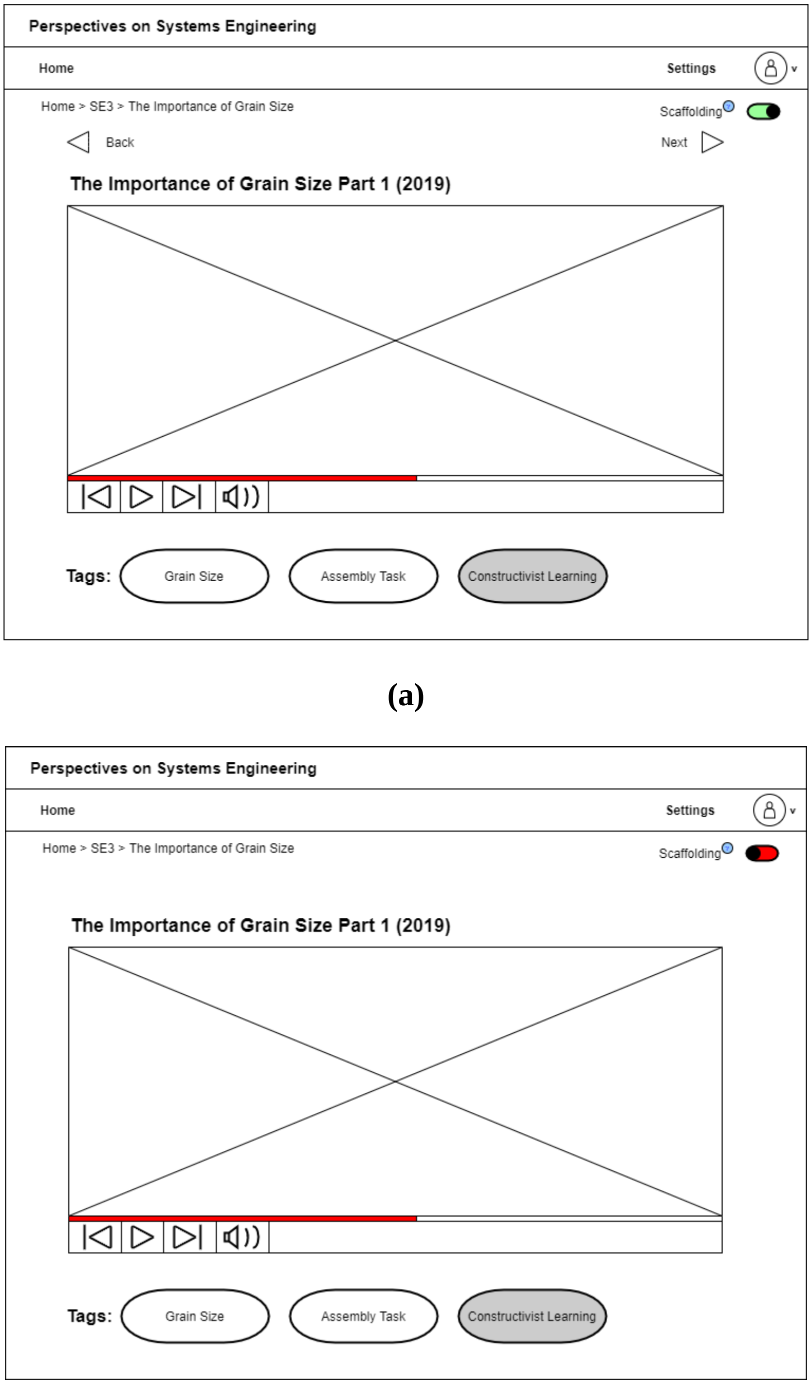
Topic names are greyed out when completed

clickable links to each document or set of videos

clickable tags to open the tag modal

clickable button to view more tags associated with the language

Figure 41: Wireframe for system language page with scaffolding off. Completed thematic topics are greyed out, while uncompleted thematic topics (never-accessed and in-progress) are shown as blue hyperlinks.



(a)

(b)

Figure 42: Video screen with the scaffolding setting turned (a) on and (b) off

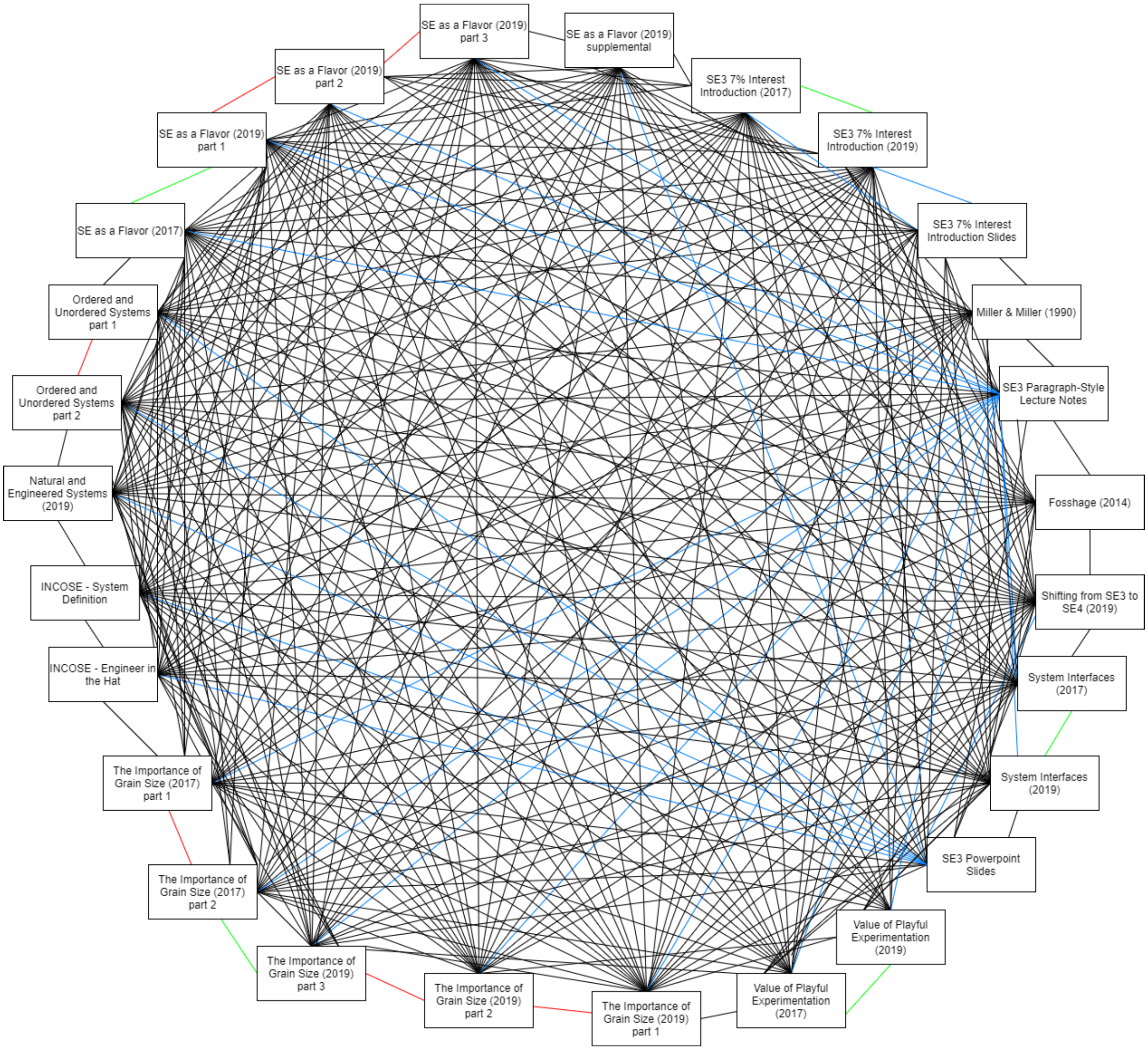


Figure 43: Network diagram showing the navigable pathways between video segments using the tagging interface in the SE3 module. Red links represent a sequential relationship between video segments. Blue links represent a relationship between lecture segments and their corresponding paragraph or slide-style notes. Green links (around the outer border) indicate roughly comparable video segments. Each of these types of links, as well as the black links, implies the existence of an available tag-based navigation pathway.

4.7 Adaptable Information Presentation Customization

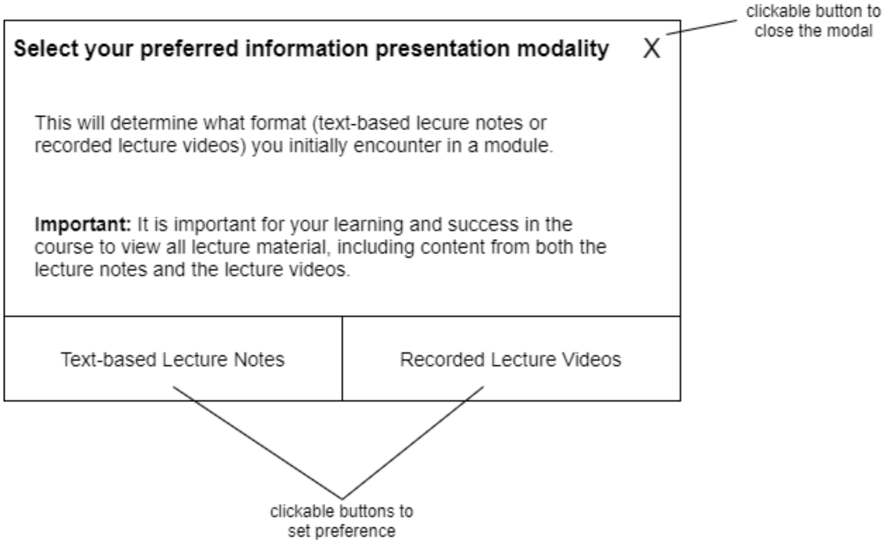
The adaptable information presentation system provides an opportunity for customization that emphasized the medium through which information is initially presented to the user. Much of the initial PoSE material is “parallel” in that the lecture recordings present and expand on the material in the paragraph-style lecture notes. Therefore, the different material within each thematic topic is not independent, and the paragraph or slide-style lecture notes, relevant assigned readings, and recorded lecture videos (some of which contain material from two semesters) do not have a straightforward sequence (as depicted in Figure 43). Considering this, it could be valuable to consider learner preference for information presentation when selecting which medium to initially provide when they navigate to a thematic unit. For example, some users may learn better via or have a preference for watching audiovisual media, and therefore presenting the videos first would provide the most cohesive user experience. In contrast, other learners may learn more effectively or have a preference for reading the text, and thus presenting the lecture notes initially would facilitate their performance of the learning task.

The PoSE learning environment should utilize an adaptable interface rather than an adaptive interface because the preference for text compared to audiovisual presentation is a personal one that varies across learner types, personae, immediate goals, and even situational constraints. As such, the locus of control for selecting this setting should lie firmly with the learners. Additionally, this preference is unlikely to evolve over the course of a single session, which further indicates the appropriateness of an adaptable interface. It is worth noting, however, that not all information presentation media are equal. The recorded lecture videos are rich with context for the presented content, further explanations, and questions asked by learners at the time of recording. The paragraph-style lecture notes provide some context but are not as detailed as the lecture presentation. The assigned readings may be detailed but can lack a clear connection to the topic when considered independently of the lecture videos. Finally, the slide-style lecture notes frequently have little context and little detail, with greater reliance on video segments for elaboration. Regardless of the learner’s preference and the initial information presentation modality, then, it is critical that all learners interact with the recorded lectures at some point during their learning experience. This adaptable interface is not meant to suggest that all the presentation media are equally detailed, but instead focuses on the emphasized presentation modality for the course content.

4.7.1 Adaptation Trigger

The adaptation trigger for the adaptable information presentation modality system is a self-selection of a preference. A prompt similar to the one shown in Figure 44 could be provided to learners when they first access the system. This prompt should allow the user to select either text-based presentation or an audiovisual presentation as the initial way material is provided to them.

Learners should be able to update this preference later if they wish. This preserves the learner's continued control over their learning experience. However, the immediate availability of this trigger is considerably less important than the adaptable information structure and navigation mechanism trigger. As such, the preference associated with information presentation modality could be updated from a separate settings page similar to the wireframe given in Figure 45.



Select your preferred information presentation modality

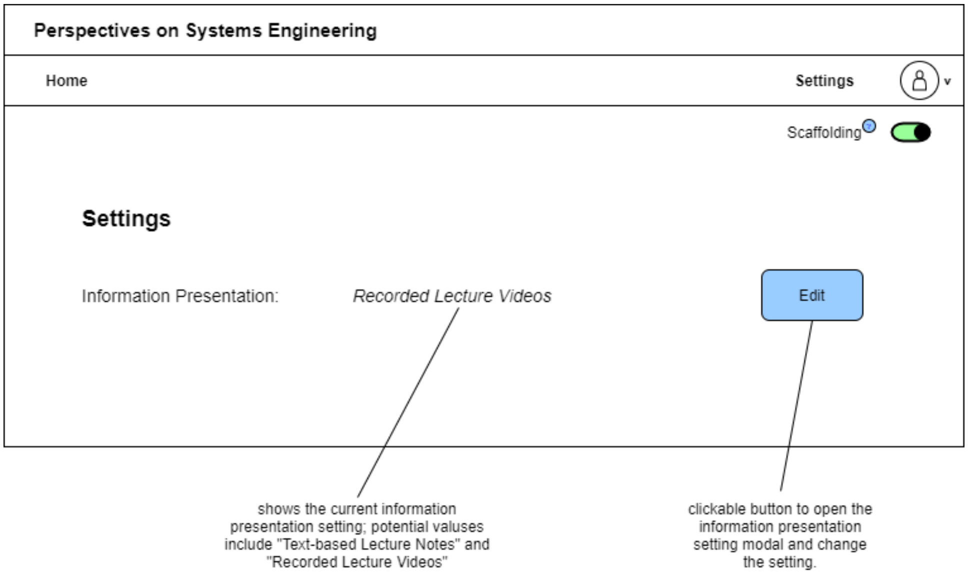
This will determine what format (text-based lecure notes or recorded lecture videos) you initially encounter in a module.

Important: It is important for your learning and success in the course to view all lecture material, including content from both the lecture notes and the lecture videos.

clickable button to close the modal

clickable buttons to set preference

Figure 44: Wireframe for selecting information presentation modality preference



Information Presentation: *Recorded Lecture Videos*

shows the current information presentation setting; potential valuses include "Text-based Lecture Notes" and "Recorded Lecture Videos"

clickable button to open the information presentation setting modal and change the setting.

Figure 45: Wireframe for editing information presentation modality from the settings page

4.7.2 Adaptation Behavior

There are two adaptation behaviors that occur as a result of the adaptation trigger being set. The first behavior is that the modality of the material initially presented upon navigating to a thematic topic will reflect the set preference. For example, if the information presentation preference is set to “recorded lecture videos,” then the lecture videos will load first upon selecting the thematic topic. If the preference is set as “text-based lecture notes,” then the paragraph-style or slide-style notes associated with that thematic topic will be presented first. Because thematic topics were determined based on the content presented within the lecture videos, rather than the text-based notes, it is possible that some thematic topics will not have associated notes. However, the content is highly characterized by the use of visual material, so in most cases where notes may not be associated with a thematic topic, an assigned reading would be. In this case, the assigned reading will be presented initially when the “text-based” setting is in use. If there is no text-based document associated with a thematic module, then the lecture video will load regardless of the preference setting.

The second behavior is related to the ordering of the “additional instances” in the tagging interface (see Figure 35). If the preference is set to “text-based lecture notes,” then tags that appear in the paragraph-style or slide-style lecture notes, as well as assigned readings, will be listed above instances that occur in videos. When the preference is set to “recorded lecture videos,” the opposite will be true: tag instances in videos will be listed above those in text-based documents. This is more subtle but supports quicker navigation to material within the desired modality, especially in the unscaffolded information structure and navigation configuration.

4.8 Summary

The results presented in this chapter represent the design decisions associated with the IA and UX case design of the specific online, asynchronous learning environment for the PoSE course content. These results utilize examples of user personae to support an understanding of the diversity of prospective learners. These learners may range from undergraduate students to c-suite executives: it is important to consider the different backgrounds, experiences, goals, and needs that may characterize these users.

To address attention, time, and bandwidth constraints, the existing PoSE content was modularized into thematic topics, which were then further modularized into individual video segments less than 16 minutes in length. The process for doing so was more complex when multiple semesters of material were available due to inconsistent sequentiality of information presentation. However, even for modules associated with only a single semester of recorded content, the time requirement to watch and re-watch the lecture content and validate the timestamps on the final segments was considerable. Outputs of this process included 138 individual videos between 1:10 and 15:45 in length.

The non-sequential design of modules allows learners to utilize different entry points into the material. This supports a range of different learner backgrounds and goals by supporting learners in accessing the systems language module they are most familiar with first. The exception to the non-sequential presentation of modules is the engineering case study module, which can only be completed after all five systems languages modules have been completed. This module has a strict sequential dependency because the assessments associated with the case study module require integration of knowledge about the systems languages.

Tag identification was performed based on a content analysis performed on the lecture notes (paragraph and slide-style), assigned readings, and captioning files associated with the lecture videos. These tags were identified through considering single word and 2-4 word combination frequencies along with how many documents the keyword occurred in. The relationships between tags were identified and characterized as being hierarchical, equivalent, or associative. This process resulted in outputs including tag tables and example tag trees, as well as word clouds associated with each module.

The adaptable information structure and navigation mechanism influence the primary structure and navigation mechanism in the learning environment. The scaffolded configuration utilizes a hierarchical information structure and navigation approach, with some contextual navigation in the form of tags. The unscaffolded configuration utilizes a non-sequential information structure and primarily contextual navigation via the identified tags. This adaptation behavior can be triggered by learner selection of a setting that should be available to them at all times within the learning environment. This will allow learners to add or remove the scaffolding as needed and will preserve their control over their experience.

Finally, the initial medium and interface design associated with information presentation can also be altered with an adaptable interface. The information presentation preference may be either text-based documents or recorded audiovisual lecture material. The corresponding medium will be loaded first upon learners navigating to a thematic topic and will be listed above instances occurring in other media types in the tagging interface.

Throughout this chapter, example wireframes were provided to give insight into the user experience. The design of the precise mechanisms to perform the functionalities described and the verbiage presented is in the scope of user interface (UI) design rather than UX design. These wireframes have not been subject to UI or UX testing; they are instead sample visualizations of what the learners might experience in the PoSE online learning environment.

5. DISCUSSION

5.1 Summary of Key Design Elements

The organization of this section of the chapter will be informed by the person-content-context model. Each of the design elements represents an interaction between the elements of the person-content-context model. However, they will be related to the element within the person-content-context model that they most directly address. For example, user personae most directly relate to the personal aspect of the model. Content modularization and non-sequentiality consider the person, but act on the content. The identification of tags and keywords is an operation done on the content, but explicitly informs the design of the learning environment context. The adaptable interface that alters the user's experience of the information structure and navigation mechanism alters the context to support the person. Similarly, the adaptable interface that alters the initial content presentation modality (text-based notes or recorded lecture videos) changes the context to support the person.

5.1.1 User Personae

The user personae that were developed for the PoSE case design emphasize that the audience for this instructional material extends far beyond traditional-age, residential (or co-located students). A variety of prospective users, ranging from undergraduate students to c-suite executives, could benefit from interacting with the content and thus should be considered in an inclusive design. Of the personae developed, three were either undergraduate or residential graduate-level students (Bailey, Casey, and Devin). However, the other two were categorized as a working professional and a c-suite executive (Adrian and Eli, respectively). Considering a greater audience reveals needs around time-related flexibility in the learning environment. Additionally, the learner's context may influence the tasks that need to be performed within the learning environment. Learners who are applying their new knowledge more immediately or who need to provide support to their arguments may need to perform information finding tasks within the environment in order to discover or refind information that is relevant to their current information need.

Learners have a variety of backgrounds, needs, goals, and motivations to achieve those goals. Learner backgrounds are informed by their initial perspective on SE (or preferred SE language), as well as their experience in both academic and work contexts. These different backgrounds influence the learner's initial familiarity with the course content and their level of prior knowledge. Learner needs (or preferences) may include the level of scaffolding present, the initial information modality utilized, and support for short or flexible learning sessions due to time or attention constraints. Goals may include learning the material, earning credits toward a degree or certificate, or earning a good or sufficient grade in the course. The motivations behind an emphasis on any of these goals vary as well. An undergraduate student may want to earn a high grade in the course in order to boost their GPA, while a working professional may emphasize earning a good grade to prove to their employer that they are a worthwhile investment of the company's time and resources.

The variety that is emphasized by the development of the user personae informs the other design decisions, including content modularization, non-sequential modules, tag and indexing term identification, and development of the adaptable interfaces.

5.1.2 Content Modularization and Non-Sequential Presentation

The content modularization and non-sequential presentation of information at the module and thematic topic grain sizes will be discussed together. Implications of the requirements of the process, the exclusivity of the thematic topics, the inclusion of all content, and the original content sequence are discussed.

The content modularization process varies in complexity based on the grain size and configuration of existing material. At the module level, the inherent structure of the existing PoSE material supported the allocation of 2-4 lectures to each SE language module. The case study module could be created through identifying the different case study introductions and parsing an additional introductory lecture to provide context regarding the case study methodology.

However, identifying the thematic topics was significantly more complex and time-consuming. This process required repeatedly viewing the recorded lecture videos and taking detailed notes regarding the topics being covered. Additionally, for modules where more than one semester of material was available, the lectures from different semesters had to be viewed again side-by-side. This was required to identify what would qualify as a thematic topic given the variability in the depth of coverage of different information across semesters. Familiarity with the subject matter was critical to the identification of non-sequential thematic topics because the modularizer (the author) had to be able to identify when a discussion could be considered independently and when the discussion of that topic (and relevant context) began and ended. The cognitive load requirement for this process is significant, especially for modules that have multiple semesters of material. There was an effect reminiscent of a learning curve where the modularization process did become more efficient and less cognitively taxing as it progressed. However, it is important to emphasize that the identification of thematic topics is not a straightforward or quick process and, at times, resembles an art more than a science. Additionally, the outputs of this process are based on human judgment; therefore, the identification and parsing of specific thematic topics (and individual video segments) is subjective. Two different "modularizers" with unique perspectives may vary in what they define as a thematic topic and how to divide content between them.

The individual segmented videos within each thematic topic represented a more straightforward component of the content modularization process. This is because there were clearer requirements, including a 16-minute limit to the length of any individual video. Another straightforward requirement was ensuring that when thematic topics had to be broken into two or more video segments, the cut occurred at a natural pause in the discussion rather than in the middle of a sub-topic description or even mid-sentence. The shorter length of the thematic topic segments to review also contributed to the decrease in complexity.

The content associated with each thematic topic is not necessarily mutually exclusive in all cases. There were times when the context provided in the original lecture was relevant to two thematic topics and served as a transition between them. When this occurred, the context was included in both thematic topics to support non-sequentiality at this level. However, in order to limit repetition and redundancy, this was done infrequently and only when it was judged that the quality of the explanation would suffer from the omission of the context.

In contrast, there is some content represented in the output of the content modularization process that represent candidates for removal. The content that is recommended for removal is that were one semester's presentation of the material was significantly superior to the other semester's presentation. This was noted and recommended only when the lecture content in one semester is rushed or very high-level while the other semester's presentation is more in-depth and detailed. One example of this is found in the "SE2 at the Vet" thematic topic. The first semester's presentation of this thematic topic spanned two videos and consisted of a total of 16:28 of recorded content. The second semester only spent 2:30 on the same topic and only covered it at a very high level, presenting no unique perspective on it compared to the previous semester. As such, the second semester's segment for "SE2 at the Vet" is one candidate for removal, as the content is not detailed enough to supplement the original discussion. However, these cases were infrequent; only 2 of the 138 modularized videos fell into this category, and these accounted for only 3:40 of content. Therefore, it was significantly more common to encounter scenarios where the presentations emphasized different aspects of the topic across different semesters, used different examples, or otherwise differed significantly enough that making a judgment of superior quality between the two semesters. Removing either version would be a disservice to the learner by removing a valuable perspective on the material. As such, by default, the material from both semesters will be included, with recommendations for removal being an exception to the general rule.

The existing recorded lecture content was not originally presented with non-sequential access and viewing in mind. This content consisted of lecture recordings from two previous semesters, and thus there was an inherent sequence in the presentation of the material within each semester. The order in which topics were discussed was not uniform across the semesters, but there was a degree of implicit order that was assumed within the original content. As such, material that was originally presented later in the semester has more references to previous material compared to the content presented early in the semester. For example, the SE1 content was presented first in both semesters, so there are few (if any) references to material that had already been discussed. The only possible "call-back" reference in SE1 is to the introductory content, which provided a broad overview. In contrast, SE5 was characterized by a higher number of references to the other flavors. Of 15 total segmented videos in the SE5 module, 6 (or 40%) of them involved a major theme of comparing SE5 to the other systems languages. This highlights a challenge associated with the parsing of fully non-sequential modules from existing content that was not initially intended to be viewed non-sequentially and represents a limitation of the modularization process.

Additionally, it is possible that some thematic topics should be considered for cross-listing across two (or more) modules. The modularization process as described assumed that the content contained within the dedicated week pertained primarily to a single systems language. For example, all content within the second week of the semester was assumed to primarily relate to SE1 and thus was considered part of the SE1 module. While this assumption largely seemed to hold true, some thematic topics emerged that challenge this assumption. One example is the thematic topic "SE4 vs. SE5," which is contained within the SE4 module. To support greater flexibility regardless of presentation sequence, this thematic topic could appear in both the SE4 and SE5 modules. However, this would contribute to additional overlap between the modules and result in redundant thematic topics.

Finally, the introductory material was excluded from the content modularization process. It is possible that if this material were included in a separate introductory module and that module had to be completed before continuing on to any of the systems languages modules, some of the issues or limitations of the process described above would be addressed. This introductory module would provide a level of background knowledge that may provide sufficient context to support the existing level of flexibility of sequenced presentation.

5.1.3 Tag and Indexing Term Identification

The tag and indexing term identification processes will be discussed together, but similarly to the previous chapter, the major emphasis will be on the tagging process. All the PoSE material that was analyzed as a part of the tag identification process should be fully indexed in order to support searching functionality. In essence, the author conducted a "low automation, human-curated" level of text mining (see, for example, Alex et al., 2008; Khan et al., 2021; Singhal et al., 2016), including text-only content analysis searches and matching of thematic topics after the author's content modularization and professional transcriptions of lecture presentation videos. This low-automation text mining is in contrast to modern machine learning (ML) approaches, which rely on automated speech-to-text algorithms, as well natural language processing determinations of topic ontologies and thematic relevance (Hotho et al., 2005). Such levels of ML automation require human-curated confirmation of existing training sets, however, which did not exist for a unique and multidisciplinary course such as PoSE. The tagging and term indexing effort would thus be an example of the first-stage "human-curated" content set for any future ML effort.

The size of the information space is sufficiently small that a low-automation text mining effort would not be significantly time-consuming or complex. Little is understood about how prospective users would approach search queries within this type of learning environment. Without this information available, it can be considered proactive to index the full environment in order to support users in finding information anywhere they may be searching for it. It is also unlikely that most search query results will overwhelm users. Even if a user searched the broadest possible search term (“system” alone with no additional terms), just over 5300 results would be returned to the learner. This is the largest possible number of results and is related to a somewhat unlikely search query due to its broadness. There are only 14 individual search terms and no phrases that occur over 1000 times within the content. Most learners that encounter higher numbers of search results could be reasonably expected to formulate a different or more specific search in order to find what they were looking for, or even reach out for instructional support. There are far more intricacies to discuss in relation to the tag identification process.

Like the content modularization process, the tag identification process has significant requirements associated with time and experience with the content being taught. Multiple passes through the frequency lists are often needed in order to capture all relevant tags. As was reported in Table 10, the initial pass through the material did not sufficiently capture most tags that were ultimately associated with a given module. Although many of the tags that were initially identified ultimately were included in the final tag list for each module (approximately 76-93%, depending on the module), the initial tag identification phase (with an emphasis on lecture content and direct navigability without considering relationships between tags which may identify further relevant tags) may be insufficient to capture all (or even most) meaningful tags. Therefore, despite the higher time requirements, it is important to perform the secondary tag identification phase. It was also found to be helpful to start visualizing the relationships between tags via tag trees in order to support the identification of further relevant tags. This indicates that it may be valuable to consider an iterative process in which some tags are identified directly from the content analysis outputs and related to one another. Then the subject-matter and covered-content expert would identify possible holes within the tag trees and returns to the word and phrase frequency analyses to determine whether any of the outputs are relevant to the identified gaps. Due to the human judgment present in the tag identification process, the outputs of the process are subjective in that two different tag identifiers may identify different tags. In implementations of the tag identification process, multiple analysts could be used to validate the identified tags through independent tagging, followed by meetings to establish a consensus on any divergent tags. This could facilitate the identification of higher quality (more valuable to learners) or a greater number of tags.

The initial tagging stage is meant to provide an initial insight into the material and support future tag identification efforts that account for every output from the frequency lists. The frequency lists show all words or phrases that occur two or more times in one or more documents. However, for the initial tagging process, review of these outputs was stopped when words or phrases occurred twice in only two documents. Though meant to emphasize the critical content outcomes, this process had a significant shortcoming when it came to modules that contained less content. For example, the SE4 and SE5 modules contain approximately 116 and 152 minutes of recorded lecture content respectively, while all other modules are made up of over 200 minutes of lecture content. Due to this and the lack of lecture content from both semesters, words and phrases that would be valuable as tags otherwise may not occur at a sufficient frequency to be captured by the initial tagging process. This issue was further alluded to in Table 10, which reports the number of initial tag candidates by module. The SE4 and SE5 modules were related to fewer initial tags than the other modules, and this phenomenon was not the result of an order effect, since the order in which initial tagging was done was non-sequential (also reported in Table 10). This was the major reason why a more exhaustive consideration of the frequency lists for final tag identification was implemented.

Bias within the content analysis outputs, including the word clouds, word frequency lists, and phrase frequency lists by introducing longer readings into the content analysis. This can result in it appearing as though certain words or phrases occur with high frequency throughout the material, when they only occur very frequently in one document and may be present though not highly emphasized in other documents (i.e., closed captioning files, other readings, or paragraph-style or slide-style notes). This can be accounted for to some degree through considering how many documents the term appears in over only focusing on the frequency of the term. However, this does not fully address this bias. Instead, modules with particularly long and influential readings should be identified, which can be done in part through comparing the word clouds for each module that include and exclude the assigned readings. Word cloud pairs that more closely resemble one another indicate a lower level of bias from the assigned readings, where word cloud pairs that are significantly different suggest a greater degree of bias from longer readings. This is especially prevalent in the SE4 and SE5 modules within PoSE. To address this bias during the tag identification process, word and phrase frequency lists should be generated both with and without the inclusion of the assigned readings. If a term or phrase only appears to be relevant for consideration as a tag when the readings are included, then it is not identified as a tag.

The aggregated tags from all the individual modules may not capture all meaningful tags that could operate at an inter-module level. Some prospective tags will only be identifiable as relevant through consideration in the context of the PoSE course as a whole. While tags identified within the different modules may be finalized based on their prevalence across the other modules of material, identifying cases like this without a content analysis focused on the entire course is difficult due to the length of the word and phrase frequency lists. Considering each word or phrase in the context of the whole is extremely time-consuming and inefficient. Therefore, in order to capture the full scope of valuable tags, an additional analysis of the whole course must be performed. Any introductory material available would be reasonable to include in this analysis as well.

Finally, the identified tag-based navigation UX is similar to but distinct from traditional hyperspace (hypertext or hypermedia) navigation mechanisms. Both tag-based and traditional hyperspace navigation support non-sequential wayfinding through an information landscape. However, traditional hyperspace navigation provides contextual navigation to support wayfinding to a representation of the topic identified as the contextual link. That is, if "beer game" was a contextual link in an environment with a traditional hyperspace navigation mechanism, and the user navigated via interacting with this term when it appears in a text or audiovisual file, then they would be brought to a page titled "Beer Game" which would address the topic. However, this is not the case with tag-based navigation. The prototype tag-based navigation mechanism is not constrained by the need for navigational pathways to be based on the title of other content pages. Instead, learners can navigate directly to a number of different instances of any given tag using the tag interface described in Chapter 4. This represents a significant further contribution of the thesis to the domain: a novel form of NSIS and navigation that is distinct from hyperspace. This non-sequential information structure bears further investigation to fully understand its potential impact on learning.

5.1.4 Adaptable User Experiences

The diversity of learners described by the user personae poses a challenge in designing. There are few design decisions that truly benefit all users, and the expertise-reversal effect reveals that in some cases, design solutions that are needed by some learners are actually detrimental to others (Kalyuga, 2007; Kalyuga et al., 2003). Therefore, a static user experience can only focus on the needs of a subset of prospective users. Utilizing a dynamic user experience allows for accommodation and support of a wider variety of users with different, sometimes conflicting needs. The spectrum of dynamic user experience is often described by its two extremes: adaptable and adaptive mechanisms, which vary in terms of the locus of control of the adaptation and the time frame over which the adaptation occurs. Adaptable interfaces emphasize user control over the adaptation behavior and are used for settings that evolve on a slow time frame, if at all. Due to the level of learner control associated with both dynamic user experience elements described within this case design, the mechanisms are adaptable.

The first adaptable interface alters the user experience of the information structures and navigation mechanisms. The scaffolded user experience provides a hierarchical information and navigation structure, while the unscaffolded experience involves a non-sequential information structure (NSIS) supported by tag-based contextual navigation. The different IA design solutions for information structures and navigation mechanisms are ideal for users with different levels of prior knowledge and expertise. Subject-matter novices generally benefit from additional scaffolding in the form of hierarchical structures or restricted learning environments (DeStefano & LeFevre, 2007). In contrast, more experienced learners are less likely to become “lost” in NSISs and are more likely to experience benefits from increased learner control (Lawless & Brown, 1997). The expertise-reversal effect further highlights that an effective level of learning scaffolding for novices can even be detrimental to more experienced learners and vice versa (Kalyuga, 2007; Kalyuga et al., 2003; Kalyuga et al., 1998). For example, a search bar may be helpful for experienced users with high prior knowledge but would not be an appropriate instructional approach to assume that novice users would find any value in the search functionality. Similarly, limiting the initial available instructional environment may be helpful for novice learners, but detrimental to more experienced users who may benefit from seeing the connections between different modules. Adaptable user experiences provide an alternative to selecting a single design solution that would prioritize the needs of one of these groups (usually subject-matter novices in the case of learning environment design) over the other. Instead, both configurations are available to all users, and the information and navigation structures can be changed through an easily accessible adaptation trigger mechanism. This mechanism should be constantly available to the learners so that if they begin to feel lost or overwhelmed in the NSIS configuration, they are able to return to a more scaffolded presentation. Likewise, if a learner is becoming bored or wants to understand how the material interconnects, they are able to switch to an unscaffolded presentation.

The second adaptable user experience revolves around the initial modality (text-based notes or recorded lecture videos) through which information is presented. The preference between these modalities is based on a variety of personal user characteristics that vary across learner types and personae. This preference may change as a function of the learner's immediate goal. For example, if they are trying to refind a piece of information, they may prefer to consider text-based documents first in order to more effectively skim-read through them. If the learner is looking for more detailed information on a topic, then they may prefer to view lecture videos initially. A learner's preference for an information presentation modality may also be a function of situational constraints. If a working professional or c-suite executive was trying to find information quickly during a meeting, it would not be socially acceptable to turn on and watch lecture videos in order to locate it. This could result in a temporary preference for text-based information presentation.

Finally, the third adaptable interface element emphasizes the non-sequential nature of the modules through supporting five different possible entry points into the material. The user can select which systems language (SE1 through SE5) is most familiar to them. This represents a learner characteristic that varies throughout the prospective user population, as reflected by the user personae profiles. The learner themselves is best able to judge their relative experience with each language. The value of these different entry points into the material lies in building on the learner's prior knowledge, a principle which is reflected both in the Law of the Lesson (Gregory, 1886) and in the aggregated principles to inform universal instructional environment design.

5.2 Revisiting the Purpose of the Case Design

The contexts in which learning occurs are expanding. In a post-COVID-19 pandemic world, it is critical to acknowledge that learning can occur in a variety of physical contexts outside the classroom. This reality is further emphasized by the prevalence of online degrees and increasing emphasis on hybrid work environments. However, it is far from trivial to transform existing content into an effective distributed, asynchronous learning experience. Exploring different online learning environment configurations is critical to providing robust and quality content delivery and learning experiences. Learning environments that are robust to conditions that prevent colocation are one way of ensuring educational continuity without sacrificing learning objectives. The case design described here offers one different approach to existing online learning environments that is robust to colocation restrictions, as well as to the inability to record quality new material.

There are a wide variety of learner types that have a number of different backgrounds, goals, motivations, and needs. Learners with different goals or contexts may need to complete different tasks within the learning environment. For example, working professionals may need to be able to refind information that they had previously interacted with to support their perspective or knowledge in a meeting with their coworkers. These different tasks associated with the content should be considered and designed for in addition to the learning tasks associated with accumulating or expressing knowledge presented as a part of the course. Additionally, a competitive market advantage for industrial audiences may be observed when utilizing learning environments that support users in completing these tasks through the use of content modularization, tagging, and comprehensive searching functions.

Customizable learning environments allow learners to adapt their experience to align with their prior knowledge, interests, or needs. This thesis has described three means of customization within the learning environment. First, the mechanism to select the systems language that is most familiar to the user provides a way for the user to build on their prior knowledge and potential interests when it is appropriate to do so. A default option (beginning with SE1) is also provided for learners with low overall levels of prior systems engineering knowledge or those who do not recognize the systems language that they are most “fluent” with. Second, there is the adaptable interface element that alters the presented information structure and primary navigation mechanism from hierarchical to non-sequential and vice versa. This adaptation of the user experience of the IA design allows both subject-matter novices and more experienced learners to interact with the learning environment in a way that will support them in effective learning. Finally, the adaptation mechanism that targets the information presentation modality provides a means for users to change how information is initially presented depending on their individual preference, situational or long-term needs. These adaptable interfaces provide users with control over their learning experiences. Higher levels of learner control have been shown to be beneficial to learning in some configurations (Yildirim et al., 2001). This control can be provided while still offering default options and easily accessible detailed information about the different settings that afford scaffolding for those learners that may need it.

A major outcome of this thesis that was not identified as a primary purpose initially was revealed by the limitations observed in the non-sequential information structure (NSIS; or hyperspace) literature. The NSIS literature and cognitive flexibility theory (CFT) suggest that there may be value to utilizing contextual navigation approaches to connect different topics, particularly in highly interconnected or poorly structured domains (Lawless & Brown, 1997; Niederhauser et al., 2000; Scheiter & Gerjets, 2007; Spiro et al., 2003). However, the literature evaluating the performance of an NSIS compared to a hierarchical information structure has some important limitations to consider when approaching the PoSE design context. Much of the available literature on the impact of non-sequentially structured environments has an extremely limited temporal scope. Learners generally are allowed to interact with the environment at a grain size of minutes to hours, rather than over the course of a full semester. As such, the applicability of these conclusions to a long-term context is somewhat questionable. Additionally, many studies within the literature do not necessarily consider effective information presentation principles in the design of the NSIS systems being used, introducing confounding effects into their results.

5.3 Limitations

There are limitations associated with this case design and its associated processes that should be acknowledged and discussed. This case design is an initial proposal and instructional document to demonstrate and test the feasibility of applying transformative processes to existing content. The content modularization and tag identification *processes* were applied to the available PoSE content. However, it must be noted that content varies widely between subjects and instructors. Some content may be more easily and systematically "human-curated" due to instructor presentation styles. Courses with more standard content across delivery environments (such as introductory electronic circuits or thermodynamics content) may have enough commonality to support additional migration from human-curated to ML-facilitated content modularization and tag identification.

The case design focuses on the design and development of a digital learning environment context in which learning may occur. However, both content and context, as well as various user characteristics, influence the quality of learning. The context could be designed to support the users in exactly the desired way, but if the content is in some way inaccessible or confusing for the learner, then learning will be impaired. In contrast, when content is presented particularly clearly or accessibly, even a poorly designed learning environment may not have a significant effect on learning. This conflation of context and content represents a limitation of the design's ability to support the original problem statement of teaching interdisciplinary material to a range of users in an online, asynchronous environment. These factors are also critical to consider in efforts to implement or evaluate the design described here.

The human-curated design approach utilized here is not as easily scalable as might have been anticipated. There are significant time, cognitive load, and expertise requirements associated with completing the content modularization and tag identification processes. These requirements impose limitations on who can viably apply or implement this design approach to other courses or types of material. The individual completing the tagging especially must have a strong understanding of the material and the interconnections in order to identify meaningful tags and relate them to one another. In addition to general subject-matter expertise, familiarity surrounding the content as it was taught is needed to determine when outputs of the content analysis are meaningful and when they are referring to different uses of the same word or the result of the use of a repeated analogy. These factors ultimately limit the scalability of this design approach and suggest that implementation on a wider scale would be slow and difficult.

The subjectivity of the outputs of the content modularization and tag identification processes could also be viewed as a constraint of the human-curated case design approach. There is no single, objectively correct output from these processes; critically, also, existing ML techniques are not sufficient for more complex causal, conceptual, and semantic analyses. The objective in applying these processes should be to provide additional structure to existing material that facilitates, rather than impedes, engagement with the material, communication of knowledge, and ultimately the learning process.

Finally, it is worth re-emphasizing that the case design represents a prototype IA and UX design of a distributed, asynchronous learning environment. These designed elements were not implemented. The presented UX wireframes have not been subject to any user testing, nor has the UI design been finalized or evaluated in any way. There has been no empirical evaluation of data collection associated with the prototype design described here. Therefore, there is not currently any direct evidence regarding the learning environment's effectiveness in terms of learning outcomes. While the literature suggests that such a learning environment could be effective, there is no empirical evidence at this time, which imposes a significant limitation on the case design. However, this limitation was inherent to the scoping of the case design. As discussed above, the purpose of this thesis is not to provide a design for a learning environment that is objectively more effective for supporting learning than existing learning environments. Instead, it is meant to describe and propose a learning environment that differs from those currently in use, utilizing literature in order to support the feasibility of such an environment being effective. The restricted scope highlights the more significant contribution of the IA and UX design components to the development of a novel online, asynchronous learning environment to support a variety of users learn interdisciplinary material.

6. CONCLUSION

The purpose of this project is to address the challenge of teaching highly interdisciplinary material to a range of traditional and non-traditional students in a distributed, asynchronous format with existing course material. This purpose is achieved through the use of a case design, where an online, asynchronous learning environment is developed for a graduate-level SE course (PoSE). The scope of the case design includes consideration of prospective users, information architecture (IA) design (i.e., information structures, navigation mechanisms, labeling frameworks, and searching functions), and user experience (UX) design (i.e., how the user interacts with the learning environment to perform tasks within it). The prototype IA and UX designs represent the significant contribution of this case design to the challenges associated with online learning of highly complex, interdisciplinary material.

6.1 Key Findings

The learners described by the developed personae have a broad range of backgrounds (including levels of prior knowledge and academic and work experience), goals, and needs related to learning. Content modularization applied at the module, thematic topic, and video segment grain sizes accommodates a range of attention, time, and bandwidth constraints. The learner variety suggests the need for dynamic user experiences that allow for customization of the learning experience in the form of adaptable interfaces that provide the user with control over the dynamic behavior. Customization opportunities in PoSE include: (1) order of systems language module access, (2) the information structure and supporting navigation mechanisms experienced by the user, and (3) the initial modality through which information is presented. These customization options consider not only the learner characteristics that act as constants but also those that are variable. As the learner accumulates experience with the material or experiences cognitive overwhelm, they are able to alter the information structure and primary navigation mechanism. Additionally, users can adapt their experience to the situational constraints of their environment by controlling the initial modality that is emphasized.

The processes associated with developing the IA and UX prototype components also revealed critical outcomes that are important to consider in relation to applying the design approach.

Both the content modularization and tagging processes require a significant amount of time and content/course presentation expertise (and not simply general domain expertise). Thematic topic modularization and tag-based links cannot be applied to existing material in real-time, or without a perspective on the major learning objectives of the course. The in-depth tagging process requires a significant time commitment and an understanding of how the terms relate to one another. These processes are significant aspects of the human curation effort. Thematic curation is not yet well supported by current-generation text mining or natural language processing algorithms; indeed, automated captioning of PoSE content conducted prior to the start of this thesis resulted in high word-error rates, with particularly critical errors on important terms used as thematic tags.

Finally, the existing hyperspace literature as applied to the educational domain contains severe limitations regarding user experience and content mastery evaluations. In an effort to preserve experimental control, these evaluations tend to occur over the course of only a few hours. As a result, it is unclear how these outcomes scale to a semester-long course implementation, including whether a learning curve is associated with the use of a non-sequential navigation mechanism or whether its continued usage enables learners to develop a deeper understanding of the material. The presence of the hyperspatial contextual navigation mechanism is also frequently confoundable with information presentation design choices.

6.2 Broader User Experience Design Relevance for Learning Environments

The case design describes the IA and UX design components of an online, asynchronous learning environment that is distinct from existing environments due to the application of content modularization, non-sequential tag-based navigation, and adaptable interfaces that consider a range of learners and their interests, characteristics, and needs. This case design is applied to the PoSE course, but the processes described may be relevant for application in a variety of different courses. For example, the tagging process would be most relevant to highly interdisciplinary material or material that is otherwise rich with interconnections. Content modularization is an extremely versatile approach that supports learner needs that are universal across learning environments (i.e., time and attention) or specific to online learning environments (i.e., bandwidth). Similarly, utilizing adaptable user experiences to meet conflicting learner needs can be valuable in any learning environment where such conflicting needs can be identified in the prospective learner population.

The development of different approaches to online learning environments is particularly relevant in a post-COVID-19 world. Hybridization in both academia and the workplace was occurring before the pandemic. However, the response to COVID-19, particularly in relation to online learning, revealed that these efforts were far from stable and finalized and instead suggested the need for novel design approaches that consider the user, content, and context in which the learning is occurring. The development of robust learning environments is critical to educational continuity and consistency both within and outside states of emergency.

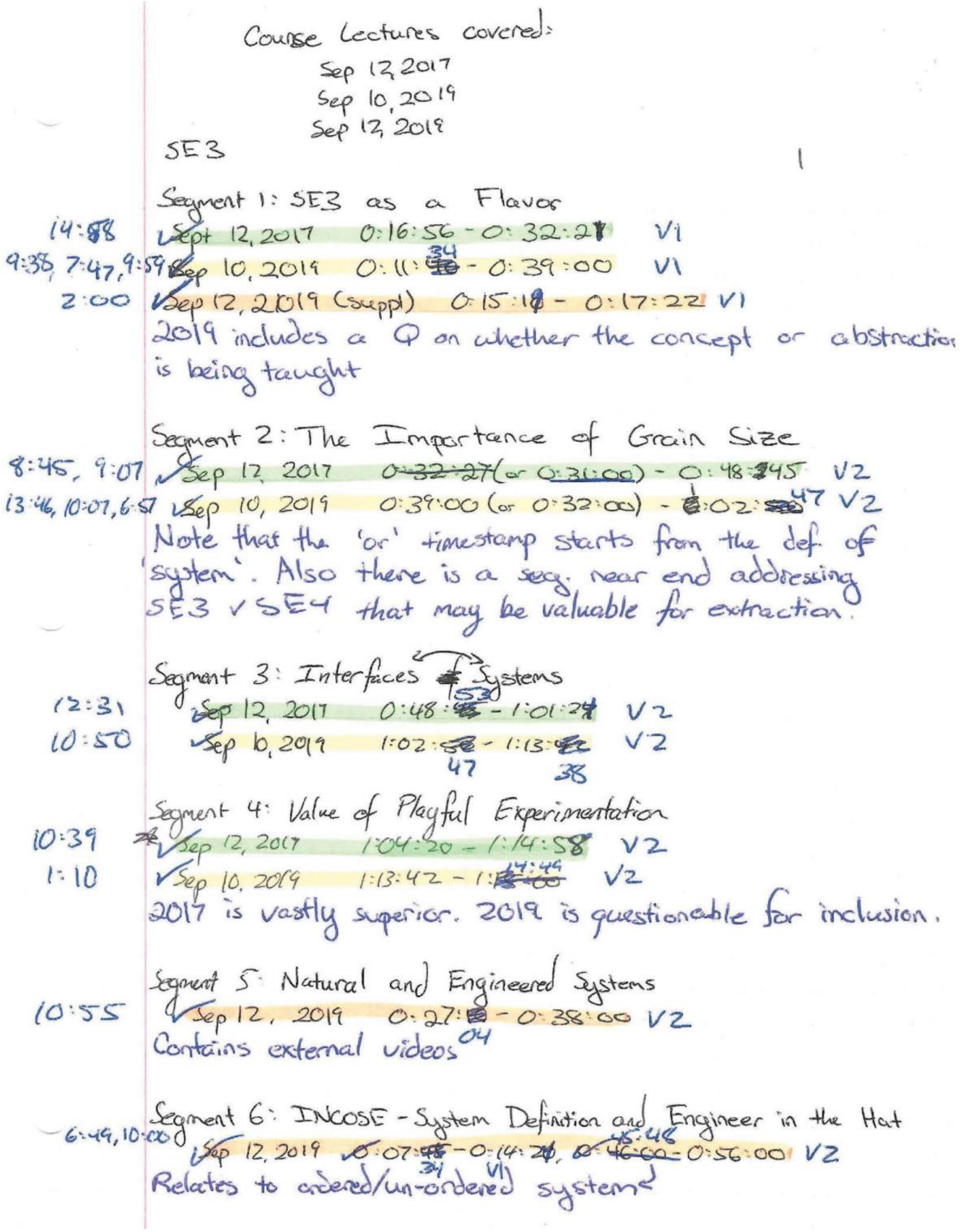
6.3 Directions for Future Work

Future work includes the design phases that were considered out of scope for this case design. The IA and UX prototype presented here should be implemented and evaluated. In addition, the user interface should be designed, prototyped, and tested based on the UX wireframes. The resulting learning interface can then be evaluated over the course of a semester to determine its influence on learning outcomes. However, the value of the learning environment may not be apparent in the learning outcomes alone, so the learners should be surveyed in order to understand their usage of and attitudes toward the UX components.

There are limitations of scope and generalizability of the previous hyperspace literature when applied to semester-length learning experiences. Non-sequential navigation mechanisms in learning environments warrant further consideration from the academic community. Higher fidelity evaluations should be performed over a longer time period and account for principles of information presentation that can influence recall. These limitations could be addressed through experimental designs that assess user experience and learning transfer over a longer time period, and consider learner performance and attitudes toward utilizing the NSISs. Information presentation best practices should be considered in the design and development of the NSIS. This will enable researchers to understand how learner utilization of non-sequential navigation varies over time and whether a higher level of continued usage impacts the depth of a learner’s understanding. Nontraditional non-sequential navigation mechanisms, such as the tag-based model presented here, should also be evaluated for effectiveness. Such an investigation should similarly consider both learner performance and learner attitudes. It is important to capture learner attitudes toward NSISs (and not just their impact on performance) because these attitudes will determine whether learners are willing to utilize the NSIS setting in an adaptable environment (such as the PoSE learning environment described in this work). Negative student attitudes, such as frustration, may also impede learning and are therefore undesirable in features of a learning environment.

Finally, the role of dynamic user experiences (both adaptable and adaptive) in online learning environments should be further considered and evaluated. Subject-matter novices and experts (or more experienced learners) can experience conflicting needs regarding the level of scaffolding present. However, these two groups are rarely distinguished, and novices tend to be designed for at the expense of their more experienced peers. Providing distinct user experiences based on learner characteristics and needs presents an opportunity for divergence from this "one size fits all" approach to course design.

APPENDIX A. CONTENT MODULARIZATION NOTES



Course Lectures covered:
Sep 12, 2017
Sep 10, 2019
Sep 12, 2019

SE3

Segment 1: SE3 as a Flavor
14:88 ✓Sept 12, 2017 0:16:56 - 0:32:27 V1
9:38, 7:47, 9:59 ✓Sep 10, 2019 0:11:34 - 0:39:00 V1
2:00 ✓Sep 12, 2019 (suppl) 0:15:18 - 0:17:22 V1
2019 includes a Q on whether the concept or abstraction is being taught

Segment 2: The Importance of Grain Size
8:45, 9:07 ✓Sep 12, 2017 ~~0:32:27~~ (or 0:31:00) - 0:48:45 V2
13:46, 10:07, 6:57 ✓Sep 10, 2019 0:39:00 (or 0:32:00) - 1:02:47 V2
Note that the 'or' timestamp starts from the def. of 'system'. Also there is a seg. near end addressing SE3 v SE4 that may be valuable for extraction.

Segment 3: Interfaces ~~of~~ Systems
12:31 ✓Sep 12, 2017 0:48:53 - 1:01:24 V2
10:50 ✓Sep 10, 2019 1:02:47 - 1:13:38 V2

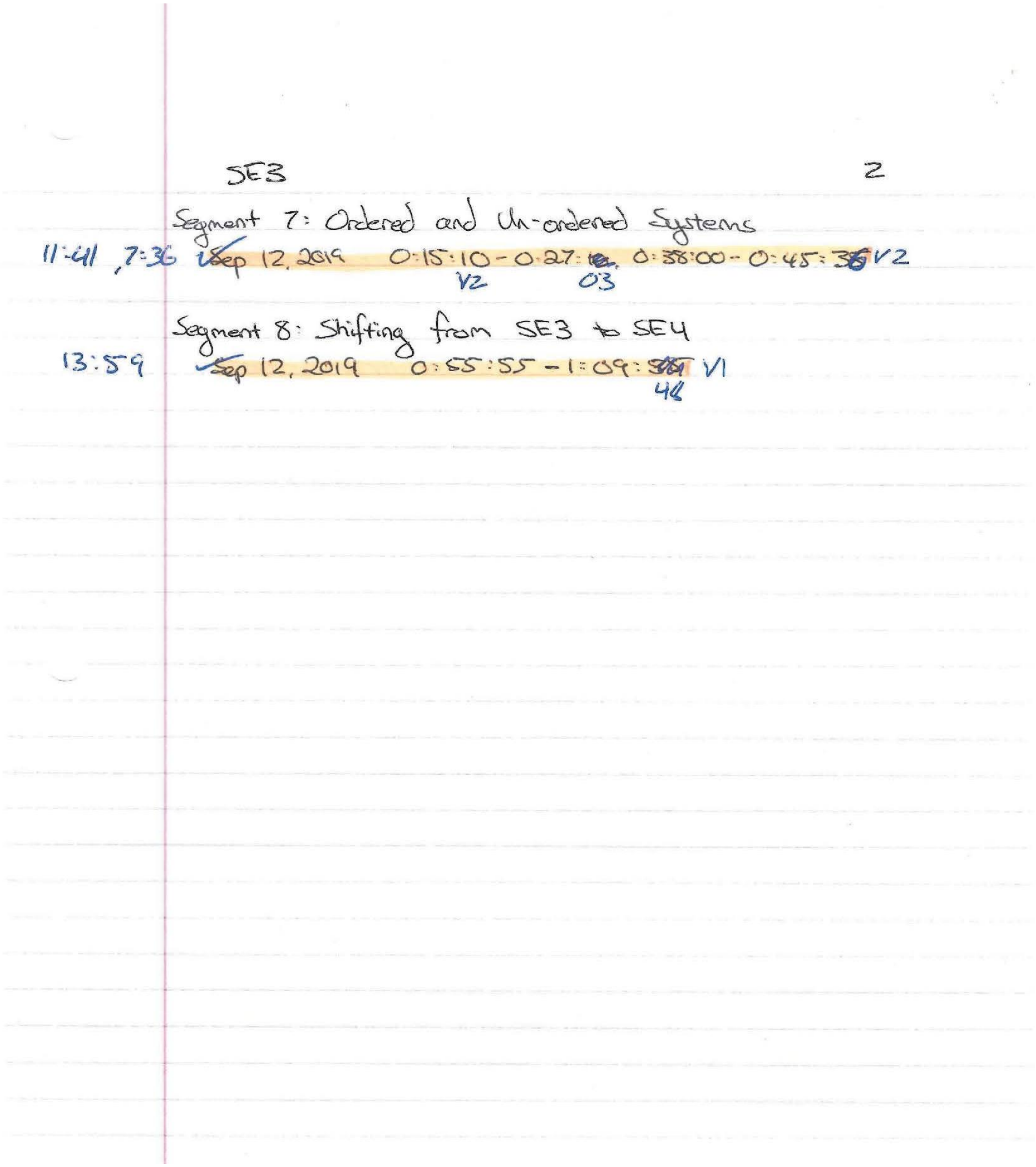
Segment 4: Value of Playful Experimentation
10:39 ✓Sep 12, 2017 1:04:20 - 1:14:58 V2
1:10 ✓Sep 10, 2019 1:13:42 - 1:14:44 V2
2017 is vastly superior. 2019 is questionable for inclusion.

Segment 5: Natural and Engineered Systems
10:55 ✓Sep 12, 2019 0:27:04 - 0:38:00 V2
Contains external videos

Segment 6: INCOSE - System Definition and Engineer in the Hat
6:49, 10:00 ✓Sep 12, 2019 0:07:34 - 0:14:20 V1, ~~0:46:00~~ 0:45:48 - 0:56:00 V2
Relates to ordered/un-ordered systems

Figure A.1: Modularization notes for the thematic topics associated with the SE3 module

Figure A.1 continued



SE3 2

Segment 7: Ordered and Un-ordered Systems

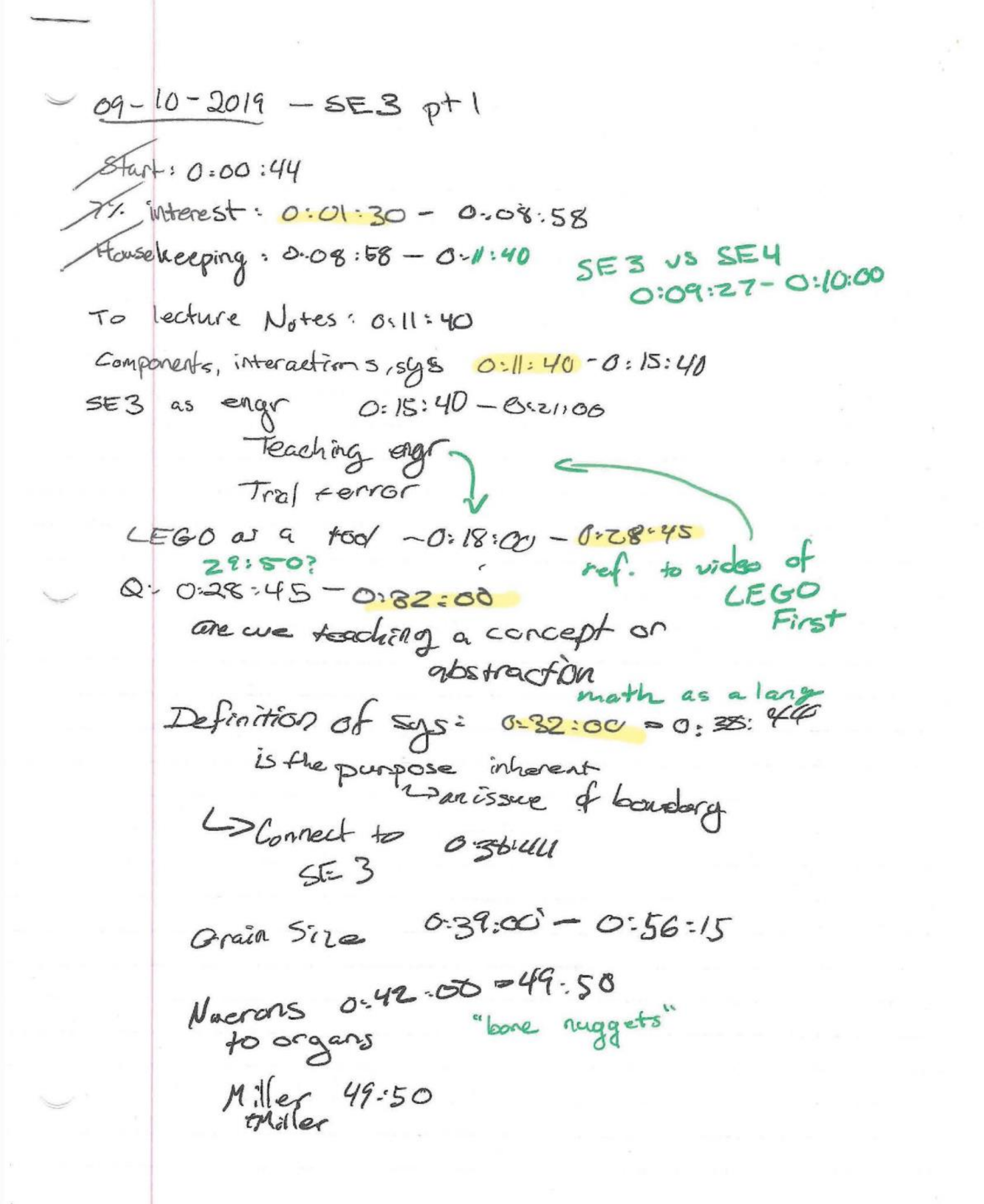
11:41 ,7:36 ✓Sep 12, 2019 0:15:10 – 0:27:~~10~~, 0:38:00 – 0:45:36 V2

V2 03

Segment 8: Shifting from SE3 to SE4

13:59 ✓Sep 12, 2019 0:55:55 – 1:09:~~58~~ V1

48



09-10-2019 – SE3 pt 1

Start: 0:00:44

7% interest: 0:01:30 – 0:08:58

Housekeeping: 0:08:58 – 0:11:40

SE3 vs SE4
0:09:27 – 0:10:00

To lecture Notes: 0:11:40

Components, interactions, sys 0:11:40 – 0:15:40

SE3 as engr 0:15:40 – 0:21:00

Teaching engr
Tral +error

LEGO as a tool ~0:18:00 – 0:28:45

29:50?

ref. to video of LEGO First

Q: 0:28:45 – 0:32:00

are we teaching a concept or abstraction

math as a lang

Definition of sys: 0:32:00 – 0:35:44

is the purpose inherent
↳ an issue of boundary

↳ Connect to SE3 0:36:44

Grain Size 0:39:00 – 0:56:15

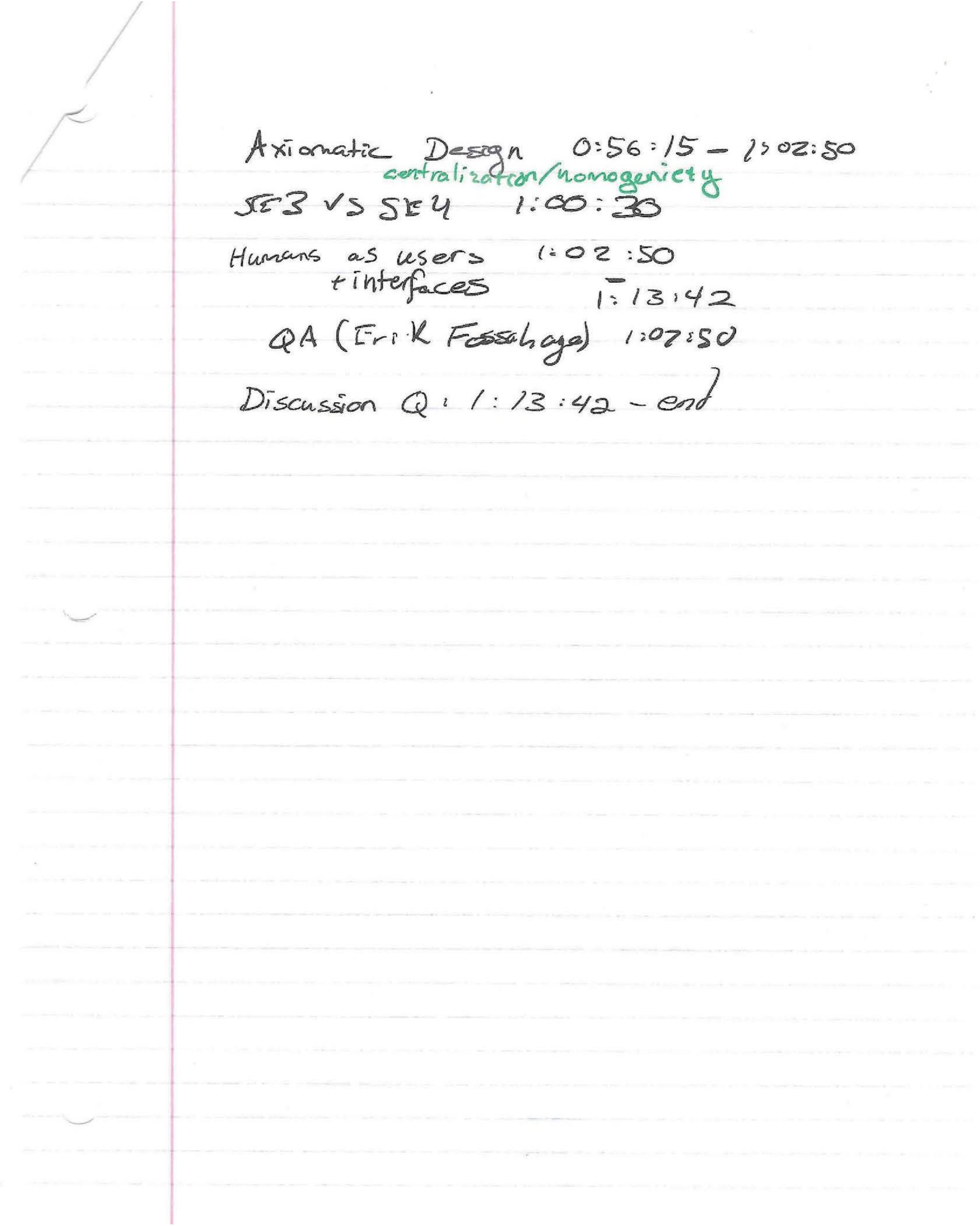
Nuerons 0:42:00 – 49:50
to organs

"bone nuggets"

Miller 49:50
Miller

Figure A.2: Notes taken during the process of reviewing the SE3 module content (lectures from 9/12/2017, 9/10/2019, and 9/12/2019) to support thematic topic identification and content modularization

Figure A.2 continued



Axiomatic Design 0:56:15 – 1:02:50
centralization/homogeniety

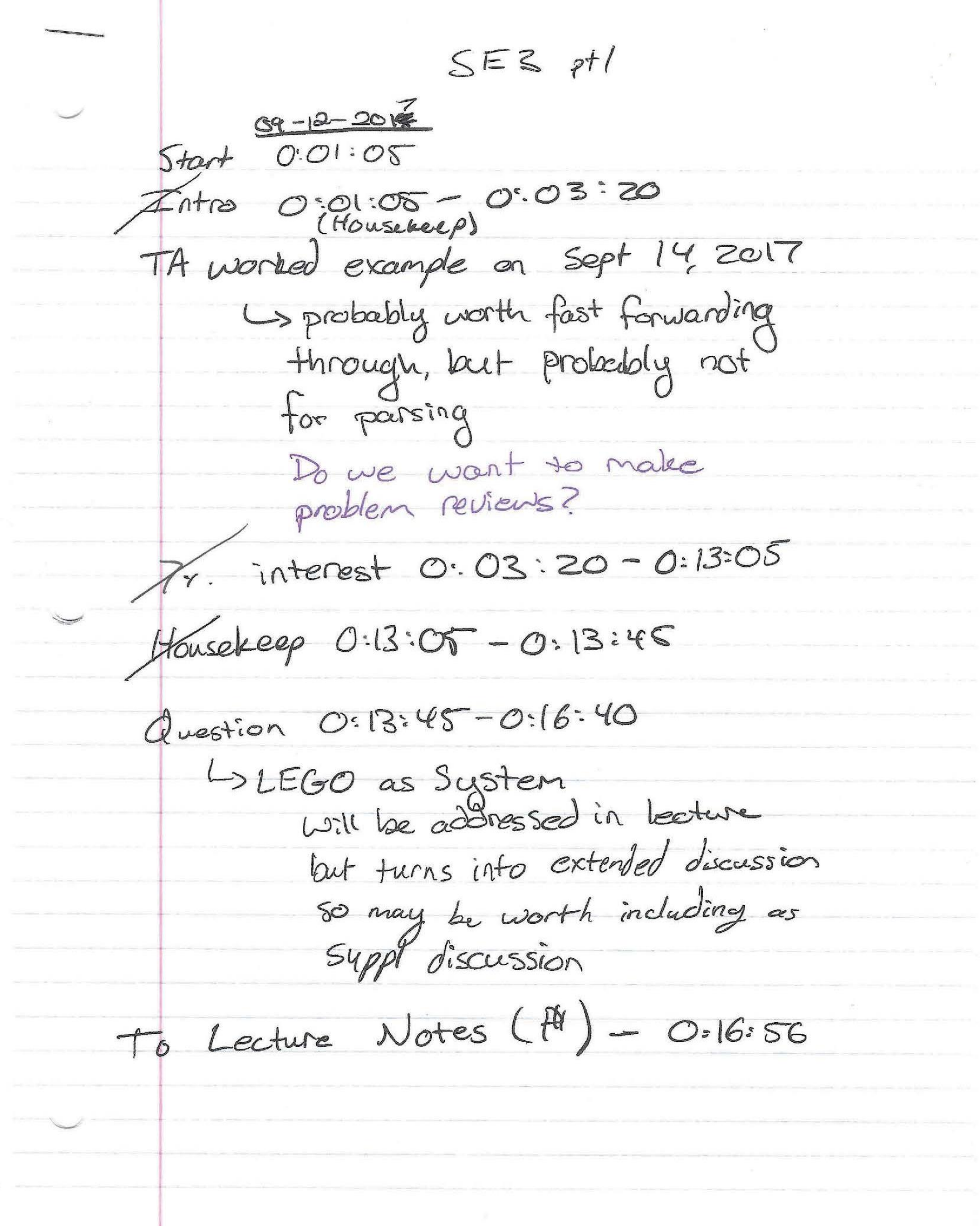
SE3 vs SE4 1:00:30

Humans as users 1:02:50
+ interfaces 1:13:42

QA (Erik Fossahaga) 1:07:50

Discussion Q: 1:13:42 – end

Figure A.2 continued



SE3 pt1

09-12-2017

Start 0:01:05

Intro 0:01:05 – 0:03:20
(Housekeep)

TA worked example on Sept 14, 2017
↳ probably worth fast forwarding through, but probably not for parsing

Do we want to make problem reviews?

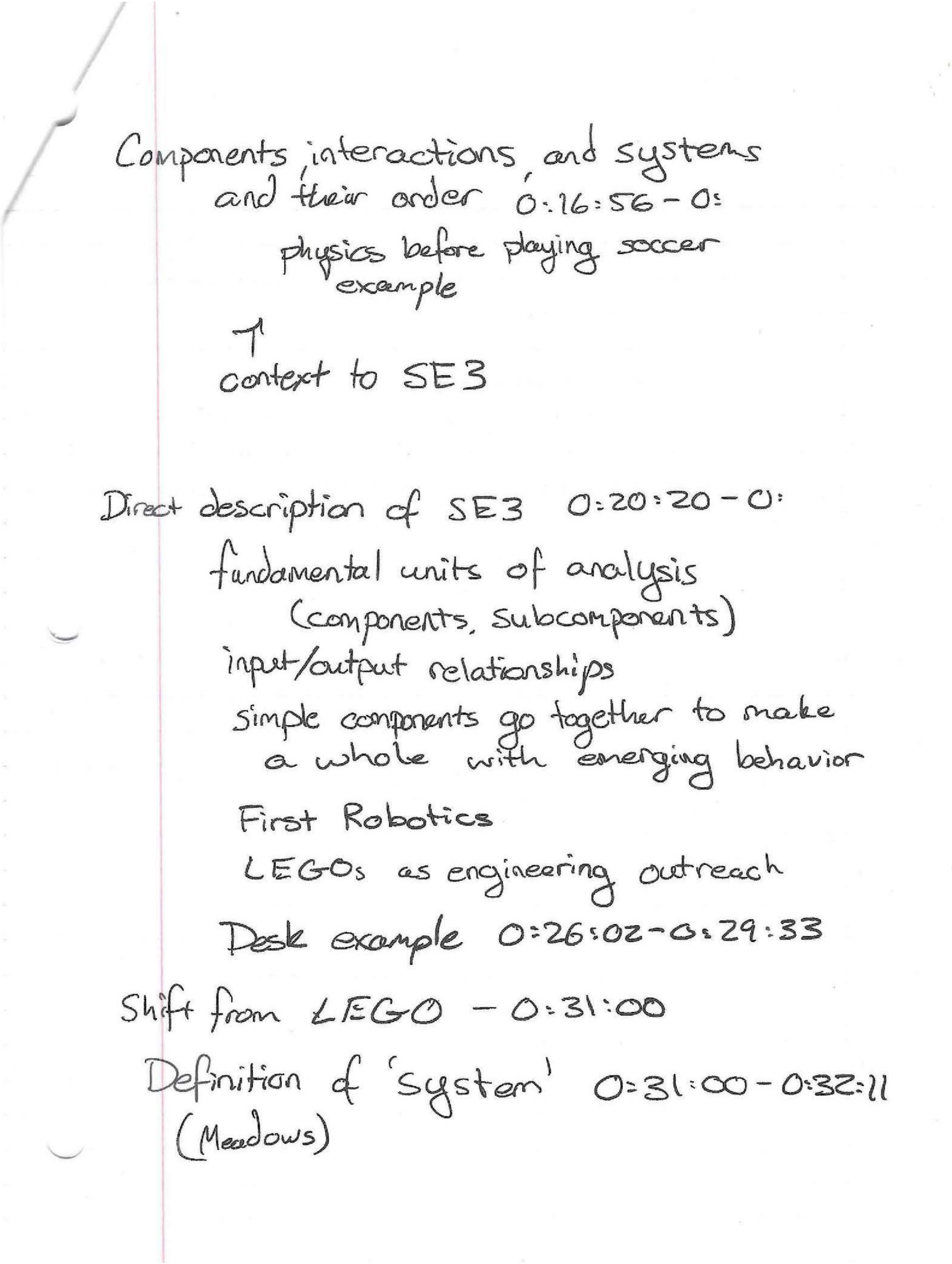
Tr. interest 0:03:20 – 0:13:05

Housekeep 0:13:05 – 0:13:45

Question 0:13:45 – 0:16:40
↳ LEGO as System
will be addressed in lecture but turns into extended discussion so may be worth including as suppl discussion

To Lecture Notes (A) – 0:16:56

Figure A.2 continued



Components, interactions, and systems
and their order 0:16:56 - 0:

physics before playing soccer
example

↑

context to SE3

Direct description of SE3 0:20:20 - 0:

fundamental units of analysis
(components, subcomponents)

input/output relationships

simple components go together to make
a whole with emerging behavior

First Robotics

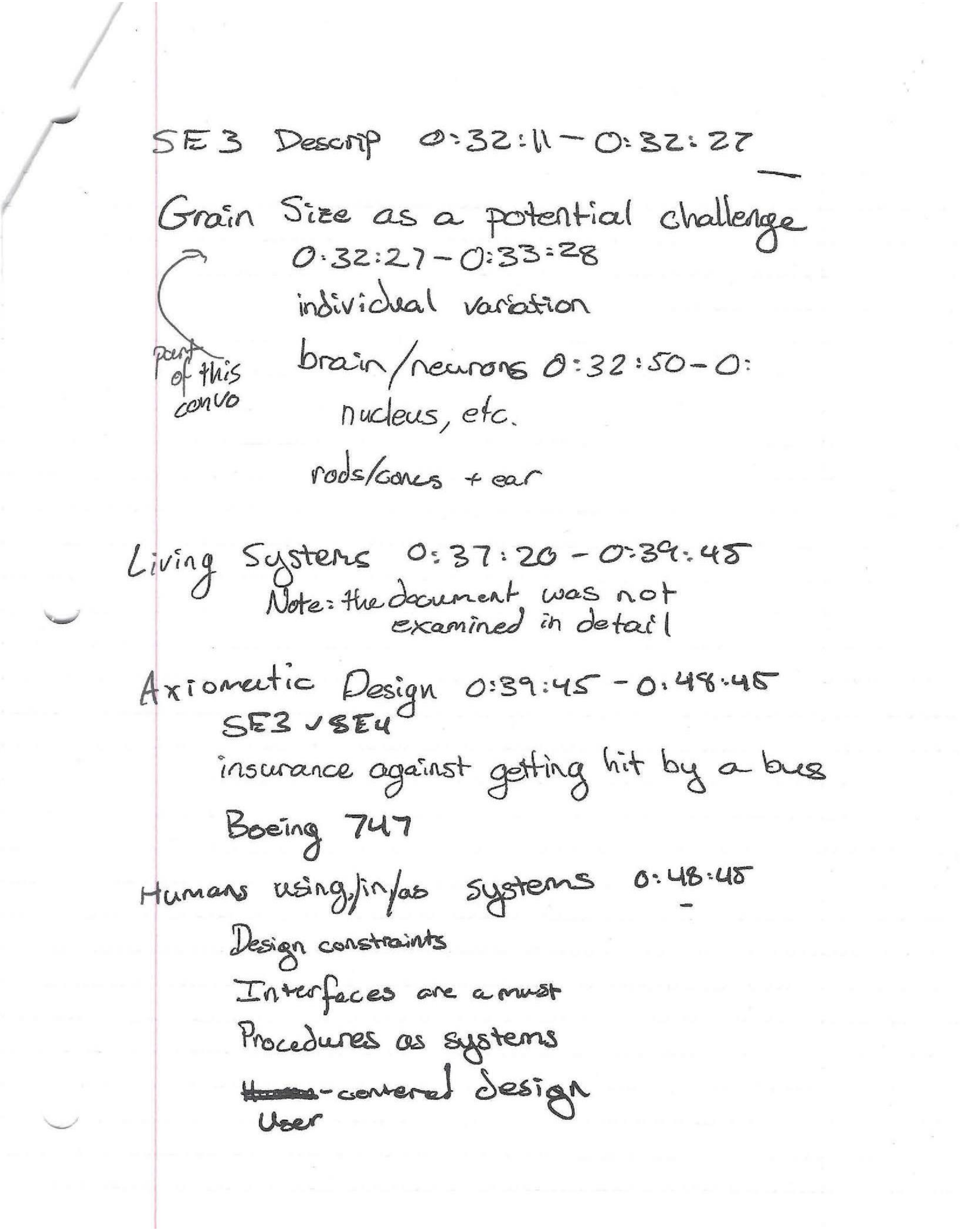
LEGOs as engineering outreach

Desk example 0:26:02 - 0:29:33

Shift from LEGO - 0:31:00

Definition of 'system' 0:31:00 - 0:32:11
(Meadows)

Figure A.2 continued



SE3 Descrip 0:32:11 – 0:32:27

Grain Size as a potential challenge
0:32:27 – 0:33:28
individual variation
brain/neurons 0:32:50 – 0:
nucleus, etc.
rods/cones + ear

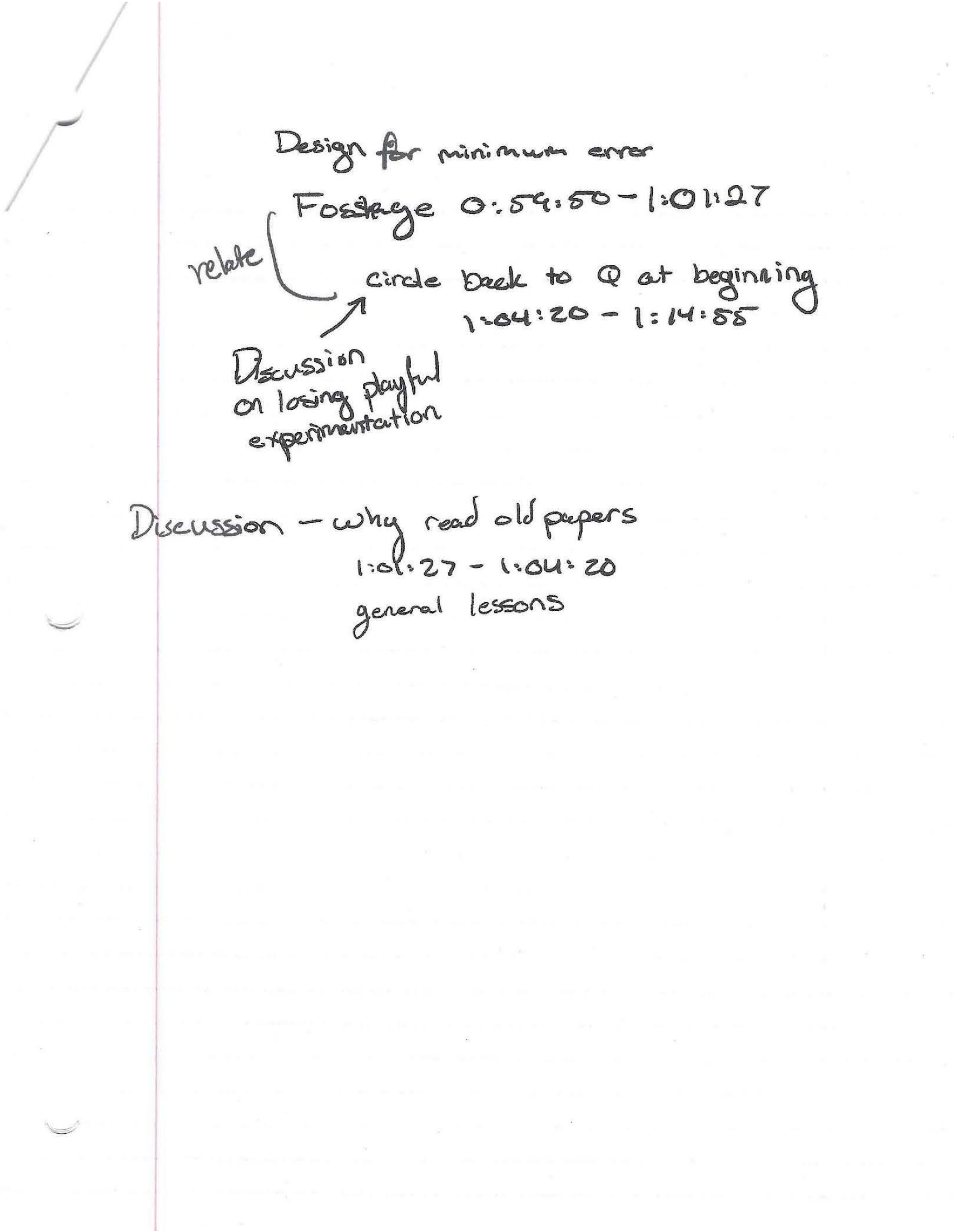
part of this convo

Living Systems 0:37:20 – 0:39:45
Note: the document was not examined in detail

Axiomatic Design 0:39:45 – 0:48:45
SE3 ✓SE4
insurance against getting hit by a bus
Boeing 747

Humans using,/in/as systems 0:48:45
Design constraints
Interfaces are a must
Procedures as systems
~~Human~~-centered design
User

Figure A.2 continued



Design for minimum error

Footage 0:59:50 - 1:01:27

relate

circle back to Q at beginning

1:04:20 - 1:14:55

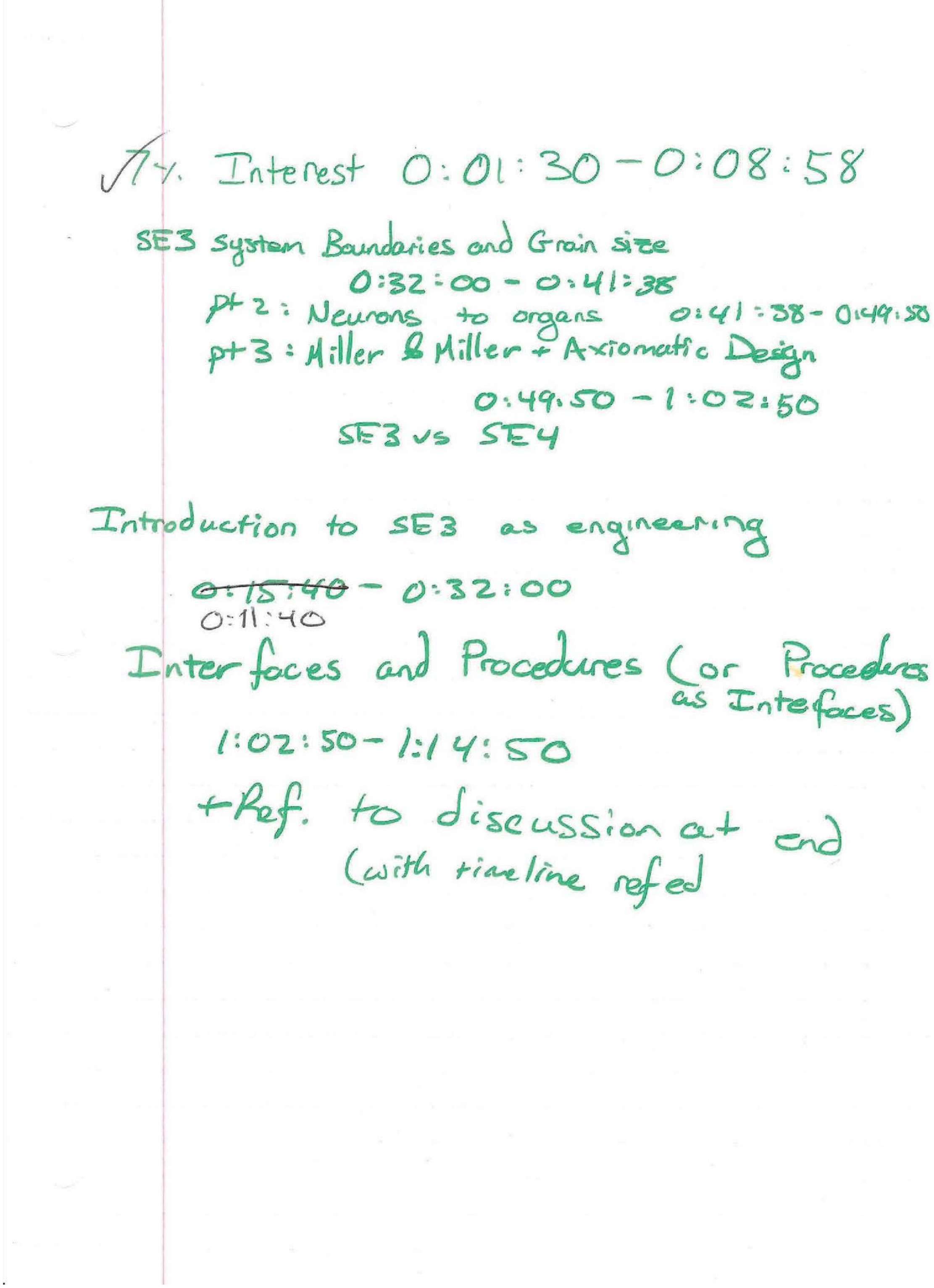
Discussion on losing playful experimentation

Discussion - why read old papers

1:01:27 - 1:04:20

general lessons

Figure A.2 continued



√7y. Interest 0:01:30 – 0:08:58

SE3 system Boundaries and Grain size
0:32:00 – 0:41:38
pt 2 : Neurons to organs 0:41:38 – 0:49:50
pt 3 : Miller & Miller + Axiomatic Design
0:49:50 – 1:02:50
SE3 vs SE4

Introduction to SE3 as engineering

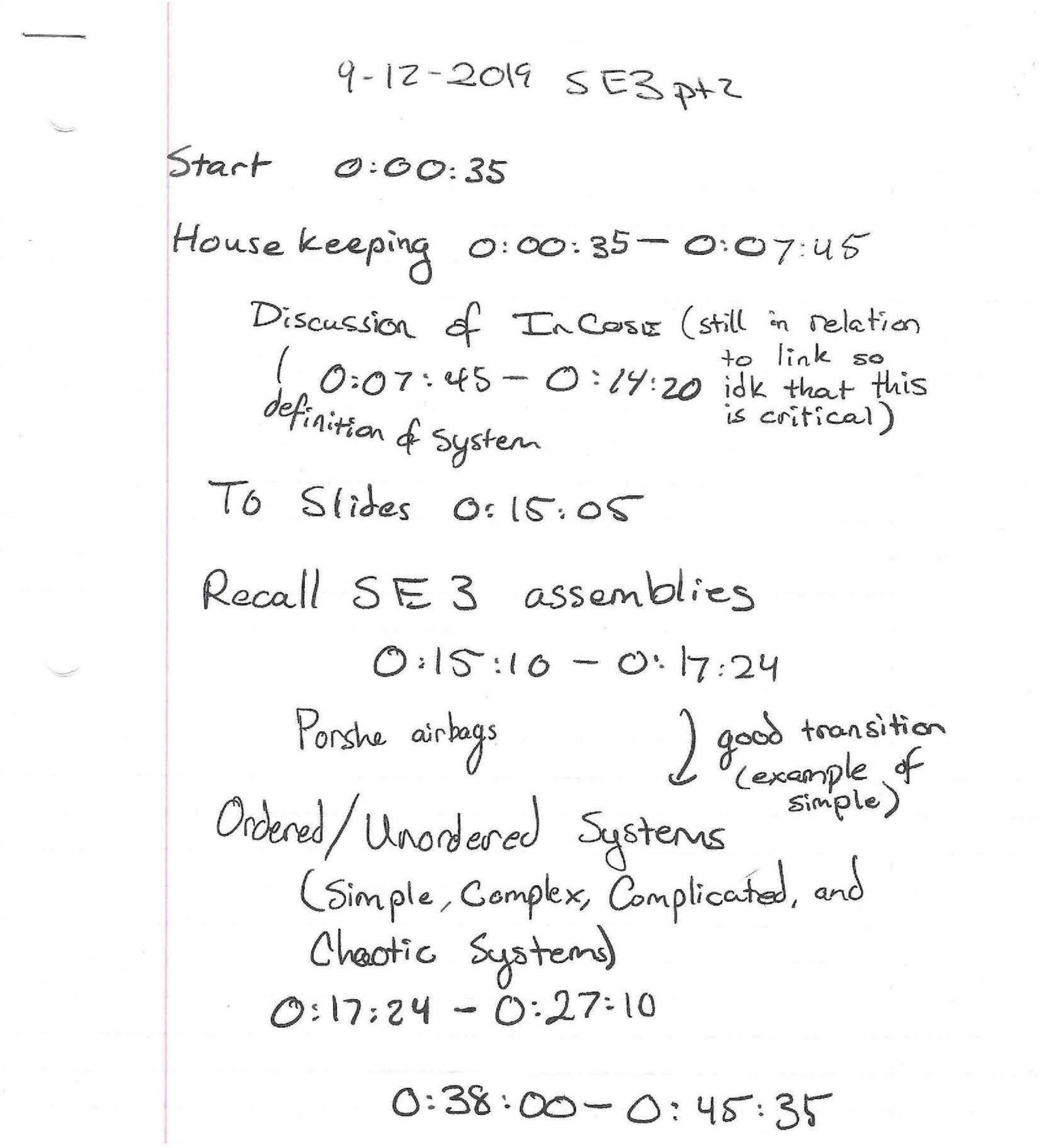
~~0:15:40~~ – 0:32:00
0:11:40

Interfaces and Procedures (or Procedures as Intefaces)

1:02:50 – 1:14:50

+Ref. to discussion at end
(with timeline refed

Figure A.2 continued



9-12-2019 SE3 pt2

Start 0:00:35

Housekeeping 0:00:35 – 0:07:45

Discussion of InCose (still in relation to link so idk that this is critical)
(0:07:45 – 0:14:20
definition of system

TO Slides 0:15:05

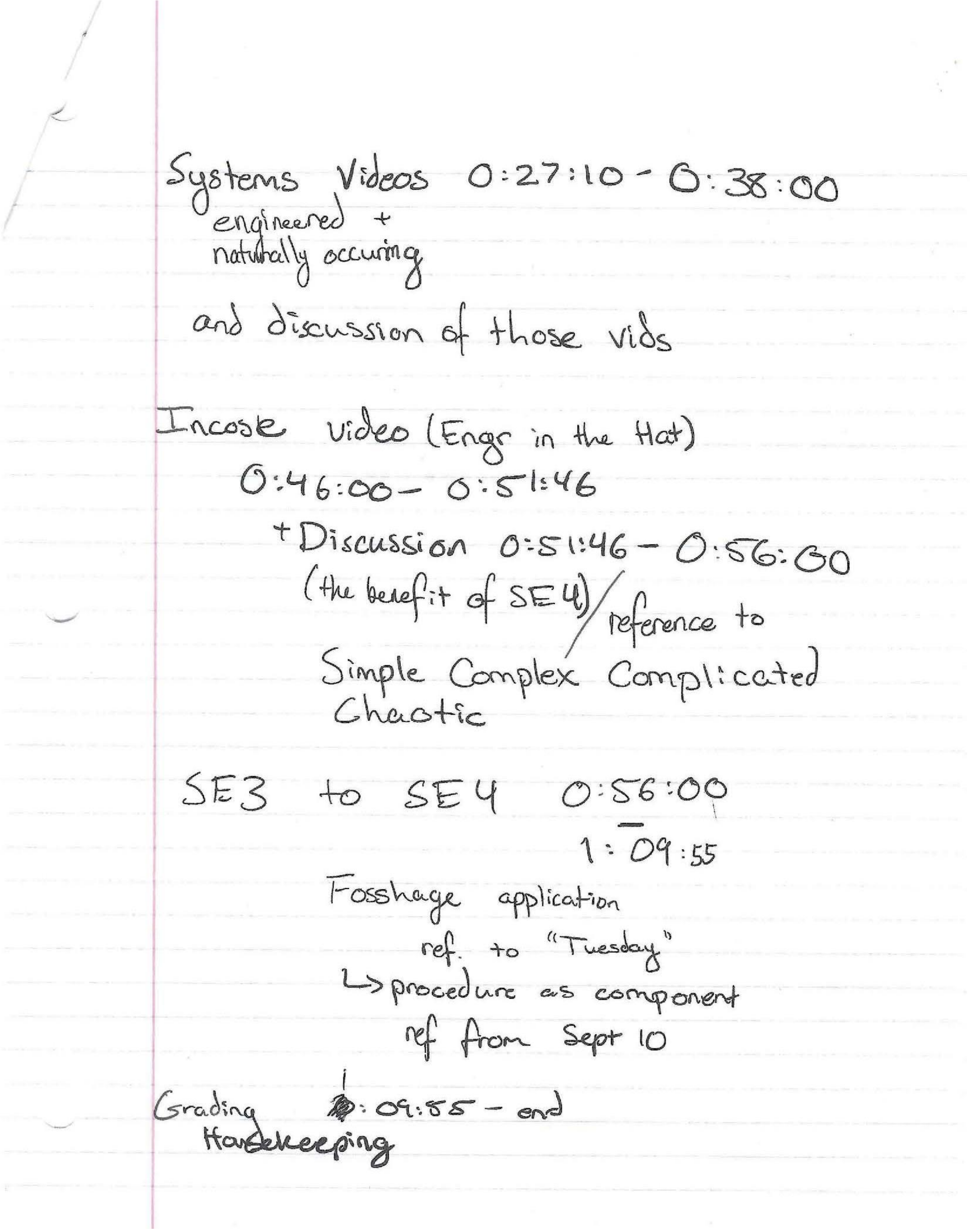
Recall SE3 assemblies
0:15:10 – 0:17:24

Porshe airbags
good transition (example of simple)

Ordered/Unordered Systems
(Simple, Complex, Complicated, and Chaotic Systems)
0:17:24 – 0:27:10

0:38:00 – 0:45:35

Figure A.2 continued



Systems Videos 0:27:10 - 0:38:00
engineered +
naturally occuring

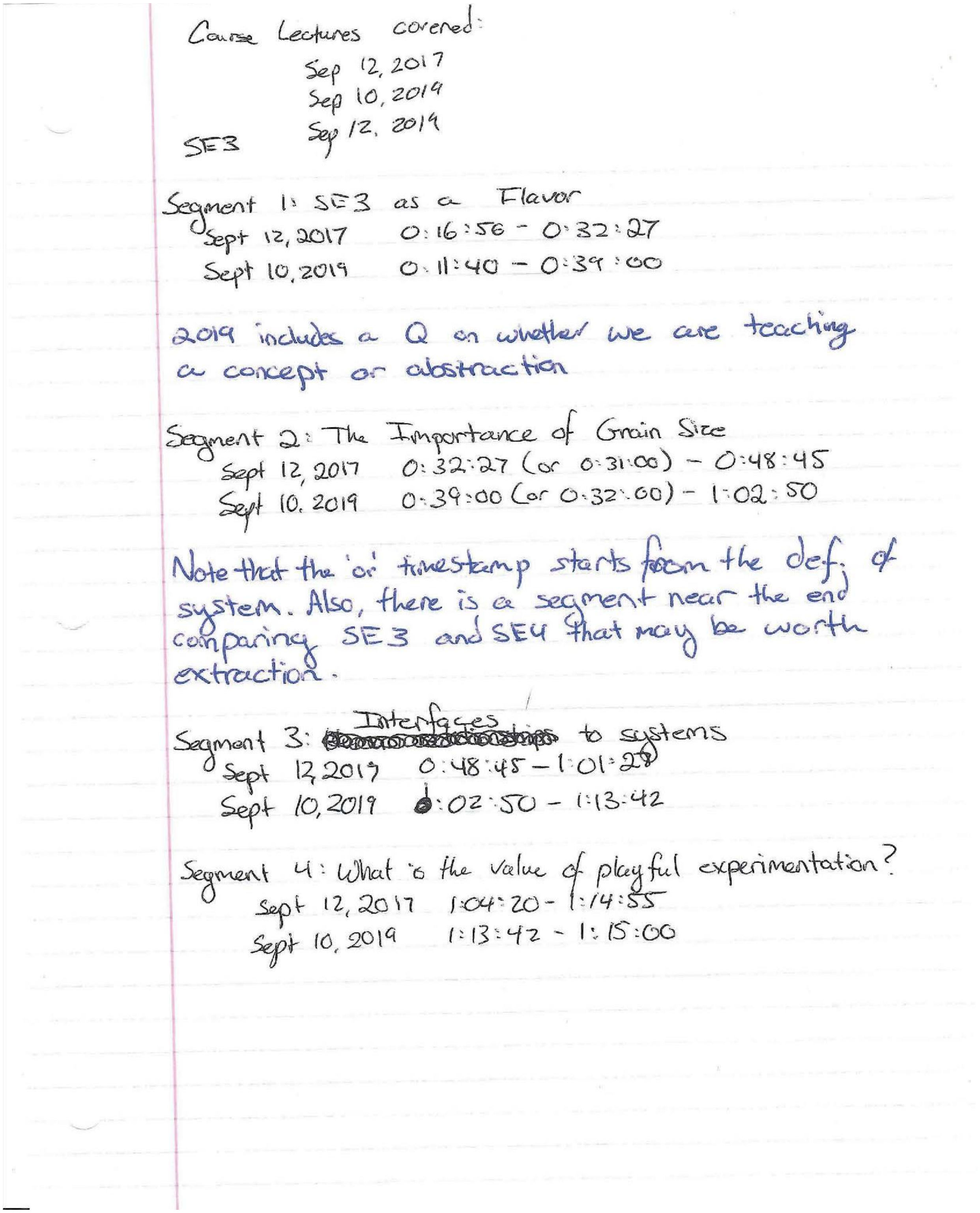
and discussion of those vids

Incose video (Engr in the Hat)
0:46:00 – 0:51:46
+ Discussion 0:51:46 – 0:56:00
(the benefit of SE4) / reference to
Simple Complex Complicated
Chaotic

SE3 to SE4 0:56:00
–
1:09:55
Fosshage application
ref. to "Tuesday"
↳ procedure as component
ref from Sept 10

Grading 1:09:55 – end
Housekeeping

Figure A.2 continued



Course Lectures covered:

Sep 12, 2017
Sep 10, 2019
SE3 Sep 12, 2019

Segment 1: SE3 as a Flavor
Sept 12, 2017 0:16:56 - 0:32:27
Sept 10, 2019 0:11:40 - 0:39:00

2019 includes a Q on whether we are teaching a concept or abstraction

Segment 2: The Importance of Grain Size
Sept 12, 2017 0:32:27 (or 0:31:00) - 0:48:45
Sept 10, 2019 0:39:00 (or 0:32:00) - 1:02:50

Note that the 'or' timestamp starts from the def. of system. Also, there is a segment near the end comparing SE3 and SE4 that may be worth extraction.

Segment 3: Interfaces to systems
Sept 12, 2017 0:48:45 - 1:01:28
Sept 10, 2019 1:02:50 - 1:13:42

Segment 4: What is the value of playful experimentation?
Sept 12, 2017 1:04:20 - 1:14:55
Sept 10, 2019 1:13:42 - 1:15:00

Table A.1: Full outputs of the content modularization process

Overall Module	**Thematic Topic**	**Video Name**	**Video Length (min)**
SE1	7% Interest	7% Interest SE1 2017	11.58
SE1	7% Interest	7% Interest SE1 2019	11.33
SE1	Analogies and Homologies	Analogies and Homologies 2017 pt1	7.35
SE1	Analogies and Homologies	Analogies and Homologies 2017 pt2	7.68
SE1	Analogies and Homologies	Analogies and Homologies 2019	13.30
SE1	Class as System	Class as System 2017	12.52
SE1	Class as System	Class as System suppl1 - intro	1.88
SE1	Class as System	Class as System suppl 2	1.82
SE1	Classifications of Systems	Classifications of Systems (Emery & Trist) 2017	10.98
SE1	Classifications of Systems	Classifications of Systems (Emery & Trist) 2019 pt1	10.13
SE1	Classifications of Systems	Classifications of Systems (Emery & Trist) 2019 pt2	5.85
SE1	Classifications of Systems	Classifications of Systems (Emery & Trist) 2019 suppl	9.33
SE1	Data, Information, Knowledge, and Wisdom	Data, Information, Knowledge, and Wisdom 2017	4.80

Table A.1 continued

Overall Module	**Thematic Topic**	**Video Name**	**Video Length (min)**
SE1	Data, Information, Knowledge, and Wisdom	Data, Information, Knowledge, and Wisdom 2019	11.75
SE1	Knowledge Clusters and Coupling	Knowledge Clusters and Coupling 2019	7.92
SE1	Knowledge Clusters and Coupling	Knowledge Clusters and Coupling suppl 2017	4.98
SE1	Properties Associated with Systems	Properties Associated with Systems 2017 pt1	6.75
SE1	Properties Associated with Systems	Properties Associated with Systems 2017 pt2	9.77
SE1	Properties Associated with Systems	Properties Associated with Systems 2019	14.75
SE1	Properties Associated with Systems	Dynamics of Entities, Flows, and Relationships 2017	12.48
SE1	Properties Associated with Systems	Dynamics of Entities, Flows, and Relationships 2019	5.85
SE1	Resources, Environments, and What Really Matters	Resources, Environments, and What Really Matters 2019	13.15
SE1	SE1 as a Flavor	SE1 as a Flavor 2017 pt1	9.72
SE1	SE1 as a Flavor	SE1 as a Flavor 2017 pt2	12.45
SE1	SE1 as a Flavor	SE1 as a Flavor 2019	11.98
SE1	SE1 as a Flavor	System Boundaries and Simplifications 2017 pt1	6.75

Table A.1 continued

Overall Module	**Thematic Topic**	**Video Name**	**Video Length (min)**
SE1	SE1 as a Flavor	System Boundaries and Simplifications 2017 pt2	11.32
SE1	SE1 as a Flavor	System Boundaries and Simplifications 2019	5.78
SE1	The Nature of Complex Problems	The Nature of Complex Problems 2017	9.93
SE1	The Nature of Complex Problems	The Nature of Complex Problems 2019	12.02
SE2	7% Interest	7% Interest SE2 2017	12.32
SE2	7% Interest	7% Interest SE2 2019	10.28
SE2	Applying Math to System Goals and Dynamics	Applying Math to System Goals and Dynamics 2017	13.22
SE2	Applying Math to System Goals and Dynamics	Applying Math to System Goals and Dynamics 2017-Sep7	12.53
SE2	Applying Math to System Goals and Dynamics	Applying Math to System Goals and Dynamics 2019 pt1	5.02
SE2	Applying Math to System Goals and Dynamics	Applying Math to System Goals and Dynamics 2019 pt2	10.75
SE2	Applying Math to System Goals and Dynamics	Applying Math to System Goals and Dynamics 2019-Sep5 pt1	5.40
SE2	Applying Math to System Goals and Dynamics	Applying Math to System Goals and Dynamics 2019-Sep5 pt2	2.70

Table A.1 continued

Overall Module	**Thematic Topic**	**Video Name**	**Video Length (min)**
SE2	Class as System Supplemental - Discussion Board	Class as System Supplemental - Discussion Board pt1	10.65
SE2	Class as System Supplemental - Discussion Board	Class as System Supplemental - Discussion Board pt2	5.95
SE2	Homologies Across Applications	Homologies Across Applications 2017 showing figure	1.57
SE2	Homologies Across Applications	Homologies Across Applications 2019 showing figure	4.12
SE2	Homologies Across Applications	Homologies Across Applications 2017	6.63
SE2	Homologies Across Applications	Homologies Across Applications 2019	8.00
SE2	Math as a Language - Benefits and Barriers	ICT System Example 2017	8.68
SE2	Math as a Language - Benefits and Barriers	ICT System Example 2019	8.47
SE2	Math as a Language - Benefits and Barriers	ICT System Example 2019 suppl	2.20
SE2	Math as a Language - Benefits and Barriers	Math as a Language - Benefits and Barriers 2017-Sep5 pt1	4.48
SE2	Math as a Language - Benefits and Barriers	Math as a Language - Benefits and Barriers 2017-Sep5 pt2	13.28

Table A.1 continued

Overall Module	**Thematic Topic**	**Video Name**	**Video Length (min)**
SE2	Math as a Language - Benefits and Barriers	Math as a Language - Benefits and Barriers 2017-Sep7 pt1	6.12
SE2	Math as a Language - Benefits and Barriers	Math as a Language - Benefits and Barriers 2017-Sep7 pt2	6.40
SE2	Math as a Language - Benefits and Barriers	Math as a Language - Benefits and Barriers 2019-Sep3 pt1	12.73
SE2	Math as a Language - Benefits and Barriers	Math as a Language - Benefits and Barriers 2019-Sep3 pt2	6.52
SE2	Math as a Language - Benefits and Barriers	Math as a Language - Benefits and Barriers 2019-Sep5 pt1	8.73
SE2	Math as a Language - Benefits and Barriers	Math as a Language - Benefits and Barriers 2019-Sep5 pt2	8.85
SE2	Math as a Language - Benefits and Barriers	Math as a Language - Benefits and Barriers 2019-Sep5 pt3	11.62
SE2	Predator-Prey Equations	Predator-Prey Equations	2.15
SE2	SE2 as a Flavor	SE2 as a Flavor 2017 suppl	8.23
SE2	SE2 as a Flavor	SE2 as a Flavor 2017	14.13
SE2	SE2 as a Flavor	SE2 as a Flavor 2019	11.23

Table A.1 continued

Overall Module	Thematic Topic	Video Name	Video Length (min)
SE2	SE2 as a Flavor	SE2 as a Flavor 2019 suppl	2.68
SE2	SE2 at the Vet	SE2 at the Vet 2017 pt1	5.75
SE2	SE2 at the Vet	SE2 at the Vet 2017 pt2	10.53
SE2	SE2 at the Vet	SE2 at the Vet 2019	2.50
SE2	System Flow Control	System Flow Control 2017	10.38
SE2	System Flow Control	System Flow Control 2019	5.25
SE2	System Stability	System Stability 2017	3.48
SE2	System Stability	System Stability 2019	12.92
SE3	7% Interest	7% Interest SE3 2017	9.95
SE3	7% Interest	7% Interest SE3 2019	7.57
SE3	INCOSE	INCOSE - Engineer in the Hat	10.00
SE3	INCOSE	INCOSE - System Definition	6.82
SE3	Natural and Engineered Systems	Natural and Engineered Systems 2019	10.92
SE3	Ordered and Un-ordered Systems	Ordered and Un-ordered Systems pt1	11.72
SE3	Ordered and Un-ordered Systems	Ordered and Un-ordered Systems pt2	7.60

Table A.1 continued

Overall Module	**Thematic Topic**	**Video Name**	**Video Length (min)**
SE3	SE3 as a Flavor	SE3 as a Flavor 2017	15.00
SE3	SE3 as a Flavor	SE3 as a Flavor 2019 pt1	9.63
SE3	SE3 as a Flavor	SE3 as a Flavor 2019 pt2	7.78
SE3	SE3 as a Flavor	SE3 as a Flavor 2019 pt3	9.98
SE3	SE3 as a Flavor	SE3 as a Flavor 2019 suppl	2.00
SE3	Shifting from SE3 to SE4	Shifting from SE3 to SE4 2019	13.98
SE3	Systems Interfaces	Systems Interfaces 2017	12.52
SE3	Systems Interfaces	Systems Interfaces 2019	10.83
SE3	The Importance of Grain Size	The Importance of Grain Size 2017 pt1	8.75
SE3	The Importance of Grain Size	The Importance of Grain Size 2017 pt2	9.12
SE3	The Importance of Grain Size	The Importance of Grain Size 2019 pt1	13.77
SE3	The Importance of Grain Size	The Importance of Grain Size 2019 pt2	10.12
SE3	The Importance of Grain Size	The Importance of Grain Size 2019 pt3 - Axiomatic Design	6.95
SE3	Value of Playful Experimentation	Value of Playful Experimentation 2017	10.65

Table A.1 continued

Overall Module	**Thematic Topic**	**Video Name**	**Video Length (min)**
SE3	Value of Playful Experimentation	Value of Playful Experimentation 2019	1.17
SE4	7% Interest	7% Interest SE4 2017	12.15
SE4	Approaches to Design	Approaches to Design 2017	10.55
SE4	People Management	People Management pt1	14.38
SE4	People Management	People Management pt2	10.65
SE4	Process Management	Process Management pt1	12.63
SE4	Process Management	Process Management pt2	12.75
SE4	SE4 as a Flavor	SE4 as a Flavor 2017 pt1	11.70
SE4	SE4 as a Flavor	SE4 as a Flavor 2017 pt2	5.40
SE4	SE4 as an Art	SE4 as an Art 2017 pt1	6.35
SE4	SE4 as an Art	SE4 as an Art 2017 pt2	4.00
SE4	System Design Models	System Design Models 2017 pt1	10.48
SE4	System Design Models	System Design Models 2017 pt2	5.15
SE5	7% Interest	7% Interest SE5 2019	12.20

Table A.1 continued

Overall Module	**Thematic Topic**	**Video Name**	**Video Length (min)**
SE5	Connecting the Flavors using Concept Maps	Connecting the Flavors using Concept Maps 2019	6.88
SE5	Desperately Seeking SE5	Desperately Seeking SE5 2017 pt1	9.62
SE5	Desperately Seeking SE5	Desperately Seeking SE5 2017 pt2	11.40
SE5	Historical Context - Libraries	Historical Context - Libraries 2019	9.37
SE5	Perspectives on Information Architecture	Perspectives on Information Architecture 2019 pt1	12.12
SE5	Perspectives on Information Architecture	Perspectives on Information Architecture 2019 pt2	8.55
SE5	SE5 as a Flavor	SE5 as a Flavor 2019	10.02
SE5	SE5 as a Flavor	SE5 as it relates to other flavors pt1 Sep24	14.80
SE5	SE5 as a Flavor	SE5 as it relates to other flavors pt1 Sep26	14.32
SE5	SE5 as a Flavor	SE5 as it relates to other flavors pt2 Sep26	6.72
SE5	SE5 as a Flavor	SE5 as it relates to other flavors pt3 Sep26	11.42
SE5	SE5 as a Flavor	SE5 as it relates to other flavors pt4 Sep26	13.35
SE5	SE5 as a Flavor	SE5 as it relates to other flavors pt5 Sep26	5.15

Table A.1 continued

Overall Module	Thematic Topic	Video Name	Video Length (min)
SE5	The Value of Metadata	The Value of Metadata 2019	6.20
Engineering Case Study	7% Interest	7% Interest Introduction to Case Methodology 2019	11.47
Engineering Case Study	Apollo 13	Apollo 13 Intro 2017	10.85
Engineering Case Study	Apollo 13	Apollo 13 Intro 2019 pt1	10.07
Engineering Case Study	Apollo 13	Apollo 13 Intro 2019 pt2	14.87
Engineering Case Study	Apollo 13	Apollo 13 Intro 2019 pt3	14.78
Engineering Case Study	Apollo 13	Apollo 13 Intro 2019 pt4	15.55
Engineering Case Study	Beer Game	Beer Game Discussion 2017	9.48
Engineering Case Study	Beer Game	Beer Game Discussion 2019	9.00
Engineering Case Study	Cord	Cord Intro 2017	14.02

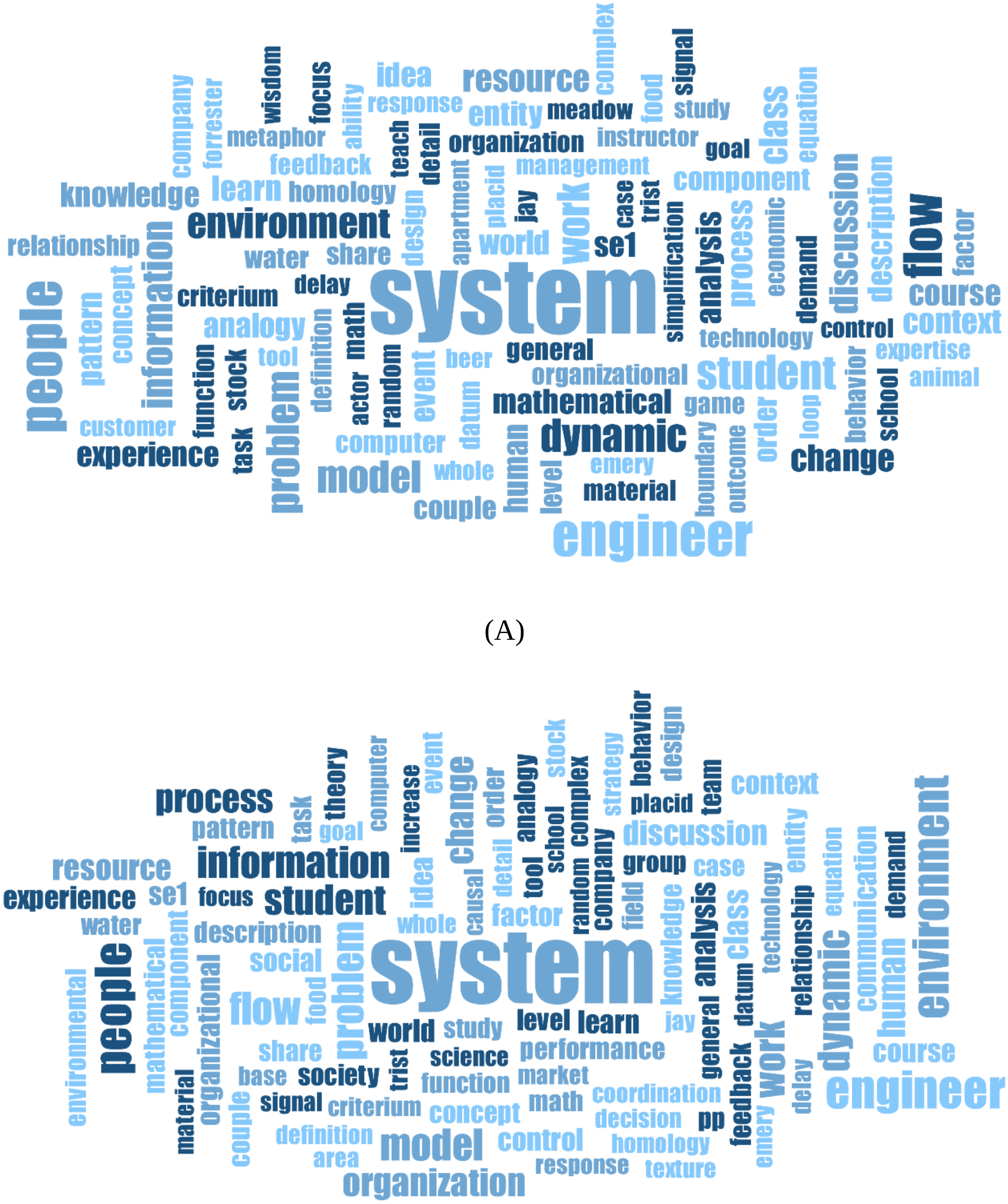
Table A.1 continued

Overall Module	**Thematic Topic**	**Video Name**	**Video Length (min)**
Engineering Case Studies	Engineering Case Studies	Engineering Case Studies	5.72
Engineering Case Studies	Historical Context to Case Methodology	Historical Context to Case Methodology 2017	11.72
Engineering Case Studies	Historical Context to Case Methodology	Historical Context to Case Methodology 2019	3.92
Engineering Case Studies	Polar Vortex	Polar Vortex 2017	15.75
Engineering Case Studies	Polar Vortex	Polar Vortex 2019 pt1 v1.0	12.50
Engineering Case Studies	Polar Vortex	Polar Vortex 2019 pt1 v2	8.53
Engineering Case Studies	Polar Vortex	Polar Vortex 2019 pt2	11.60
Engineering Case Studies	System Definition FAQ	System Definition FAQ 2017	8.88
Engineering Case Studies	Vasa	Vasa Intro 2017 pt1	15.32
Engineering Case Studies	Vasa	Vasa Intro 2017 pt2	12.22

Table A.1 continued

Overall Module	Thematic Topic	Video Name	Video Length (min)
Engineering Case Studies	Vasa	Vasa Intro 2019 pt1	11.93
Engineering Case Studies	Vasa	Vasa Intro 2019 pt2	15.18
Engineering Case Studies	Vasa	Vasa Discussion 2019	11.40

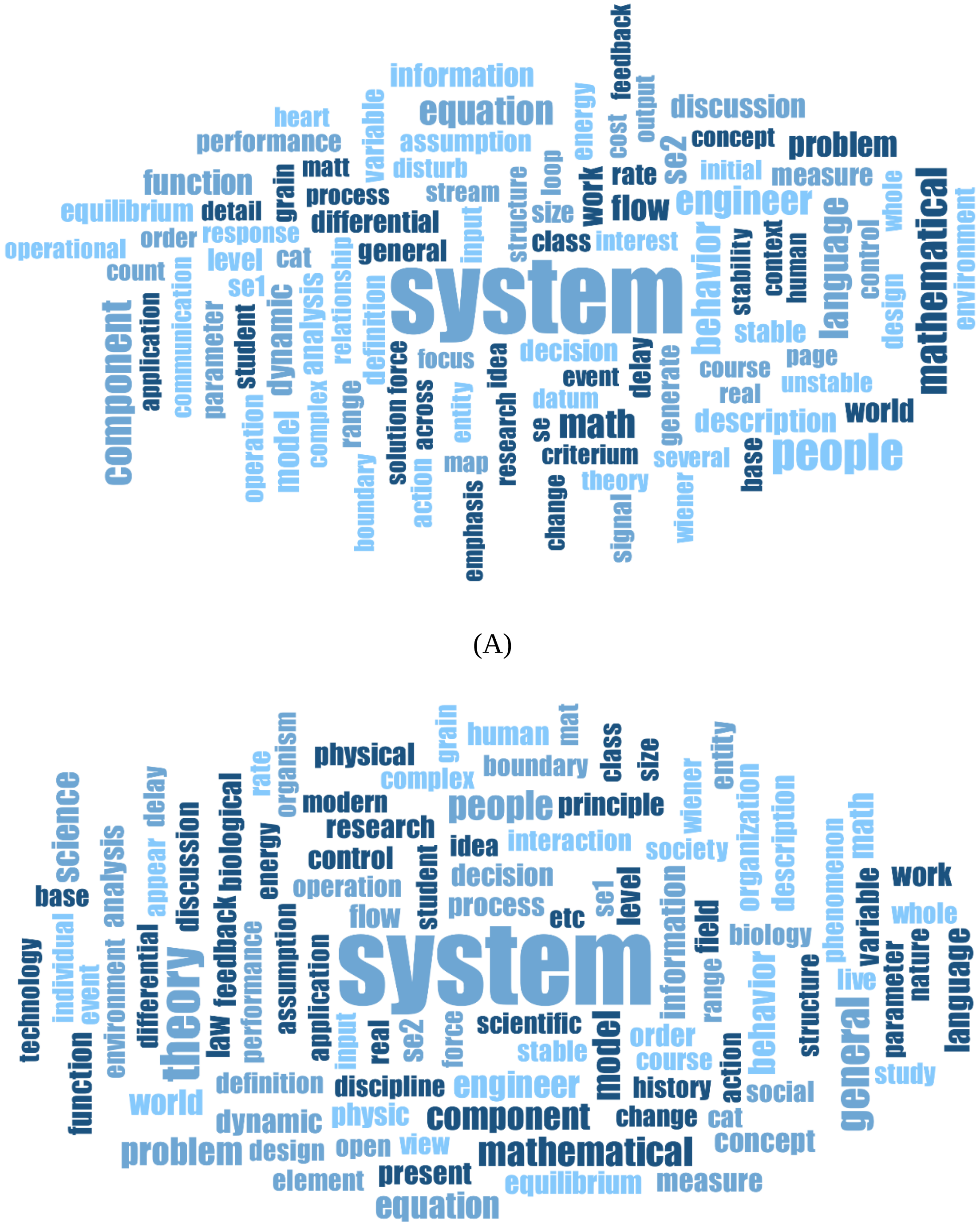
APPENDIX B. CONTENT ANALYSIS AND TAGGING OUTPUTS



(A)

(B)

Figure B.1: Word clouds describing the SE1 module (A) excluding assigned readings and (B) including assigned readings



(A)

(B)

Figure B.2: Word clouds describing the SE2 module (A) excluding assigned readings and (B) including assigned readings

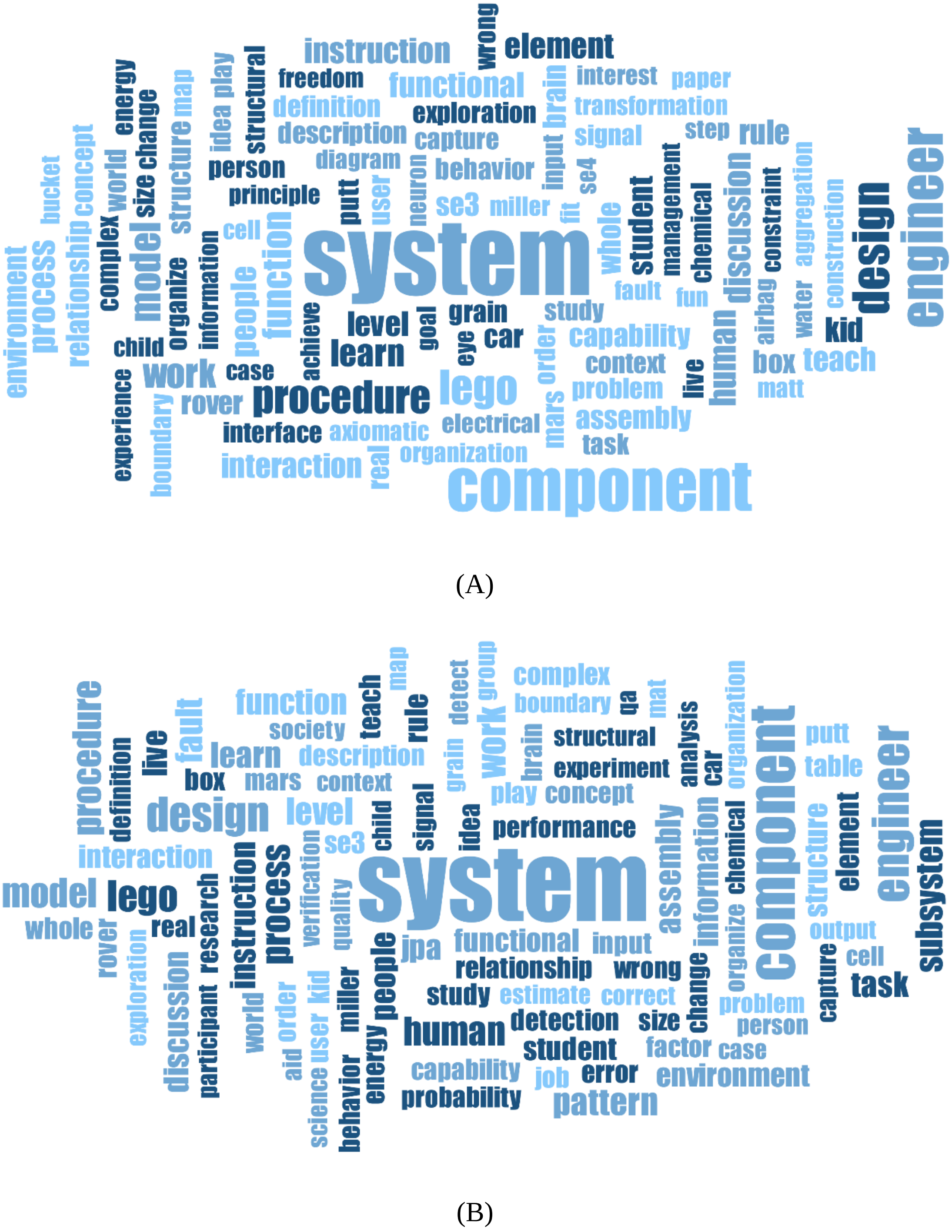


Figure B.3: Word clouds describing the SE3 module (A) excluding assigned readings and (B) including assigned readings

(A)

(B)

Figure B.4: Word clouds describing the SE4 module (A) excluding assigned readings and (B) including assigned readings

Figure B.5: Word clouds describing the Engineering case studies module (A) excluding assigned readings and (B) including assigned readings

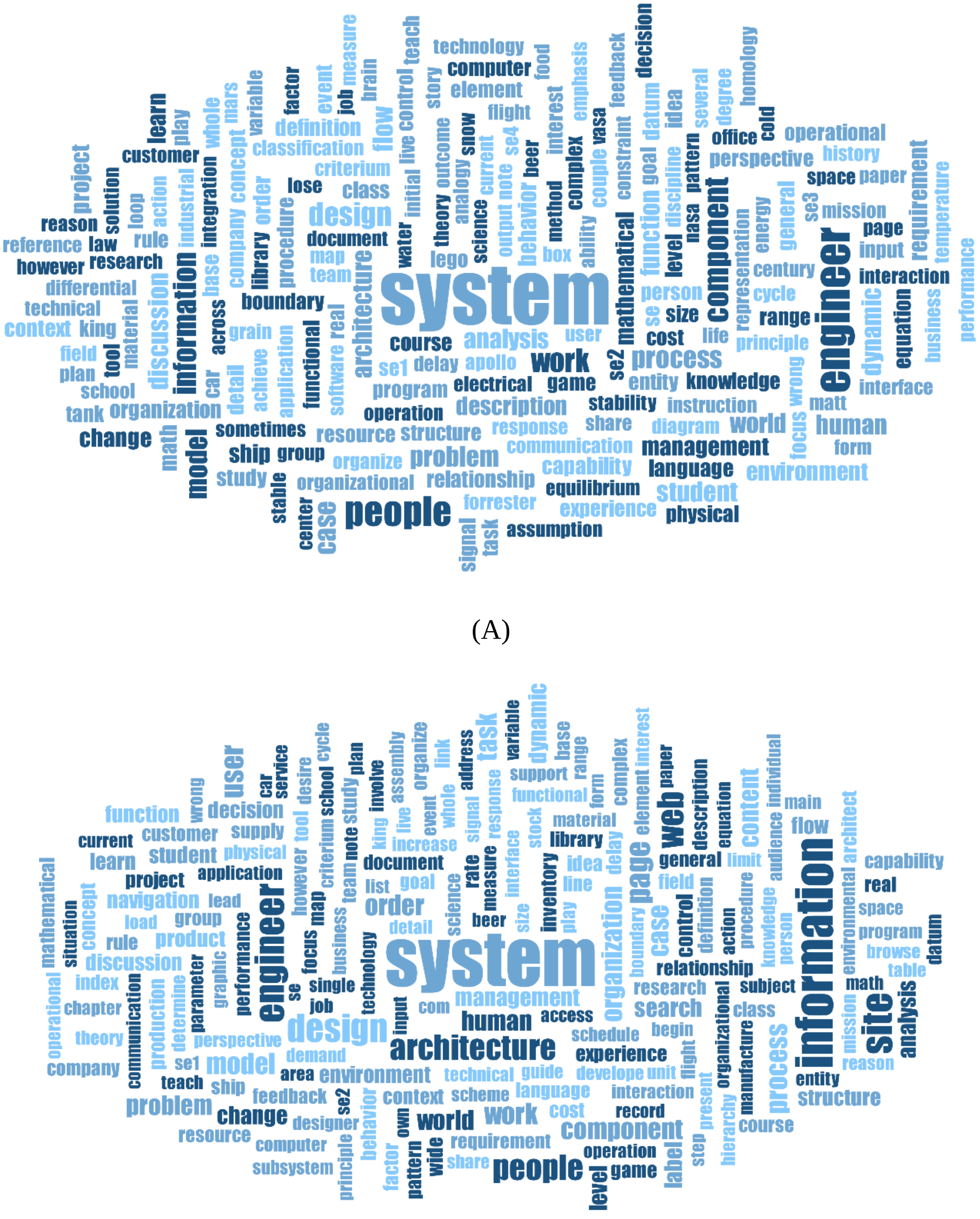


Figure B.6: Word clouds describing all of the PoSE material (A) excluding assigned readings and (B) including assigned readings

Table B.1: Tagging table example for the SE3 module showing the 124 identified tags and their relationships

Tag Name	Synonyms	Higher-level Tags	Lower-level Tags	Examples	Related Tags
SE3	Component whole Component-whole Component-whole relationship Component-whole relation	Systems engineering			SE1 SE2 SE4 SE5
System	Subsystem		System boundary Component Transformation Constraint Input Output Operational range Feedback	Nonliving system Living system Sensory system Natural system Engineering system Supranatural system	Model Systems engineer Grain size Emergent capabilities Work Meadows Stability Entropy Simulation Homeostasis
Nonliving system	Abiotic factor Nonliving subsystem Nonliving	System			Living system Natural system Ecosystem
Living system	Biotic Living subsystem Living entity	System	Cell Organ Organism Group Organization Community Society Supranational system Sensory system	Reproducer Boundary (Living Subsystem) Ingestor Distributer Converter Producer Matter-energy storage Extruder Motor Supporter	Ecosystem Natural system Miller Living systems theory Nonliving system

Table B.1 continued

Tag Name	Synonyms	Higher-level Tags	Lower-level Tags	Examples	Related Tags
Sensory system	• Sensory subsystem	• System • Living system			• Signal detection
Natural system		• System			• Ecosystem
Ecosystem					• Nonliving system • Living system • Natural system
Engineering system	• Engineered system	• System • Engineer		• Aircraft • Apollo	• Design process
System Boundary	• System boundaries	• System			
Component		• System	• Functional component • Structural component • Centralization • Decentralization • Heterogeneity • Homogeneity		• Reproducer • Boundary (Living Subsystem) • Ingestor • Distributer • Converter • Producer • Matter-energy storage • Extruder • Motor • Supporter
Transformation		• System	• Functional transformation		• Input • Output
Constraint		• System			
Input		• System			• Output • Transformation
Output		• System			• Input • Transformation

Table B.1 continued

Tag Name	Synonyms	Higher-level Tags	Lower-level Tags	Examples	Related Tags
Functional	• Functionally		• Functional transformation • Functional capability • Functional component • Functional model • Functional purpose		
Structural	• Structurally		• Structural component • Structural model		
Functional Component		• Functional • Component			
Structural component		• Structural • Component			
Functional capability		• Functional			
Functional transformation		• Functional • Transformation			
Functional purpose		• Functional			
Model			• Functional model • Structural model • Homology	• Lego model • Plastic model • Model car • MER model	• System
Functional model		• Functional • Model			• Structural model
Structural model		• Structural • Model		• Exploded diagram	• Functional model

Table B.1 continued

Tag Name	Synonyms	Higher-level Tags	Lower-level Tags	Examples	Related Tags
Exploded diagram		• Structural model			• Assembly task
Lego model		• Lego • Model		• Mars rover • Saturn V	
Plastic model		• Model		• Lunar module	• Model car
Model car		• Model			• Plastic model
MER model		• Model			
Mars rover (model)	• Exploration rover • Mars exploration rover	• Lego model			• Saturn V (model) • Lunar module (model) • NASA
Saturn V (model)		• Lego model			• Mars rover (model) • Lunar module (model) • NASA
Lunar module (model)		• Plastic model			• Mars rover (model) • Saturn V (model) • NASA
Systems Engineer		• Engineer			• System • INCOSE
Grain size					• System
Emergent capabilities	• Emerging capabilities				• System
Engineer			• Engineering structure	• Systems engineer	• Design
Engineering structure		• Engineer			

Table B.1 continued

Tag Name	Synonyms	Higher-level Tags	Lower-level Tags	Examples	Related Tags
Design		•	• Design process		• Engineer
Design process		• Design			
Living systems theory					• Living system • Miller
Axiomatic design		• Design process			• Assumption
Assembly	• Subassembly • Sub-assembly • Sub assembly		• Assembly task		
Assembly task		• Assembly • Task	• Playful experimentation • Proceduralized recipe		• Lego • Job performance aid • Exploded diagram • Fosshage
Job performance aid	• Job performance • JPA • JPAs				• Assembly task • Quality assurance
Quality assurance	• QA checker • QA observer • QA		• Validation • Verification		• Job performance aid • Human error • Fosshage • Expert • Novice
Playful experimentation	• Construction freedom	• Assembly task			• Proceduralized recipe
Proceduralized recipe	• Procedural recipe • Procedularized	• Assembly task			• Playful experimentation

Table B.1 continued

Tag Name	Synonyms	Higher-level Tags	Lower-level Tags	Examples	Related Tags
Human error		Errors			Quality assurance Fault
Operational range	Operational envelope	System			Resilience Robust Stability
Human-machine interaction	Human machine Human technology Human-computer Human computer				Interface
Verification	Verify	Quality assurance			Validation
Validation	Valid	Quality assurance			Verification
Fault					Human error Errors
Errors			Human error		Fault
Process		Task	•		Procedure
Work			Task		System
Task		Work	Process Procedure Assembly task		•
Procedure	Instructions	Task			Process Assembly task
Brain		Organ			Memory
Memory					Brain

Table B.1 continued

Tag Name	Synonyms	Higher-level Tags	Lower-level Tags	Examples	Related Tags
Aircraft	- Airplane	- Engineering System			
Apollo					- NASA
Uncertainty					- Assembly task - Fosshage - Design - Entropy
Parameter		- SE2			-
Assumption					- Fosshage - Axiomatic Design
Fosshage					- Quality Assurance - Assembly task - Job performance aid - Uncertainty - Assumption
Homology		- Model			- Analogy
Analogy					- Homology
Meadows					- System
Robust	- Robustness				- Resilience - Operational range
Resilience					- Robust - Operational range
Team					- Group

Table B.1 continued

Tag Name	Synonyms	Higher-level Tags	Lower-level Tags	Examples	Related Tags
CAD		• Structural model • Exploded diagram			•
Centralization	• Centralized	• Component			• Decentralization • Heterogeneity • Homogeneity
Decentralization	• Decentralized	• Component			• Centralization
Expert					• Novice • Quality assurance
Novice					• Expert • Quality assurance
Homogeneity		• Component			• Heterogeneity • Centralization • Decentralization
Heterogeneity		• Component			• Homogeneity • Centralization • Decentralization
INCOSE					• Systems engineer
Stability					• System • Operational range
Entropy	• Entropic				• Uncertainty • System
Cell		• Living system	• Nucleus	• Neuron	• Miller
Organ		• Living system		• Brain	• Miller
Organism		• Living system			• Miller
Group		• Living system			• Team • Miller

Table B.1 continued

Tag Name	Synonyms	Higher-level Tags	Lower-level Tags	Examples	Related Tags
Organization		• Living system			• Miller
Community		• Living system			• Miller
Society		• Living system			• Miller
Supranational system	• Supranational	• Living system			• Miller
Neuron	• Neuronal	• Cell	• Axon • Myelin sheath • Synapse • Dendrite • Nucleus		
Axon		• Neuron			
Myelin Sheath	• Myelin	• Neuron			
Synapse		• Neuron			
Dendrite		• Neuron			
Nucleus		• Neuron • Cell			
Taxonomy	• Classification • Classify (classified) • Category • Categorize • Categorization				
Miller					• Living systems • Reproducer

Table B.1 continued

Tag Name	Synonyms	Higher-level Tags	Lower-level Tags	Examples	Related Tags
					Boundary (Living Subsystem) Ingestor Distributer Converter Producer Matter-energy storage Extruder Motor Supporter Cell Organ Organism Group Organization Community Society Supranational system
Reproducer		Living system			Miller Component
Boundary (Living subsystem)		Living system •			Miller Component System boundary
Ingestor	Ingester	Living system			Miller Component
Distributor		Living system			Miller Component
Converter		Living system			Miller Component

Table B.1 continued

Tag Name	Synonyms	Higher-level Tags	Lower-level Tags	Examples	Related Tags
Producer		• Living system			• Miller • Component
Matter-energy storage	• Matter-energy • Matter energy	• Living system			• Miller • Component
Extruder		• Living system			• Miller • Component
Motor		• Living system			• Miller • Component
Supporter		• Living system			• Miller • Component
Lego	• Lego™ • Legos™ • Lego® • Legos		• Lego model		• Constructivist learning
Constructivist learning		• Learning			• Lego
Signal detection	• Signal				• Sensory system
SE2	• Mathematical analyses • Cybernetics		• Parameter		• SE1 • SE3 • SE4 • SE5
SE4	• Engineering deployment • Project management				• SE1 • SE2 • SE3 • SE5
Goal	• Objective				
Risk	• High-risk				

Table B.1 continued

Tag Name	Synonyms	Higher-level Tags	Lower-level Tags	Examples	Related Tags
Simulation					- System
NASA					- Apollo - Mars rover (model) - Saturn V (model) - Lunar module (model)
Homeostasis					- System
Feedback		- System			
Aircraft	- Airplane				
Variation	- Variance				
Information					- Data - Knowledge - Wisdom
Data					- Knowledge - Information - Wisdom
Knowledge					- Data - Information - Wisdom
Wisdom					- Data - Information - Knowledge
Interface					- Human-computer interaction

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