ABSTRACT

Title of dissertation: USING ENGINEERING DESIGN PROJECT JOURNALS TO INFER INDIVIDUAL ACTIVITY AND ASSESS TEAM BEHAVIOR

Werner C. Born
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Dissertation directed by: Professor Linda Schmidt
Department of Mechanical Engineering

Design is critical to our society and yet we still do not understand a great deal about the underlying processes which occur as the engineering designer solves a problem. Analyzing such information could provide a wealth of insight on not only how design works but also how individuals work design. Concurrently maintained design journals kept by mechanical engineering students enrolled in capstone design courses offer a rich avenue to explore this phenomena. By applying a classification scheme to design journals, the entries of design activity of both individuals and teams were analyzed to determine relative time on each activity. These proportions were then examined across multiple project intervals defined by key deliverable dates in addition to across the project as a whole. Recurring sequences within these activities were also identified. Beyond the use of the classification scheme, other aspects of design journal analysis were explored. Specific concepts were tracked across a team, which were also used to calculate ratios of how often a member of

a team references concepts by their teammates, themselves, and the final concept. With the addition of entry dates this information will also be used to map the exchange of ideas across a team and to chart the life of each concept. Journal content was codified and tested. Discoveries were made not only about the activity frequencies but how much those frequencies varied from person to person and team to team. The most common activity recorded in journals was *Analysis*, which averaged 23.13% of journal segments. Students were moderately accurate at identifying the frequency of *Analysis* and *Reflection* work. The most common sequences of unique activity were *Idea Generation* and *Analysis* along with its reverse. There were 3 distinct patterns of how individual behavior related to team members. 3 of 13 teams examined had uniform proportions of activity, while at the other extreme another 7 teams had little to no uniformity. The three activity classes found to be most affected by a project's time line were *Problem Understanding*, *Idea Generation*, and *Decision Making*, which each were found to have a statistically significant change in recorded activity over time.

USING ENGINEERING DESIGN PROJECT JOURNALS TO INFER INDIVIDUAL ACTIVITY AND ASSESS TEAM BEHAVIOR

by

Werner Christian Born

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Advisory Committee:

Professor Linda Schmidt, Chair and Advisor
Professor David Bigio
Professor Jeffrey Herrmann
Assistant Professor Mark Fuge
Associate Professor David Akin, Dean's Representative

Foreword

"If you're alive, kick into drive. Chase whimsies. See if you can turn dreams into a way to make a living, if not an entire way of life." - Kevin Smith

Dedication

This dissertation is dedicated to my parents, in the hope that it may it serve as a small token of my appreciation for all they have provided me with in life.

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List of Abbreviations

Segs	Segment count
Info	*Information Seeking and Noting* design activity class
Prob	*Problem Understanding* design activity class
Idea	*Idea Generation* design activity class
Anlys	*Analysis* design activity class
Decs	*Decisions* design activity class
PM	*Project Management* design activity class
Refl	*Reflection* design activity class
Int#	Interval 1 2 or 3 of the capstone project
ENME472	Mechanical engineering undergraduate capstone design course
IRB	Institutional Review Board
UMD	University of Maryland

Nomenclature

C^T	set of all concepts created by members of team T_i
C_{J_i}	set of all concepts appearing in journal J_i
$C_{J_i}^{J_k}$	set of all concepts appearing in journal J_i created in journal J_k
c_T^*	final design concept selected for team T
$c_{xJ_i}^{J_k}$	the x^{th} concept appearing in journal J_i created in journal J_k, where $x = 1, 2, ..., X$
J_i	identification number for each journal author, where $i = 1, 2, ..., I$; in this dissertation's study $i = 1, 2, ..., 112$ or $P1, P2, ..., P7$
m^T	number of members on design team T_i
N_{J_i}	number of concepts that appear in journal J_i
$n_{J_i}^x$	number of times concept x appears as a referencing instance in journal J_i
$r_{J_i}^*$	final concept reference ratio
$r_{J_i}^o$	others concept reference ratio
$r_{J_i}^s$	self concept reference ratio
$r_{J_i}^t$	team concept reference ratio
S_{J_i}	total number of referencing instances appearing in journal J_i
T_i	identification number for a design team, where $i = 1, 2, ..., I$; in this dissertation's study $i = 1, 2, ..., 18$

Chapter 1: Introduction

The process of design is one of the most significant intelligent behaviors exclusive to humans [1]. Unlike other methods that attempt to find contributing behavior information based on perceptions at the end of a project, paper based design journals are living documents created and maintained by each individual throughout a project. They provide a method to look into the actual project work being done by each designer, as well as how that those activities compare and relates to the rest of their team. Moreover, records like a design journal uniquely enable the examination of these patterns across time. Journals provide several benefits for their authors, including improved decision making, increased metacognitive strategies, pedagogical benefits, and expansion of thought [2]. Despite the known benefits, the potential uses of engineering design journals are still not fully understood.

This dissertation seeks to advance the understanding of design thinking and more specifically design journal use by exploring the content of 83 student journals using a variety of analysis methods.

1.1 Research Motivation

Design constitutes the core intellectual activity for a professional engineer. Herbert Simon called it a "science of the artificial" [3]. While artificial often is given a negative connotation that implies some kind of falseness, Simon defined it as meaning that design is a part of a science not pertaining to the forces of nature or biology but rather the creations of man. Despite the critical significance of design to human achievement, there is still a great deal about design that is unknown. The act of carrying out design work is difficult to observe, as a great deal of it occurs in a designer's mind. Design does not quite fit in with purely analytical science, nor does it fit in with the arts. Engineering design is a multidisciplinary field that depending on the project could incorporate any number of different subject areas. The spanning of disciplines is what draws many designers to the field, this dissertation's author included, as individuals who can embrace and appreciate their integration.

It is necessary to explore the designer's mind in order to better understand design. Understanding the processes occurring the mind of the designer could be of great value. A better understanding of this phenomena would enable researchers to improve engineering education, develop more comprehensive tools to aid the design process, and aid the evolution of automated design performed by computer systems [4]. By exposing what is occurring in a designer's mind it would be possible for improvements to be made to the design process itself [5]. Such improvements could facilitate correcting the approaches taken by novices or for experts to learn further. To date there is no definitive method to capture this information, especially in earlier stages of design when projects are more abstract and conceptually driven. Later in a project when work becomes increasingly computationally intensive engineers are likely to make use of various computer based tools which create records that could be analyzed for design activity, but perfectly capturing the earlier stages still eludes researchers.

Evaluating the significance of team engagement and interaction in design is also not fully understood. Engineers are often expected to operate in teams in the professional world, and their ability to function successfully is of significant importance to their employers. Knowing an individual's design competencies and their contribution towards a group project is valued information to an employer and is extremely valuable to an instructor. Final products or work generated by the team as a whole, like reports, don't accurately reflect this information. Exit surveys and retrospective accounts often can fall short or be skewed by overemphasizing recent efforts and performance as well as collegiality among team members. While gaining more insight on the inner workings of design teams would be highly beneficial, it is extremely difficult to do with expert level designers. Variance in individual background, age, experience, group history, intellectual property concerns, constantly changing project timelines, disturbing work flow, and employee overturn are just a short list of the factors as to why examining a professional team is troublesome. In contrast, capstone design teams offer great opportunity to explore engineers working in team environments. While generalizations must be made cautiously, observing student teams can be highly beneficial as they eliminate many variables by having more consistent backgrounds, ages, and experiences [6].

Many mechanical engineering undergraduate programs use a one or two semester capstone design course that is entirely a team-based project. While capstone teams will never perfectly mirror a team of all expert-level designers, they offer the best approximation available in an educational setting. All members of a capstone team are typically at the same level of design expertise, which is very near that of an entry-level engineer. Capstone projects also operate within the same exact time frame. These two facts address some of the troublesome variables, making results much easier to reproduce.

Design researchers have proposed a wide range of methods in attempts to gain insight into what occurs on an individual and team level in design. Concurrently maintained design journals are one such method. Journal entries have received less research attention than other methods in part because they have such intensive preprocessing requirements necessary before being able to interpret the data. This data type offers several unique positive qualities. Journals serve as a tool for a designer to record their ideas, while doubling as a tool for researchers to observe that designer *in situ*. An author is free to use a journal on their own schedule and to the benefit of their own personal strengths. Prior research has found that capstone design students who use journals record a wide range of information including ideas, calculations, notes, questions to ask, analysis, sketches, meeting notes, to- do lists, project milestone issues, review of options not taken, and more [7–11]. Entries become documentation that is a basis for reflection on earlier work, with an inherent chronological structure. Unlike reflective methods they offer a live view at how a designer perceived a problem at any given time. Journals have not been thoroughly studied however, and much remains to be determined on what the full impact of their use is.

1.2 Goals of the Research

The aim of this dissertation is to explore the efficacy of using concurrently kept engineering design journals to obtain insight into individual design activity behavior and team interaction. The culmination of this work is to explore the four following research questions:

1. **What can engineering design journals reveal about the specific activities an individual performs in a design project?** Currently obtaining an unbiased view of what actually occurs within a team is difficult. Answering this question is of great value for both professional and academic environments by providing a new method of assessing an individual within the context of a team. Especially in an academic setting, where less specialization is expected, it would be extremely beneficial to evaluate individual design activity levels within a team setting.

2. **Do distinct design activity sequences exist in individual journal records?** If trends could be found in activity class sequences it would provide researchers with a new look at how design is accomplished. If patterns are found to involve rapid shifts in activity types, it would confirm findings in other design studies that have indicated that expert designers make use of

rapid shifts in activity to solve design problems.

3. **What do design journals indicate about the interaction an individual has with their team and their team's concepts?** This would be of particular value to educators to be able to measure how much a student is interacting with their team. Journals may identify who on a team is actively participating and engaging in their team's design work in a way that peer evaluations and reports cannot offer. At a higher level this information could reveal a great deal about what a typical team looks like and how the activity of design teams evolves over the course of a project.

4. **How does design journal activity differ as a project advances?** How an individual uses their design journal at the onset of a project is unlikely to be the same as how they use it in later design phases. Being able to quantify what those changes could influence smarter structuring of project and educational aids to be more relevant to time-sensitive activities. It would also be beneficial to determine if there are certain points in design projects where journals are most impactful.

1.3 Outline of Dissertation

The research presented in this dissertation is based on 83 student journals which were collected from 2014–2016. Students enrolled in University of Maryland's mechanical engineering capstone design course were recruited each semester to participate in the study, with additional effort made to recruit full teams. Participants were provided a brief set of instructions on what they could or could not include in journals but were largely free to use them in any format and style that they would like. Journals were maintained throughout the semester and then recollected for post hoc analysis.

This dissertation is organized in such a way as to provide a concise account of the findings from this research. For brevity all data is available but not included within this text. The remainder of this dissertation is organized as follows: Chapter 2 provides a review of literature from the various fields which are connected to this research. Chapter 3 details the methodology that was used for data collection as well as the majority of calculations and analyses. Chapter 4 focuses on patterns in individual activity, while Chapter 5 pertains to sequences in that activity. Chapter 6 uses team data to analyze how members of the same team differ, as well as how different teams compare. Chapter 7 discusses concept tracking across a team and the rate at which members of a team reference team ideas. Chapter 8 provides a look at the impact time makes on project activity discussed in previous chapters. Finally, Chapter 9 contains closing remarks, and discusses project limitations as well as opportunities for future research.

Chapter 2: Literature Review

This dissertation topic exists in an intersection of a variety of research fields including engineering design, team behavior, and data extraction. In this section an overview of these areas will be provided to offer context and a framework before discussing the work of this study.

2.1 Engineering Design

Steve Jobs said that, "[Design] is not just what it looks like and feels like. Design is how it works." [12]. Particularly in technical design fields, like engineering, design can be treated like problem-solving [13]. The notion of "engineering design" is a relatively recent idea, however, when looking at the course of humanity's relationship with engineering. Around the turn of the 20th century, the rapid growth of scientific knowledge available accelerated to the point where it became both practical and necessary for specializations within engineering to exist [14]. Prior to this it was fairly typical that an engineer would manage a project soup-to-nuts. The vast majority of specializations that emerged are rooted in highly-analytical branches of science, and many of them have a great deal of research and an expansive knowledge base.

Conversely, engineering design has a significantly younger knowledge base. In 1970 Blumrich wrote that design was in essence the opposite of analysis. He stated that this led to an elusive quality, which up that point had steered any design research to orient around structure and not the design process itself [14]. Just a decade later, American companies began to pursue high-quality design after witnessing the success of international competitors who embraced high-quality design as a means to distinguish their products [15] (hereinafter the term "design" will be used to mean engineering design).

Design occurs in several phases. The first of these phases is when designers have the greatest freedom to exercise creativity and apply their own experiences. Once a design problem has been defined, the first activity is ideation the act of conceiving ideas. Ideation occurs at the beginning of conceptual design and is the activity that determines the breadth and novelty of the concepts that will be developed during the remainder of the conceptual design phase [15]. Work in this early stage is often error-prone, challenging, and frustrating because vast amounts of information are gathered from disparate sources, in a variety of formats and representations [16, 17]. Establishing a greater understanding of the designer's activity during the concept phase is of significant importance, as it is estimated that $70-80\%$ of a product's cost is committed by the end of this phase [18].

2.2 Design Cognition

There is currently no direct method for observing an individual's cognitive processes [6]. The difficulty of this task is amplified when it involves an area that requires heavy application of experience-based knowledge such as mechanical engineering design [19]. Dorst states that things are complicated further because every designer is unique and has their own way in which they perceive and interpret design problems [20].

According to Lawson and Dorst, one might say design is the 'platypus' of the cognitive world, a philosophical term referring to something that eludes neat and easy classification [13, 21]. As the platypus is a blend of traits seen in dissimilar classes of the animal kingdom, design is a blend of the divergent realms of science and art. Due to this split nature, design cognition has not been studied as thoroughly by researchers who are predominantly aligned with either of those domains. That has begun to change over the course of the last 40-50 years.

Coinciding with rising interest levels in the science of design, empirical research on design's underlying cognition has also undergone a period of growth beginning in the 1970's [22]. Work done by Nersessian [23], among others [24–26], are testaments to the notion that as researchers continue to better understand the human mind or the impact of the design process, design cognition has become an increasing area of interest within engineering.

The process of design is one of the most significant intelligent behaviors exclusive to humans. Moreover, it has a profound relationship with the study of cognition [1]. Design cognition research encompasses understanding design tasks, solutions, and the rationalizations behind them. Research has shown that there are two distinct cognitive operations occur when an individual is creatively functioning: generation and exploration [27]. Cognitive processes can be represented as a sequential set of internal operations which are performed on information contained in an individuals memory [28]. For design engineers these internal operations first manifest as they develop concepts (generation). This occurs while simultaneously evaluating inputs such as constraints, engineering characteristics, experiential data, and new external information generated from research (exploration).

In one of the first studies to examine design, Akin noted that a unique aspect of design behavior is the constant generation of new task goals and a redefinition of task constraints [29]. Fundamentally, design tasks are problems. A large amount of psychology literature exists which examines humans performing problem-solving, but much of it is about well-defined problems that can be solved in short periods of time and arbitrary domains [4]. It has been noted since the earliest formal studies on design that real world design tasks are often ill-defined and open-ended [30–32]. In design, unlike other problem-solving areas, some objectives and constraints may be known at a task's onset, but a considerable amount of effort by the designer is required in defining and structuring the problem. Experiments on designers in a range of fields by Thomas and Carroll found that even when presented with a well-defined problem, designers will frequently treat the problem as though it was ill-defined and open-ended before reframing it to their own liking [33, 34]. Considering the breadth of possibilities is paramount to many designers.

Stempfle & Badke-Schaub stated that design cognition is one of the most important issues in design research, and that design thinking studies can be sorted into one of three strains of research [6]. The first is the *normative strain*, which utilizes systematic approaches to reach an optimal result. It is based on rational analysis of design tasks and is what is typically found in engineering text books. The second group is the *empirical strain*. These empirical studies have questioned whether designers actually follow any methodology at all, and attest that formal methodologies do not properly account for external factors like team cohesion and time [35]. The final strain is *design-as-an-art*, led by the work of Schön, which argue that the design process simply cannot be properly grasped by any methodology [36]. In this strain, design is rather viewed as being more comparable to how an artist maintains flexibility to incorporate a variety of methods in their work [6]. The work presented in this dissertation falls into this category and attempts to better identify this flexibility between preset methodology structures and individualism.

Time is another factor that differentiates typical design tasks from the problems analyzed in most psychology studies. A designer is required to repeatedly access their stored knowledge throughout a project. The need to recall prior knowledge and reevaluate concepts is rarely present in studies outside of design research. Even within design research, the majority of studies have involved tasks that were short, had low complexity, and did not require extensive prior user knowledge [37, 38].

2.3 Team Mental Models

Cognition plays an important part in determining the success of product development team [39]. A variety of constructs have been proposed to study this such as transactive memory, group learning, shared/team situation awareness, and strategic consensus [40–44]. *Team Mental Models* (TMM) are another way to represent this construct. First introduced 1990's by Cannon-Bowers and Salas, the main concept of TMM is that teams with a common model for taskwork and teamwork are better equipped by team members being in tune with each other [45]. This ultimately has benefit to the team's performance [46]. Mohammed, Ferzandi, and Hamilton conducted a comprehensive review on the state of TMM research, covering a 15 year span from its inception in 1990 to the late 2000's. They stated that early work on TMM was heavily criticized and even supporters were unsure of its prospects [44, 46]. Despite that it has gained increasing research interest and has since become regarded as one of the better developed frameworks for group cognition [47,48]. Methods to measure TMM typically involve determining the similarity in how members of a team individually perform a task like paired comparison ratings or card sorting [44]. Dong, Kleinsmann, and Deken used latent semantic analysis along with reflective practice analysis to model team cognition over time in a 2012 study [49]. Their results indicated that latent semantic analysis provided insight into whether the members of a team had aligned mental models.

2.4 Teams and Team Roles in Design

It is generally accepted that having more diverse ideas leads to better problem-solving and consequently better designs. This diversity of ideas is easily created by using a team. Individuals increase the number of ideas by contributing unique solutions to the team, and provide unique personalities, experiences, skills, and perceptions. It has been proven that team dynamics play a major role in decision making [50]. A NASA study on engineering team perceptions found that engineers place group well-being as a critical element for success, and furthermore that engineers often self-describe themselves as "a person who knows ones role and responsibilities on the team" [51]. Specialization within a team not only increases perceived efficiency, but also improves actual team performance. Team composition is a key factor in influencing team performance [52].

There is a wealth of models for roles taken in teamwork. One framework is defining roles based on supporting the dynamics of individual interactions on a team. One of the oldest of any team role systems falls into this category and was developed by Benne and Sheats in 1948 [53]. They defined fifteen roles in total. Seven of their roles support the dynamics of the team: encourage, harmonizer, compromiser, gatekeeper and expediter, standard setter or ego ideal, group-observer and commentator, and follower. The other eight roles are for members of a team who act in their own interest: aggressor, blocker, recognition-seeker, self-confessor, playboy, dominator, help-seeker, and special interest pleader [53]. Schutz developed Fundamental Interpersonal Relations Orientation (FIRO), which is a three-dimensional model based on an individual's expressed and wanted behavior in three fundamental interpersonal areas: affection, control, and inclusion [54]. Mintzberg identified ten roles specifically for managers [55]. Team behavior is of major concern to engineering researchers.

Another type of role specialization is based on the activity a team member is providing. The Belbin Team Role Self Perception Inventory is one of the most heavily documented systems for combining roles associated with group dynamics and those defining functional duties [56]. In his work Belbin distinguished between what he called functional and team roles. While functional roles incorporate information regarding technical skills and operational knowledge that are being utilized, team roles instead pertain to an individuals behavior, contribution, and interrelation tendencies with their team. In a broader sense, team roles describe how an individual fits into a team rather than describing what they are doing as part of it [52, 57]. Belbin's system identifies nine roles that an individual can potentially fill on a team: plant, resource investigator, coordinator, shaper, monitor-evaluator, team worker, implementer, completer finisher, and specialist. Belbins team role theory states that teams which are more balanced across the various team roles tend to perform at a higher level [52]. Furham, Steele, and Pendleton argued that while Belbins model of team roles is not necessarily invalid, their examination of his theory found issues with obtaining reliable and consistent results [58].

Studies involving undergraduate engineering teams have also found that specialization is very present in group work at the novice level. While industry teamwork often dictates the necessity of specialization, it is not appropriate for an educational environment [59]. A University of Maryland investigation into functional specialization found that while students in all four years of study believed specialization was more time efficient [60], students began to realize in their second year that more can be learned if roles were not repeated on teams [61]. A study of software engineers at the University of Melbourne also found that the specialization of their students decreased readiness for professional positions [62].

2.5 Analyzing Design Activity

There already exists a number of proposed methods to examine underlying cognitive processes in design.

2.5.1 Verbal Protocol Analysis

Verbal protocol analysis is the method which has received the most use and attention. This type of research has been spread over several different but similar technically-oriented fields, including architecture, industrial design, mechanical and electrical engineering, and even software design [22]. Studies typically involve team design tasks rather than individual design ones. One advantage of analyzing teams instead of individuals is that in a team setting, communicating design thinking in a verbal way is a critical aspect of the work. This provides insight into the basic design thinking process [6].

In protocol analysis for design activity analysis designers are instructed to verbalize their thoughts. This activity is recorded and transcribed in conjunction with an exact time log. Additional notes on any motor activity by the designer are added at their appropriate time stamps. Different verbal protocol analysis methods have been developed [63–65]. Atman and Bursic found that verbal protocol analysis provided a measure to assess the process skills of students instead of simply evaluating their final design work [65]. In their study two students were given the same task and provided markedly different timelines of design steps . Gero and McNeill developed and implemented a verbal protocol which coded problem domains along with micro and macro strategies [64]. It was found that a designer's actions could be systematically defined and that it was suitable for macroscopic analysis of how designers think [63].

Protocol analysis has been utilized both concurrently and retrospectively [66]. A great deal has been gained from verbal protocol research and it may be the most efficient design thinking method used today, some design researchers have suggested that it provides one specific look and not the complete picture [22, 67]. It cannot capture non-verbal thought processes, and the ones it does capture are a curated view provided by the designer.

2.5.2 Reflective Journal Use

Studies have examined the impact of reflective practice as evidenced by student review of prior and on-going work [36, 68]. Schön wrote about how engineers, among other professions, actually solve problems. His work argues that the highly formalized and analytically based design methodologies are inadequate to truly capture the design process. Instead, Schön states that every design task is unique and a designer must resolve how to approach the particular problem with each new one. His alternative was "reflection-in-action" [36]. Building off of this work, Valkenburg and Dorst developed a scheme to code the activities performed by two student teams ($N = 8$) recorded on video while solving a design problem [68]. The scheme they created based on Schön's work uses four activities: naming, moving, reflecting, and framing. They found that this scheme was successful and efficient in providing insight into a design team's activities. They also stressed that a researcher must make a decision about the level of detail they desire to obtain [68]. Dong, Kleinsmann, and Deken used the scheme created by Valkenburg and Dorst to code how often a frame occurred and how many activities occurred within the frame to measure team mental models, tying together team mental models, design activity schemes, and activity density all at once [49].

2.6 Changes in Activity

The frequency in which a designer changes their activity has also been explored, often in conjunction with a protocol study. While the granularity of how many possible modes a designer can enter varies between such studies, similar results have been discovered. Akin and Lin used three modes: drawing, examining, and thinking. While tracking for novel decisions made by engineering designers ($N = 2$), they found that the majority of decisions occurred following rapid succession of mode shifts [69]. In their study comparing freshmen and senior engineering students, Atman et al. also reported on this rapid alternation phenomenon. They found that overall quality of design concepts increased with this behavior [70]. Kavakli and Gero similarly reported that expert designers were observed as having nearly triple the amount of simultaneous cognitive actions compared to novices [71]. The change, patterns, and density found in designer activity are a primary concern of the research presented in this dissertation.

The level of expertise a designer possesses has been observed to play a key role in their activity. In a 1992 protocol study involving junior ($N = 10$) and senior ($N = 10$) industrial design students, Christiaans and Dorst found that the junior students did not get fixated on information gathering because they were sometimes unaware of additional criteria. In contrast, some of the seniors spent a great deal of time gathering data to define the problem as a "substitute for actually doing design work" [72].

Identifying how individuals allocate their design activity has been explored in other studies as well. In a 1994 study at the University of Plymouth, researchers analyzed design activity over a longer period of time to replicate real-world design tasks. In their work, seven ($N = 7$) senior electronics engineering undergraduates chosen at random worked on design projects which they defined as being "long-term". Student activity was analyzed from a combination of self-recorded weekly summaries and interview data [4]. Participants were compensated monetarily for their involvement. Subjects spent a large amount of early design work developing clearer understandings of the ill-defined problem, particularly by determining functional requirements and constraints. Participants were widely found to utilize a top-down and depth-first approach, with the inference being that as semi-expert designers they made use of a more generic high-level schema for design [4].

Table 2.1 – Cognitive action scheme developed by Suwa, Purcell, and Gero [63]

Category	Names	Description
Physical	D-action	Make depictions
	L-action	Look at previous depictions
	M-action	Other physical actions
Perceptual	P-action	Attend to visual features of elements
		Attend to spatial relations among elements
		Organize or compare elements
Functional	F-action	Explore the issues of interactions between artifacts and people/nature
		Consider psychological reactions of people
Conceptual	E-action	Make preferential and aesthetic evaluations
	G-action	Set up goals
	K-action	Retrieve knowledge

Suwa, Purcell, and Gero developed a cognitive coding scheme to apply to designer actions observed in video/audio protocols [63]. Actions were subdivided into four categories, which each had subcategories of their own as listed in Table 2.1. The four major categories corresponded to the cognitive levels of information processing: physical, perceptual, functional, and conceptual. An architect was tasked with designing a museum in 45 minutes while verbalizing actions. It was determined that a designer's cognitive actions were systematically definable with this scheme, and that using a macroscopic look with broader categories was beneficial for initial exploration [63].

Stempfle & Badke-Schaub suggested a similar scheme based on cognitive operations: generation, exploration, comparison, and selection [6]. Using this model they coded a one day design task done by three teams of $4-6$ mechanical engineering students. They found that there was a remarkable difference in the rate of communication between teams, ranging from $810 - 2877$ communicative acts. They also discovered that all three teams spent 2/3 of their time on activities related to content and the remaining 1/3 on ones pertaining to the group [6].

Findings in a verbal protocol study in 2007 by Atman et al. were similar to that of Christaans and Dorst [72, 73]. Atman's work comparisons were made between the design processes used by undergraduate freshmen ($N = 26$), seniors ($N = 24$), and experts ($N = 19$). The experts came from a variety of engineering disciplines and industries. Participants were tasked with designing a playground in three hours. To analyze the observed work, the coding scheme found in Table 2.2 was developed. Experts in this study were found to spend a significantly higher amount of time on the overall task and especially problem scoping [73]. Experts spent over 31 minutes on problem scoping while freshmen and seniors spent 19 and 18.5 minutes, respectively. The experts spent a total of 132 minutes for the entire experiment on average compared to just 104 for freshmen and 110 for seniors.

Table 2.2 – Protocol coding scheme used by Atman et al. [73]

Design Activities	Design Stages
Problem Definition Gathering Information	Problem Scoping
Generating Ideas Modeling Feasibility Analysis Evaluation	Developing Alternative Solutions
Decision Communication	Project Realization

A study by Cross in 2004 showed expert designers in a different light, finding that they were often "ill-behaved" in terms of how little of their time was spent on defining a problem [34]. It is believed that part of this is because experts store and access larger "cognitive chunks" than novices, and so are better able to recognize underlying principles. Unlike problem-focused scientists or novice designers, expert designers are solution-focused [34].

2.7 Design Journals

Journals have been used by designers as a means to capture, reflect upon, and reuse information [11]. Leonardo da Vinci famously maintained meticulously detailed journals, many of which are now displayed in museums. He recorded journal entries daily and composed over $13,000$ pages of notes throughout lifetime [74]. Many other famous inventors and creative thinkers have also been known to be avid journal keepers. Thomas Edison wrote an astounding $3,500$ notebooks during his life [75]. Similarly, Richard Branson is known to always keeps a small notebook on him at all times for recording his thoughts [11, 76].

Studying design journals is another method for reviewing design. Active journals are regarded as being beneficial for the enhancement of thinking skills, but relatively little research has been conducted on the relationship between cognition and using a journal [7]. In his doctoral thesis examining the use of diaries by industrial designers, Pedgley found that perhaps the greatest strength of using journals was that, compared to other capture methods, they did not impinge the designer or their natural workflow [38]. Pedgley went further on to state that design journals were an under utilized but valuable data collection method with unrealized potential in his more recent 2007 follow up [77]. Codifying work done by a designer on paper can also be beneficial from an organization's standpoint for retaining knowledge [78,79].

Journals provide benefits to the designer as well as the researcher. A 2001 study at Arizona State University compared the academic performance of $N = 317$ first year engineering students over the course of a semester. Each time a quiz was administered in the course students could submit an updated engineering journal for extra credit. They found statistical evidence which suggested that maintaining a reflective journal improved thinking skills and an individual's ability to learn content [10].

2.8 Coding Design Journals

Researchers analyzing design journals have proposed a wide range of coding schemes, just as with verbal protocol analysis. Sobek noted that there was a lack of research on design journals, and performed some of the most extensive work in this area in a study at Montana State University [8, 9, 80]. As a course requirement, mechanical engineering students enrolled in a capstone design course were instructed to maintain design journals throughout their senior design projects. 15% of each student's grade was directly tied to their journal efforts. Researchers checked journals throughout the semester, and a rubric for evaluation was used to provide feedback while taking care as to not influence what a student would or would not opt to record in their journals [80].

In total Sobek examined $N > 70$ journals across 21 projects, and concluded that applying a coding scheme to a design journal provided a rich dataset [8].The journals were analyzed by creating and applying a $4x3$ coding matrix, seen in Table 2.3. This coding scheme enabled the investigators to determine how long was spent in each step of the overall design process. One axis indicated the level of the design and abstraction that a journal entry belonged to (concept, system, and detailed designs). The other axis was comprised of four types of activity at the core of design (problem definition, idea generation, engineering analysis, and design refinement). Two additional levels describe non-design activity (project management, and delivery) [8]. The content of this scheme served as a basis for the scheme this dissertation utilizes and shares a large deal of overlap on a macro level.

Table 2.3 – The coding matrix employed by Sobek [8]

	Concept Design (C)	**System-Level Design (S)**	**Detailed Design (D)**
Problem Definition (PD)	C/PD	S/PD	D/PD
Idea Generation (IG)	C/IG	S/IG	D/IG
Engineering Analysis (EA)	C/EA	S/EA	D/EA
Design Refinement (DR)	C/DR	S/DR	D/DR

Project Management (PM)	PM
Delivery (RW, PP)	RW, PP

Other formative work on design journals was conducted by Ekwaro-Osire and Orono [81, 82]. Their work involved using design notebooks in both freshman and senior design classes which involved team projects. In their 2006 study, they had a total of $N = 119$ participants spread across 34 teams. Like in Sobek's study, design journals had a direct impact on the course grades of participants. Each participant's journals was graded with a rubric and the resulting score was compared to their peer evaluation performance. They found that grades received by design journals served as a good indicator of the peer evaluation scores an individual would receive [81]. Additional work by used design journals to track creativity instances of students while working on team design problems [82]. This dissertation utilizes a similar number of total study participants to the work of these two core design journal works.

2.9 Westmoreland-Schmidt Journal Coding Scheme

Westmoreland and Schmidt proposed a coding scheme to categorize entries in design journals built on the foundation of previously discussed schemes by Suwa, Purcell, & Gero, Sobek, and Atman et al. [8, 63, 73]. The scheme they created allows for the tracking of, among other things, the design actions of a journals author [2, 83, 84]. In their method, journals are first subdivided into segments which represent individual design activities taken on by a journal's author. Each of these segments is coded with a six digit string, as visualized in Figure 2.1. Application of this code allows journal data to be analyzed quantitatively [2].

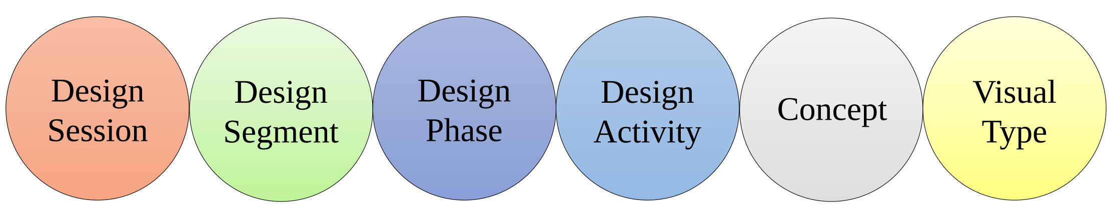


Figure 2.1 – The six digit code string proposed by Westmoreland & Schmidt [2]

A significant portion of this dissertation is built on the principle that segments can be classified into one of 36 unique design activities (updated to 39 in this work as explained in Section 3.2). Each design activity falls into one of eight design activity classes: 1)*Information Seeking and Noting* 2)*Problem Understanding*, 3)*Idea Generation*, 4)*Analysis*, 5)*Decisions*, 6)*Project Management*, 7)*Reflection*, and 8)*Other*. Like Valkenburg & Dorst stated, a decision must be made on what level of detail is desired. Macroscopic work can be done with the overarching classes, while more narrow and detailed work can be addressed with the specific activities. By tracking this information a wealth of insight can be gained about a journal author's tendencies and their interaction with their team. This dissertation is directly built upon Westmoreland's previous work. A detailed walk through of the six digit string can be found in the Methodology chapter in Section 3.5.

2.10 Results from Foundational Work

In Westmoreland's work the scheme was applied in several studies. Across three studies with student teams, a total of $N = 28$ student and $N = 1$ professional engineers were reviewed. It was concluded that the actvitiy coding scheme was adequate to code entries in design documentation. Studies indicated that activity patterns shifted during the phases of a design project, but specific sequences of activity were unable to be addressed [2]. It was also determined that it was possible to trace the development of individual concepts within a particular journal and journals belonging to the same team [2].

Prior work by the dissertation's author formed the first steps in this work. The Westmoreland-Schmidt coding scheme was applied to one capstone design team (identified as $T3$ later in this dissertation). In this pilot study it was investigated if the relative frequencies of journal activity performed by members of the same design team could provide information to supplement peer evaluations. This was unsuccessful in part because students gave such favorable peer evaluations to each other, leaving very little separation between even the best and worst performers. Additional metrics were developed to measure concept life spans and the propagation of concepts across a team [11].

In another study four teams of undergraduate seniors ($N = 24$) enrolled in the University of Maryland's mechanical engineering capstone design course were examined and their journals were studied by using the Westmoreland-Schmidt coding scheme. Journals were used to identify the activities recorded by different members of the same team. It was also found that the recorded activity classes for individuals changed over the duration of the project, and that members of a team would regularly shift to compensate the abandoned area [59]. Since the size of the sample in this study was relatively small results need to be replicated at a larger scale to confirm results.

More recent work has focused on examining the statistical distributions of activity by using 13 teams and 83 individual journals [85]. The average frequency for each activity class was found based on team samples. Distributions for classes were determined based on this data, and trends were identified about how regularly activities were performed and the variance of those classes.

Chapter 3: Methodology

This chapter provides a comprehensive look at the procedures involved in this research. The core data of this dissertation was collected from design journals that were maintained by University of Maryland undergraduates enrolled in the university's mechanical engineering capstone design course. Journal data was collected in selected semesters from Spring 2014 to Fall 2016. The main journal data was digitized, segmented, transcribed, and had a design activity coding scheme applied to it.

This section begins with a quick overview of terminology that will be used throughout this dissertation in Section 3.1 and summary of revisions made to the previous Westmoreland-Schmidt coding scheme in Section 3.2. Data Collection in Section 3.3 will cover participant selection, any variables that exist in the dataset, the instructions volunteers were given, and an overview of the exit survey which was used. Next, the combination of Preparing a Journal for Coding (Section 3.4) and Overview of the Journal Coding Process (Section 3.5) details a comprehensive look at how a design journal is coded for later analysis. Coder Training and Inter-coder Reliability (Section 3.6) contains information documenting the training process that all coders undertook and evaluations of their inter-coder reliability.

Analysis of Journal Text (Section 3.7) overviews the transcription process discusses along with the methodology and tools used for examining the resulting corpora. Section 3.8 introduces information on the implementation of a sequence identifier that was developed to find patterns in design activity. Concept Documentation in Section 3.9 defines and explains a number of equations and analyses related to team concepts. This chapter finally concludes in Section 3.10 which details the approach used for splitting up the course timeline based on key course deliverables.

3.1 Study Terminology

The data in this study is formed from 83 design journals. Participant names will be kept anonymous. Some metrics use the notation J_i to identify a specific journal, where $i = 1, 2, ..., 117$. For ease of reading, Ji is used instead outside of formal equations. For example, the journal belonging to the 56^{th} participant is identified as $J56$ rather than J_{56}. Note that while the final sample is made of 83 journals, identifier labels were created as students volunteered for the study so $J83$ is not the final journal in the sample. Select participants used an alternate journal and will similarly be referred to as JPi, where $i = 1, 2, ..., 7$). More information about these journals is expanded upon in a later section.

In a similar fashion, teams will be referred to in shorthand as T_n, where $n = 1, 2, ..., 18$. A full participant roster with all used journal labels can be seen in Table 3.3.

3.2 Revisions to the Westmoreland-Schmidt Code

The original journal coding scheme by Westmoreland and Schmidt was revised as part of this work. The original scheme was proposed with a sample of 29 journals, while this study's sample is 83. Three codes were added, two were renamed and redefined, and one was moved to another class. These changes primarily came about through discussions with the full research team during their training period (Section 3.6). Details on these activities and their definitions follow, while the fully updated code can be found in Table 3.1. Some other existing codes had their formal definitions updated. The full list of definitions can be found in Appendix B.

- *Progress Assessment*(20) - Renamed from "Design Process Notes"; Definition unaltered. Renamed for better clarity.

- *Task*(21) - Renamed from To Do Lists. "Item(s) that need to be completed for the project. Includes general / team-wide activities." This was renamed due to confusion between a To Do List and Task Assignment (code 24). Updated definitions clarify that this code is anything that needs to be completed while Task Assignment is the act of indicating a specific team member who will be responsible for a related task.

- *Meeting Minutes*(23) - Moved to *Reflection* from *Project Management*. Definition unaltered. This was moved because many meeting minutes were found to have been written after the actual meeting, and their purpose for a design team is more in line with other types of *Reflection*.

Table 3.1 – Updated journal coding scheme design activities

Activity Class	Specific Design Activities and Code Numbers
Class 1) Information Seeking and Noting	Search(1), References(5), Questioning(11), Price Quotes(26), Feedback(32∗), Definitions(36), Categorization / Labeling(38∗)
Class 2) Problem Understanding	Customer Requirements(2), Problem Statement Clarification(3), Criteria Lists(17), Engineering Characteristics(37), Market Consideration(39∗)
Class 3) Idea Generation	Project Ideas(4), Material Options(6), Analogical Reasoning(8)
Class 4) Analysis	Estimates(7), Assumptions(9), Calculations(10) Testing Procedures(12), Variables(13), Explanations(16)
Class 5) Decisions	Recommendations(14), Conclusions(15), Design Changes(18)
Class 6) Project Management	Task(21†), Task Assignment(24), Inventory(25), Task Completion(27), Project Milestones(28), Field Trip Notes(29)
Class 7) Reflection	Personal Notes(19), Progress Assessment(20†), Revelations(22), Meeting Minutes(23‡), Mistakes(30), Cross References(31)
Class 8) Other	Illegible Entries(33), Designer Signature(34), No Evidence of Cognitive Activity(35)

∗ *this activity was added.*
† *this activity was renamed and redefined.*
‡ *this activity was moved from another class.*

- *Feedback*(32) - New code. “Information received from an external source in response to prior work. Typically comes from a professor or industry expert. Includes assessment of grades received for the project.” Added to cover a gap in the scheme.

- *Categorization / Labeling*(38) - New code. “Contextual information provided typically to group several related segments.” Added to cover a gap in the scheme, specifically to differentiate between when an individual is labeling an activity versus performing that activity (i.e. often journals will say things like “Criteria List” underlined with the actual Criteria List activity below it).

- *Market Consideration*(39) - New code. “Information regarding the target market of the concept. Including but not limited to locations where the product could be used, descriptions of socioeconomic classes, etc.” Added to cover a gap in the scheme. A large amount of students were discovered to have some kind of market consideration early in their project.

3.3 Data Collection

Journal data forms the backbone of this research and journals were collected over a period of five semesters from spring 2014 to fall 2016. A breakdown of the total study enrollment can be seen in Table 3.2. The first column lists the total number of participants recruited each semester. The second column lists the number who completed the entire semester in the study. A total of 25 participants over five semesters dropped from the study. All of these drops occurred within a week or two of the beginning. The reason for dropping was always cited as either not realizing the time commitment necessary or dropping because other team members dropped. The final column is the number of journals which were used for the final dataset. An additional 9 participants completed their work but their journal was excluded from the final dataset. For 8 of these it was due to having handwriting that was difficult to interpret. The 9th participant excluded was due to their journal predominantly consisting of printed material taped into the journal which could not be attributed solely to the participant. As a result, not all members of all teams continued the study through its completion. The 4 teams with partial participants can be seen in Table 3.3.

Table 3.2 – Overview of study enrollment

Semester	**Started Study**	**Finished Study**	**Included in Final Sample**
Spring 2014	19	15	12
Spring 2015	15	5	1
Fall 2015	24	24	23
Spring 2016	37	31	30
Fall 2016	22	17	17
Total	117	92	83

3.3.1 Participant Selection and Study Enrollment

Data analyzed this in research was generated from design journals maintained by senior mechanical engineering undergraduate students enrolled in the University of Maryland's semester-long capstone design course, Integrated Product and Process Development (ENME472). The dissertation's author, who also served as the course's teaching assistant, handled volunteer recruitment, participant management, and data collection for the study. All research was conducted in accordance with the University of Maryland's Institutional Review Board (IRB) and all policies related to protecting the rights and welfare of human participants. The board's approval letters can be found in Appendix A.

The capstone course is offered every semester and is a graduation requirement for undergraduates. As a capstone course, it is typically taken by students in one of their two senior semesters. The course has a typical enrollment upwards of 150 students per semester. The course's structure allows for students to freely create their own teams of five to six members. Most teams also freely determine their design project topic, but some may work with a professor who brings project topic recommendations inspired by external contacts.

Required deliverables exist for teams including two interim reports, a final report, a working prototype, three peer evaluations, and ultimately presenting their work to faculty and guests on the department's "Design Day". The dates for these deliverables bracket the design activity periods used in time based analysis work, as expanded upon in Section 3.10 and Chapter 8.

Student volunteers were recruited at the start of each semester. Recruitment occurred through a combination of in-class announcements and electronic bulletins posted on the course's web page. All student participants signed consent forms approved by University of Maryland's IRB (a copy of the consent form can be found in Appendix A.2) and were assigned a unique, anonymous journal ID. Academic standing in the course was not affected by participation. Students were compensated for their participation through electronic Amazon gift cards with semester totals of either $75.00 or $100.00, depending on which semester they participated. While earlier participants received slightly higher compensation, their work load was no different and the decrease in payment was not related to study parameters. The decrease in compensation is expected to not have been significant enough to impact any findings. The electronic Amazon gift card payment was subdivided across regular check-in periods.

Volunteers were free to exit the study at any time for any reason. Students were also told that they could be asked to leave the study if their journal was repeatedly found to have a lack of new entries. However this was never necessary, and all students who exited the study did so of their own volition.

Of the 17 teams in this study 5 are full teams, 8 are missing one member, and the remaining 4 are missing two or three members. Two individuals participated by themselves. Table 3.3 is a breakdown of the final participant roster.

3.3.2 Alternate Methods for Journal Capture

While 109 of the 117 total study participants used traditional paper journals, 7 volunteers utilized a combination of Livescribe™ journals and Sky™ wifi smartpens [86]. In Table 3.3 these participants are identified as $JP1 - JP7$. In the Spring 2014 group, one full team ($JP1 - JP5$, $T3$) used these smartpens. One team in Fall 2015 ($J49 - J53, JP7$, $T8$) initially signed on to participate in the study while using the smartpens and journals. The majority of this team requested to switch

Table 3.3 – Complete roster of journal sample collection by semester. Teams noted as "partial" lack two or more completed journals and were not used for team-based statistical analysis.

Semester	Team	Journal Range
Spring 2014	individual	$J1$
	individual	$J2$
	$T1$ (partial)	$J4, J6 - 7$
	$T2$	$J10 - J13$
	$T3$	$JP1 - JP4$
Spring 2015	individual	$J30$
Fall 2015	$T5$	$J31 - J36$
	$T6$	$J37 - J42$
	$T7$	$J43 - J48$
	$T8$	$J49 - J53, JP7$
Spring 2016	$T9$	$J54 - 57, J59$
	individual	$J60$
	$T10$ (partial)	$J61 - 62, J64 - 65$
	$T11$	$J67 - 69, J71 - 72$
	$T12$ (partial)	$J73 - 74, J77 - 78$
	$T13$	$J79 - 83$
	$T14$	$J85 - 90$
Fall 2016	$T15$	$J92 - 96$
	$T16$ (partial)	$J97 - 100$
	$T17$	$103, J105 - 107$
	$T18$	$J108 - 110, J112$

to traditional journals after the first week of their study period. Two students from this team opted to continue to use the smartpens, identified as $P6$ and $P7$. The students who requested to switch to normal journals did so because they found difficulty in having the smartpens synchronize with their accounts. For the purposes of data analysis, the use of smartpens by these seven volunteers was interchangeable with tradition journal keeping. The only real difference caused by their use was eliminating the necessity to digitize the analog journals. One final volunteer participated in a method other than hand-kept journal in Spring 2016, identified as $PC1$. This student was set to participate through a computer but they opted on their own to exit the study before the first check in of that semester. With that student's voluntary exit, all final data collected took the same format.

3.3.3 Instructions Given to Participants

Students were given a single page of guidelines on proper journal usage derived from design journal guidelines that Sobek similarly used with undergraduate students [11, 87]. Chief among the guidelines was that every new entry in a journal should be properly dated. This was a critical instruction to participants as a significant portion of analysis discussed later in this dissertation is reliant on being able to compare design activity witnessed on a journal page and the date which it was recorded. A copy of the instructions provided to participants can be found in Appendix A.3.

3.3.4 Exit Survey

An exit survey was created for the Fall 2016 cohort. The survey's purpose was multi-faceted. The first was to look at how the perceived activity distribution compared with what journal coding found.

An amendment to the study's IRB was approved to include this. At the closure of that semester's study, participants were electronically sent a copy of the survey to fill out and return in order to receive their final payment. The survey in its entirety can be found in Appendix A.4.

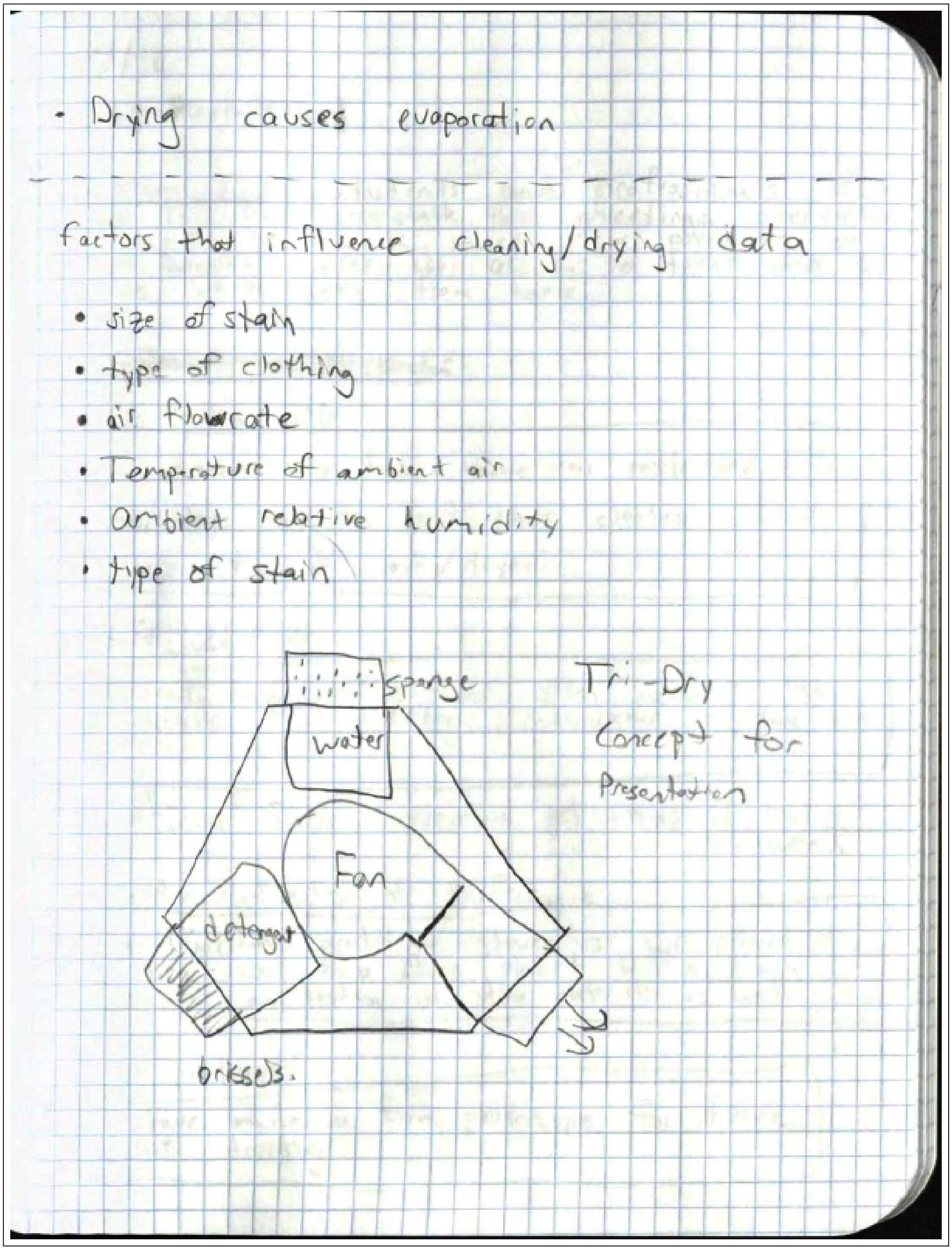
3.4 Preparing a Journal for Coding

The next two sections of methodology itemize the steps necessary to apply the Westmoreland-Schmidt coding scheme to a design journal. Before being able to do actual code application, a couple of preparatory actions must be taken.

3.4.1 Digitizing Journals

Journals must be first digitized before any coding can occur. In the rare case that the journal was made with a Livescribe™ journal and Sky™ wifi smartpen [86], this step simply involves downloading the automatically uploaded digital copy of the participant's notes.

In the more common case where a traditional journal was used, each page must be cleanly scanned. All digital copies used in this research were made with a self service book scanner and digital archiver. Figures 3.1 & 3.2 depict what journal


- Drying causes evaporation

factors that influence cleaning/drying data

- size of stain
- type of clothing
- air flowrate
- Temperature of ambient air
- Ambient relative humidity
- type of stain

Figure 3.1 – A scanned page from $J64$

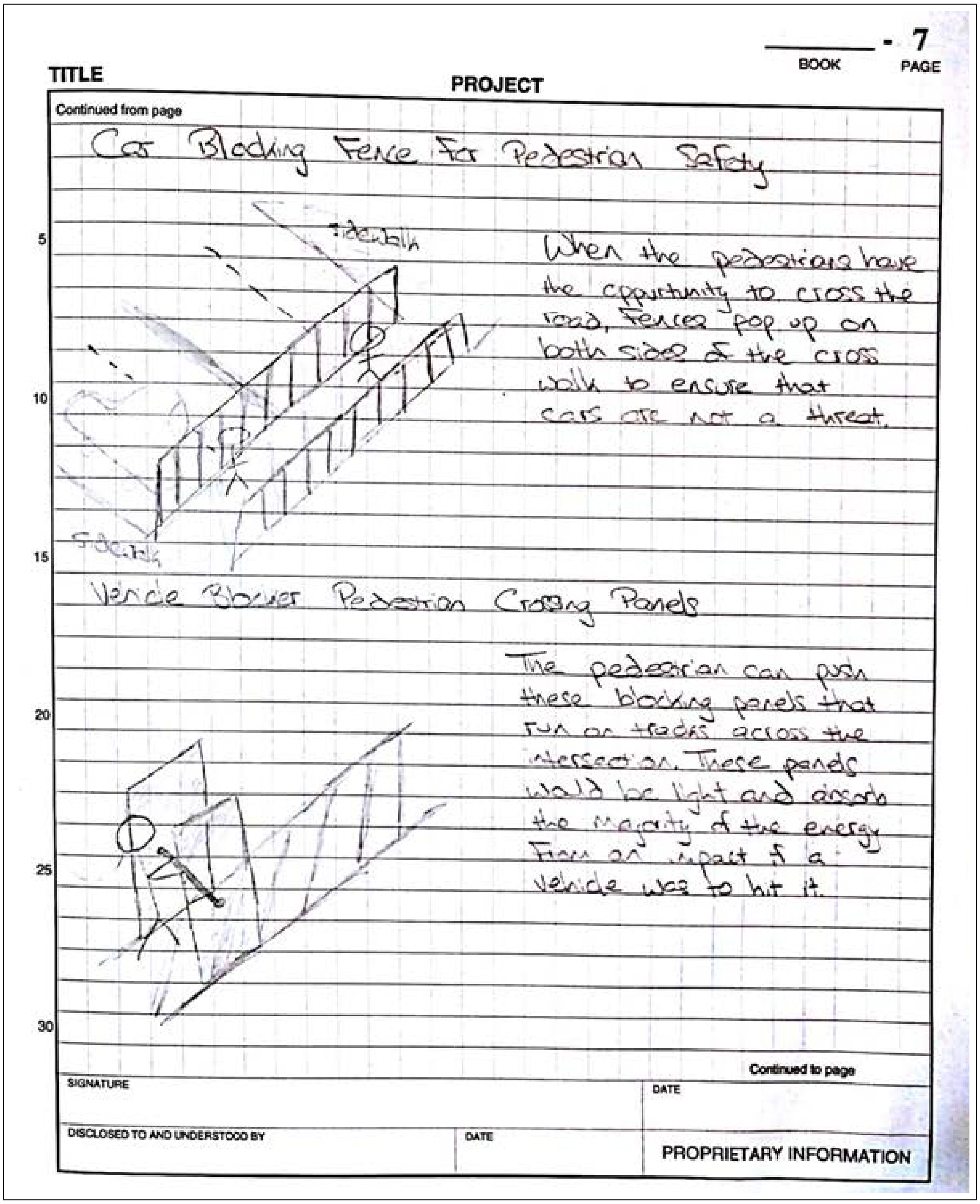


Figure 3.2 – A scanned page from $J22$

pages look like after scanning.

3.4.2 Segmenting

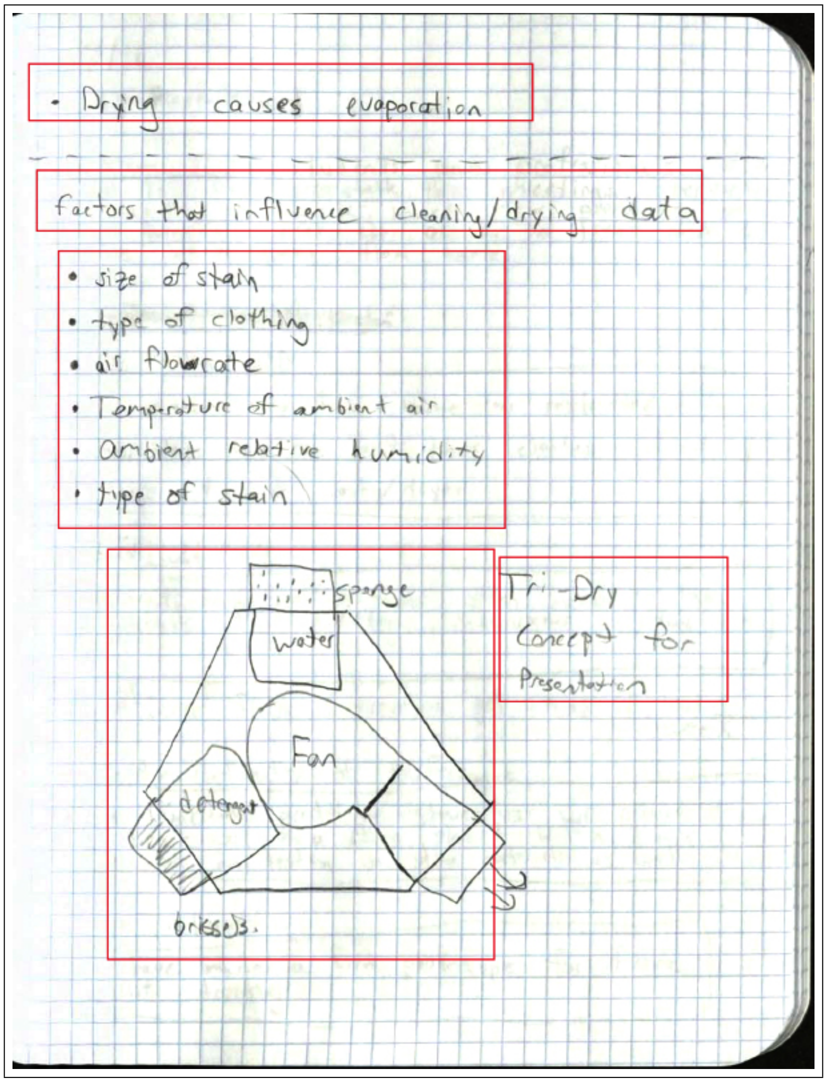


Figure 3.3 – The scanned page from $J64$ now segmented

The most challenging aspect of applying the coding scheme is the need to decompose journal entries into segments. A segment can be best equated to a single train of thought or evidence of a type of singular design activity. Some journal authors make very clear segmentations of their own by including lines between activities, indentations, using different ink colors, or even by specifying exact entry time. Other times segments can be identified by obvious changes in the type of entry being used. For example, one section of a page may contain a list, the next a sketch, the next some sentences, and next a diagram. These are not hard rules, however, because one segment may include both a graphic and text (e.g. captions, labels, part call outs). The segmented version of the journal page scanned in the previous section can be seen in Figure 3.3. Thus, difficulty arises at times in discerning when one thought or action ends and another begins.

One must have a strong understanding of the activity codes to be truly successful at segmenting. Due to this and the magnitude at which segmenting impacts any analysis work performed later on, it is critical to maximize the consistency of the scheme's basic unit of measurement. As such, all segmenting for all journals in this study was performed by the dissertation's author.

3.5 Journal Coding Process

Once a journal has been segmented, a researcher procedurally applies the updated Westmoreland-Schmidt coding scheme to each segment. As outlined in the literature review and visualized in Figure 2.1, this scheme involves six digits separated by period symbols. The six digits codify the design session, design segment, design phase, design activity, concept, and visual type. A page taken from *J*64 has been used to highlight the steps in this process in Figures 3.3 through 3.8.

3.5.1 Design Session

The first digit is the *Design Session*. Sessions are identified by the journal entry's date. At times journal users may use several pages in a row that all originated on the same date. In these cases they often will not write the date on each page but rather just once a new session begins. The first session of a journal is recorded as "1", the second as "2", and so on. Figure 3.4 contains a fully coded journal page. Note that the first digit in all of the page's segments is a "4", indicating that these were contained in the *4th* session of this journal.

3.5.2 Design Segment

The next digit is *Design Segment*. The first segment within a session is labeled as "1" and subsequent segments will count upwards until the session ends. Each time a new session begins, the segment count resets back to "1". The page found in Figure 3.4 includes the beginning of that session, so the segments are simply coded in order as segments $1 - 5$.

3.5.3 Design Phase

Design Phase is the third digit. There are five possible choices for design phase code. Each indicates one of the three phases of the design process as defined by *Engineering Design* [15]. These are: Concept design (1), Embodiment design (2), Detail design (3). Additional options are for this digit Redesign (4) and Other (5). Other is for journal entries such as non-design process work. All of the segments in

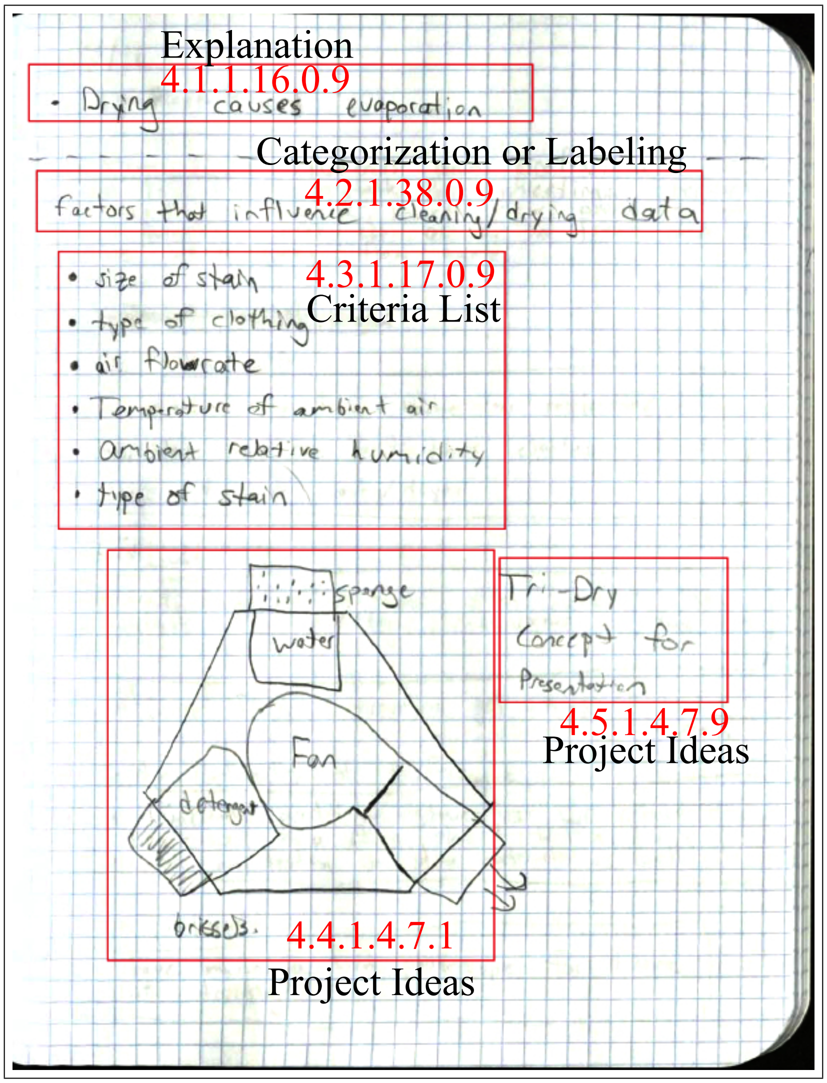


Figure 3.4 – The page from $J64$ fully coded

Figure 3.4 were made during the concept design phase, and so they all contain "1" as their third digit.

3.5.4 Design Activity

The fourth digit in the code string is perhaps the most critical for this work. The *Design Activity* code contains the most detailed information in the code string. There are 39 specific actions, split across eight activity classes. The complete list of classes and their activities can be seen in Table 3.1, while select examples of particularly common activities can be found in the Section 4.1.

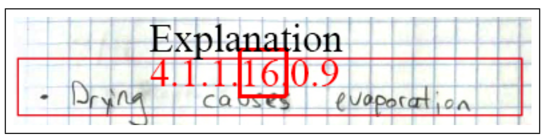


Figure 3.5 – Activity in Segment 1 is an *Explanation*, indicated by "16" in the fourth digit. Segment from *J*64.

Segment 1 from the previously coded page is an *Explanation* so its fourth digit is coded with a "16", as seen in Figure 3.5. Meanwhile, Segment 4 contains a concept sketch, which typically indicates that the activity is *Project Ideas* so its fourth digit is coded as a "4" as seen in Figure 3.6.

Activity can be analyzed on two levels with this scheme by either using the eight overarching classes or the 39 specific actions. Both types of analysis are valid and choice between them is determined based on what a researcher is most interested in examining. Using the action level specificity is good for performing very specific inquiries such as finding what analogies were used or how often the team took meeting minutes. The majority of work in this dissertation utilizes the broader

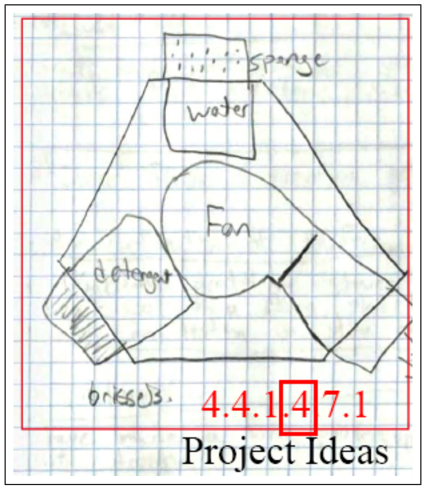


Figure 3.6 – Activity in Segment 4 is classified as *Project Ideas*, marked by a “4” in the fourth digit. Segment from $J64$.

classes to better capture what role individuals were serving on their teams.

3.5.5 Concept

The next digit in the string is the *Concept*. Each time a new alternative design appears in a journal, it is assigned the next sequentially available concept number. Segments which relate to no specific concept are coded as “0”. Examples of segments with no specific concept tied to them are constraints, customer requirements, and labeling. Westmoreland stated that for the purposes of the coding scheme application, “a concept is one that is clearly defined by the students with a label. A concept can also be final assembly of the product that was not previously seen in the journal” [2].

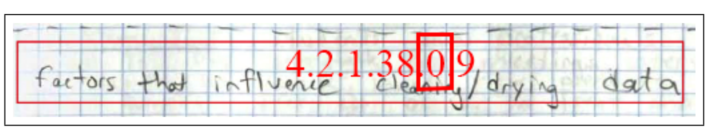


Figure 3.7 – This segment is not about a specific concept, so it is marked by a “0” in the fifth digit. Segment from $J64$.

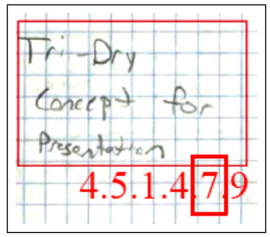


Figure 3.8 – This segment pertains to the 7^{th} concept generated by $J64$'s team, so the fifth digit is marked "7". Segment from $J64$.

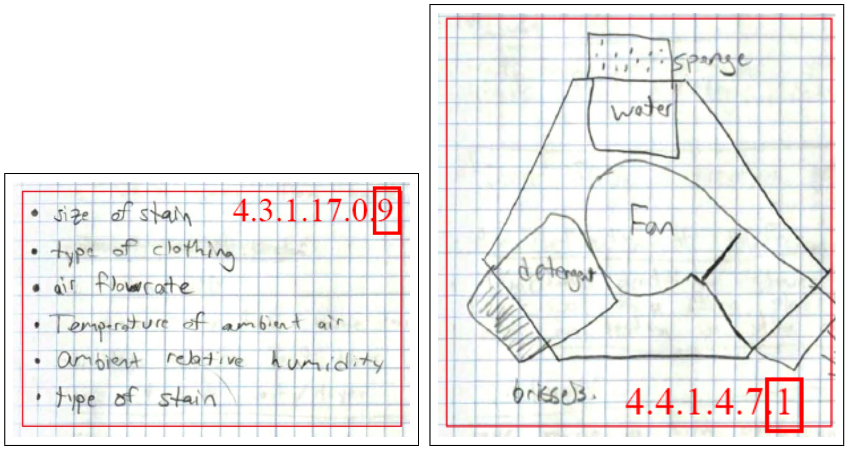
The first few segments in Figure 3.4 are concept neutral, so are coded with a "0" like in Figure 3.7. The last two segments, however, pertain to the chronologically seventh concept the team has recorded so are both coded with a "7" as in Figure 3.6.

This piece of data is particularly useful for team analysis. When coding journals belonging to a team, the same *Concept* codes should be shared throughout the team. This enables analysis of concepts propagating across the team and tracking their use by other members, which will be discussed later in this chapter.

3.5.6 Visual Type

The final digit in the code string is the *Visual Type*. This indicates the type, or the absence of, visual information contained in the segment. In all there are nine possibilities for this digit, which can be found in Table 3.4.

Segment 5, as seen in Figure 3.9 (a), contains no visual element so the last digit is coded with a "9". Segment 4, seen in Figure 3.9 (b), conversely involves a sketch and so its last digit is coded as a "1".



(a) No visual (b) Sketch visual

Figure 3.9 – Figure A contains no visual contained in the segment, so a "9" is recorded in the last digit. In Figure B the segment contains a sketch, so is coded as "1". Segments taken from *J64*.

Table 3.4 – Visual types and their respective codes

Visual Type	Code
Sketch	1
CAD	2
Photo	3
Simulation	4
Line Drawing	5
Electrical Drawing	6
Chart / Table	7
Engineering Diagram	8

3.5.7 Limitations of the Dataset

Limits do exist in journal data. It cannot be assumed that all participants give equal attention to their journal. Not all people are faithful recorders so some activities are likely missing in journals. When students do record though, their entry is known to be an activity they are doing.

3.6 Coder Training and Inter-coder Reliability

Three trained coders were used for all content contained in this dissertation, the author and two undergraduate research assistants hired in fall 2016 specifically for this task. The undergraduates at the time of their hiring were senior mechanical engineering students. They were both enrolled in ENME472 at the time. They and their teams were ineligible to participate as study volunteers.

Over the course of this training and calibration period, each researcher coded four journals and over 700 segments. The assistants were initially given a training packet and asked to review its contents (a final version of which can be seen in Appendix B). The next step was to as a group procedurally go through a journal previously coded by the dissertation's author. Along with the author they were walked through each segment while discussing why it was coded the way it was. Next they were provided with another journal which had been segmented but was not coded (specifically, $J36$). The dissertation's author and both assistants each coded it, resulting in three versions of the same journal.

These codes were used to evaluate the first round of inter-coder reliability, and subsequently determine a starting baseline. Krippendorff's alpha was used as the measure of reliability [88–91] because it is well suited for more tests involving more than two coders. The reliability was found to be $\alpha = 0.6137$.

His α is ultimately a modified version of Cohen's κ so there is overlap regarding accepted guidelines evaluating strength of reliability. While a wide variety of benchmarks exist [89, 90], the most commonly cited is from Landis & Koch [91]. They define strengths of 0.21-0.40 as fair, 0.41-0.60 as moderate, 0.61-0.80 as substantial, and 0.81-1.00 as near perfect agreement.

Using Landis & Koch's benchmarks would mean that the first round of testing had a substantial level of reliability strength. After this first journal, the three coders reconvened to discuss differences in codes and which selection was ultimately best for a particular segment. Main difficulties in the first round related to action codes which were very similar by definition. This resulted in making several recommendations for updating the coding scheme. These revisions included the addition of some terms and moving certain actions to more appropriate classes.

Next all three researchers coded another journal ($J34$). This time reliability was only moderate at $\alpha = 0.470$. A few obvious differences existed in coding choices which stemmed from different interpretations of just a few specific actions. Once these codes were clarified between the team, each researcher was asked to update the specific segments which were related to their confusion. Only 54 of a possible 696 ($J34$ contained 232 segments) segments were changed, less than 10%. Of the segments changed, 40 came from one coder. After these changes were done, reliability improved to substantial strength at $\alpha = 0.6322$. After this second round of calibration a few definitions were again updated in the coding scheme.

A third calibration journal ($J31$) was coded by the research team. Initially moderate reliability was found $\alpha = 0.4593$. As with $J34$, a few specific things were causing disparity in coding which prompted updating several definitions. Amending the problematic segments resulted in reliability increasing to $\alpha = 0.6282$. A fourth and final calibration journal was coded. Without needing any adjustments or clarifications, reliability was the best yet at $\alpha = 0.6348$. This value would be identified as substantial by Landis & Koch. Even across other benchmarks, values in this range are typically considered to be between a "good" and "substantial" level of reliability. After a sufficient level of inter-coder reliability was achieved, each journal was coded in full by only one researcher for the remainder of the study.

3.7 Analysis of Journal Text

Text analysis was added to this work to identify word cues for the eight activity classes. If certain words are unique to a particular class it could be used to assist any attempt at automation. There are two components to the methodology of examine the text contained in a journal. The first is to transcribe it and the second is to perform the actual corpus analysis. In this work transcript analysis was performed using Voyant, a web-based analysis tool [92]. Voyant offers a range of tools to compare individual documents. Most significant to this work is the ability to determine which words are distinctive to a specific document. A word is considered distinctive to a class if it appears at a higher rate within the transcripts of one class than the rate in which it appears within the text as a whole.

3.7.1 Journal Transcription

In addition to the design code string, a transcription of the text contained in each segment was also recorded. The majority of segments contain only text and so are transcribed verbatim.

For segments containing non-text elements, several special descriptor terms were created. A segment containing a visual was transcribed as "fig_(visual type)", where (visual type) corresponds to the list in Table 3.4. For example a sketch would be transcribed as "fig_sketch".

Segments which contained only numbers, were transcribed with a preceding number sign (#), with no space between. For example, a segment which only contains "20,450,150" would be transcribed as "#20,450,150". If a segment contains text in it as well it is not necessary to do this. This was made necessary for work inputting the transcripts into Python, so that the coding language would not view the number as an operable value.

Rather than transcribe entire segments of math calculations any segment containing this was recorded as "#equations". Similarly, if a segment contained code for a programming language it was transcribed as "#coding". The preceding number sign was important to distinguish these entries from a journal author writing the words equations or coding.

Table 3.5 – Example transcript of the journal page taken from $J64$

Session	**Segment**	**Transcript**
4	1	Drying causes evaporation
4	2	factors that influence cleaning/drying data
4	3	size of stain type of clothing air flowrate Temperature of ambient air Ambient relative humidity type of stain
4	4	fig_sketch
4	5	TriDry concept for Presentation

3.7.2 Text Analysis

At a study-wide level, text analysis will be used to look into qualities of journal entries belonging to each of the design activity classes. By creating a document which contains all the transcripts of a particular class and repeating for each of the classes, it is possible to compare them to identify words that are distinctive for each class. The vocabulary density is another measure which can be calculated. Vocabulary density measures the variety of terms used in each class by determining the ratio of unique words to total words used per class. Table 3.6 provides a basic example of what this analysis can provide. This text analysis was performed using 17 journals from the fall 2016 cohort.

Additionally, transcripts will be examined on an individual, team, and cohort level. Performing this on an individual level will provide a look at any possible correlations that exist with an individual's vocabulary usage and their design activity. By combining the transcripts of each member of a team into one corpus, team vo-

Table 3.6 – Example of text analysis work performed using 17 journals

Design Activity Class	Total Words	Vocab Density	Most Distinctive Word & Count
Information Seeking and Noting	3351	0.391	meeting (45)
Problem Understanding	671	0.642	holder (6)
Idea Generation	3142	0.306	description (31)
Analysis	2661	0.439	kayak (27)
Decision Making	996	0.568	explanation (3)
Project Management	2658	0.396	name1 (17)
Reflection	1164	0.54	reviewed (4)

cabulary and lexicons can also be explored. This provides another possible measure of evaluating individual engagement, by looking at overlap of key terms between an individual and the rest of their team. Finally, by repeating that process on a cohort level observations about the similarities and/or differences of different enrollment classes will be examined.

3.8 Activity Sequence Tabulation

In order to identify recurring sequences of activity a program was written in Python [93] to find and count them [94]. All coded activity was compiled into a single document, sorted by segment order and transformed to an array. The program is designed such that a user can define what minimum and maximum length sequences should be tabulated. The code cuts the data up into bunches of the minimum specified and counts the patterns found. It then repeats this process increasing the cut length by 1 each time until the maximum length is reached. The code that was used can be found Appendix C.2. An additional portion of code was created specifically to ignore segments until there is a change in activity class, which can be found in Appendix C.3.

3.9 Concept Documentation

The concept digit of the Westmoreland-Schmidt scheme enables several analysis metrics when examining a set of journals belonging to the same team. A typical journal would be expected to contain documentation and development of that journal author's own concepts, but a thorough one will also include references to concepts created by other team members. Once conceptual design has been completed and a final concept has been selected, only that final design and variations on it are expected to appear in a journal for the remainder of the project [2]. This has value in that measuring the frequency in which a journal author references designs made by other team members or their team's final concept can convey inferences on an individual's level of engagement with their team.

Especially in earlier stages of a project's timeline it is quite common to find a page that contains segments belonging to different concepts. Figure 3.10 is a page taken from $J109$ which includes several segments belonging to their team's 3^{rd} and 4^{th} concepts. Any time these concepts appear in any journal of Team 18 they will be coded with the same tracking numbers 3 and 4, respectively.

3.9.1 Concept Referencing Ratios

In this section a number of variables and equations are introduced. These equations and their definitions were developed by Westmoreland [2], with an update to some of the variable selections. Table 3.7 provides a summary of terms, while

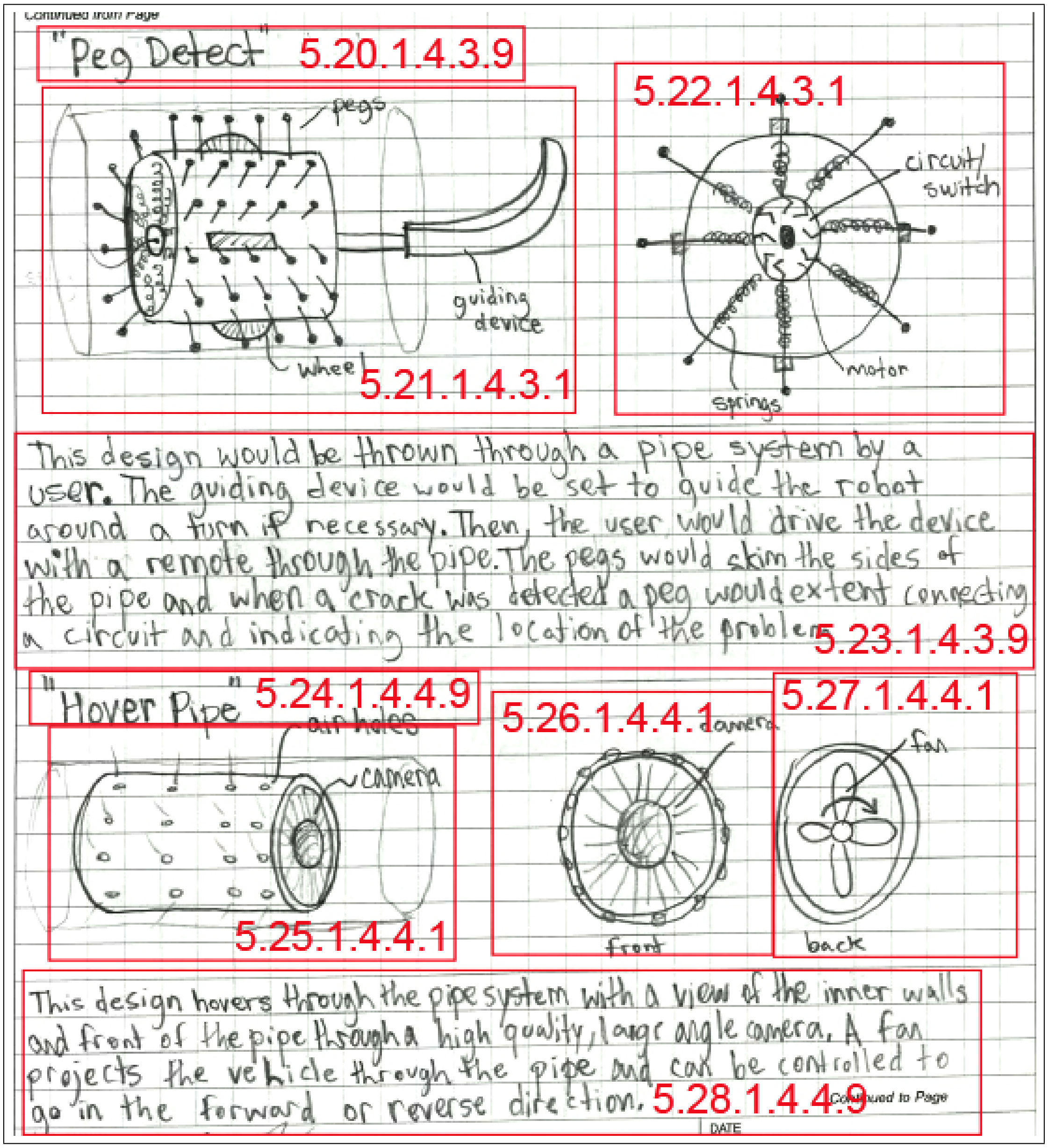


Figure 3.10 – This page from $J109$ contains segments belonging to two unique concepts. For $J109$'s team these concepts will always be identified as concepts 3 and 4, as recorded in the 5th digit of codes here.

Table 3.8 summarizes the equations.

Each concept that appears in a team's constituent journals will have a unique numeric identifier (x). The actual value of this identifier does not indicate any sort of magnitude or importance, simply it represents the chronological order in which the concept was coded by the research team. Journals were coded in a random order, and so there is no significance to this identifer beyond being a tag. Concept numbers are exclusive to a specific team. That is, each team will have its own concept 1, concept 2, and so on.

Table 3.7 – Summary of all variables for concept reference tracking, adapted from Westmoreland's dissertation [2]

Term	Definition
J_i	identification number for each journal author
T_n	identification number for a design team
C^{T_n}	set of all concepts generated by members of team T_n
C_{J_i}	set of all concepts in journal J_i
$C_{J_i}^{J_k}$	set of all concepts in journal J_i created in journal J_k
$c_{xJ_i}^{J_k}$	the x^{th} concept in journal J_i created in journal J_k, $x = 1, 2, ..., X$
$c_{T_n}^{*}$	the final design concept selected for team T_n
m^{T_n}	number of members on design team T_n
N_{J_i}	number of concepts that appear in journal J_i
$n_{J_i}^{x}$	number of referencing instances to concept x in journal J_i
$r_{J_i}^{s}$	self concept reference ratio
$r_{J_i}^{o}$	others concept reference ratio
$r_{J_i}^{t}$	team concept reference ratio
$r_{J_i}^{*}$	final concept reference ratio
S_{J_i}	total number of referencing instances appearing in journal J_i

A concept is attributed as originating from whichever journal contains the first chronological appearance of it. It is possible that the first journal to mention it may provide attribution of the idea to another team member, in which case that member would be identified as the originator.

The set of all concepts (x) appearing in a given journal J_i that were generated by another team member's journal J_k can be defined as $C_{J_i}^{J_k}$ as described in Table 3.8 (Equation 3.1).

All concepts that exist in a given journal J_i on team T can be found by applying this for each possible J_k (including themselves), as shown in Table 3.8 (Equation 3.2).

Taking this another step further, Table 3.8 (Equation 3.3) defines a set containing all of the concepts created by team T.

Table 3.8 – Summary of all equations for concept reference tracking, adapted from Westmoreland's dissertation [2]

Name	Equation
Concepts in J_i created by J_k	$C_{J_i}^{J_k} = \{c_{xJ_i}^{J_k} \mid \forall x\}$
All concepts in J_i	$C_{J_i} = \{c_{xJ_i}^{J_k} \mid \forall k \in T_n; \forall x\}$
All concepts for team T_n	$C^{T_n} = \bigcup_{i=a}^{z} C_{J_i}$, where a through z contains all members of team
Self concept referencing ratio	$r_{J_i}^{s} = \frac{\lvert C_{J_i}^{J_i}\rvert}{\lvert C_{J_i}^{T_n}\rvert}$
Other concept referencing ratio	$r_{J_i}^{o} = \frac{\lvert C_{J_i}^{T_n}\rvert - \lvert C_{J_i}^{J_i}\rvert}{\lvert C_{J_i}^{T_n}\rvert}$
Team concept referencing ratio	$r_{J_i}^{t} = \frac{\lvert C_{J_i}\rvert}{\lvert C^{T_n}\rvert}$
Total referencing instances	$S_{J_i} = \sum_{x=1}^{N_{J_i}} n_{J_i}^{x}$
Final concept referencing ratio	$r_{J_i}^{*} = \frac{n_{J_i}^{*}}{S_{J_i}}$

Westmoreland also created four referencing ratios for evaluating an individual's engagement with their team [2]. The first of these is the *Self Concept Referencing Ratio* ($r_{J_i}^{s}$), shown in Table 3.8 (Equation 3.4). This ratio is the proportion of the set of concepts contained in a journal J_i which originated in that same journal J_i.

The second ratio, found in Table 3.8 (Equation 3.5), is the *Others Concept Referencing Ratio* ($r_{J_i}^{o}$). This measures the proportion of the set of concepts which originated in a teammate's journal.

The *Team Concept Referencing Ratio* ($r^t_{J_i}$) measures the breadth of concepts an individual referenced. It is the proportion of all of team T_i's concepts that appear in journal J_i, as defined in Table 3.8 (Equation 3.6).

Of all the concepts contained in set C^T, one will ultimately be chosen as their final design (c^*_T). It is of interest to know how much of each team member's journal is related to that final concept.

Each time a journal segment is associated with any concept, that is a *concept referencing instance*. The total number of referencing instances contained in one journal can be calculated by Table 3.8 (Equation 3.7), where $n^x_{J_i}$ is the number of times concept x is referenced in journal J_i and N_{J_i} is the total number of concepts that appear in journal J_i.

The last of the four ratios, the *Final Concept Referencing Ratio* ($r^*_{J_i}$), builds off of this to measure how many of the total concept referencing instances contained in a given journal J_i pertain to the final concept c^*_T. Unlike the previous ratios, in this case the frequency in which concepts appear is accounted for as seen in Table 3.8 (Equation 3.8).

3.9.2 Concept Reference Automation

To expedite the process of calculating the various concept ratios, a code was developed in Python 3 [93] [95]. After converting the tracked concept information into a tab separated plain text file, this code identifies which journal was the first in a team to first use a concept based on segment date and calculates the equations detailed in the previous section. The code, which can be found in Appendix C.1, processes a single team at a time and so the user must indicate the text file for the specific team they wish to analyze.

3.10 Project Time Intervals

One of the major questions being asked by this research related to the impact that time has on journal activity during a project. Any of the previously discussed methods can also be performed using portions of the project's timeline to track changes. Course dates for two interim reports and a final report are used as major breakpoints in the schedule. The exact dates for each of the semesters when data collection occurred can be found in Table 8.1

Chapter 4: Individual Journal Activity Classes

This chapter pertains to Research Question 1 and also serves as a summary of the dataset as a whole. The results presented in this chapter were found using all 83 journals to investigate the patterns in individual journal activity.

Some parts of the work presented here were used as the basis for papers which were presented at the ICED 2015 and the Design Theory & Methodology track of the ASME IDETC & CIE 2016 conferences [11, 59]. These papers were written during early stages of the overall research and so the data contained in them is not the full dataset.

Section 4.1 summarizes the types of entries associated with each activity class as well as a look at vocabulary usage for each. Section 4.2 discusses the activity class frequencies for individuals, which are further detailed in study-wide manner in Section 4.3. Section 4.7 continues the study-wide look with analysis on how frequently activity classes were favored or not by individuals. Section 4.8 details the comparison between participant survey results indicating their perceived activity breakdown versus their observed activity. Finally Section 4.9 concludes this chapter with closing remarks.

All work performed in this section is done with the use of the full sample of all 83 journals.

At times in this dissertation, analysis will be made regarding "primary activities". This is refers to the first 7 activity classes beyond *Other*.

4.1 Activity Class Observations

In this section an overview of findings related to each specific class will be detailed. Examples will be provided for specific classes. Details about the vocabulary usage specific to each activity class will also be discussed. A corpus for each activity class was created from the transcripts of 71 journals, considered to be an adequate and representative sample. Each corpus is organized as a spreadsheet where each cell is the transcript of one segment.

Transcripts were analyzed using the web tool Voyant [92]. As discussed in Section 3.7, the text for segments which did not contain words were transcribed using special codes such as "#fig_sketch" in place of a sketched image. In total the 71 transcripts contained 10,305 unique words and 112,009 total words.

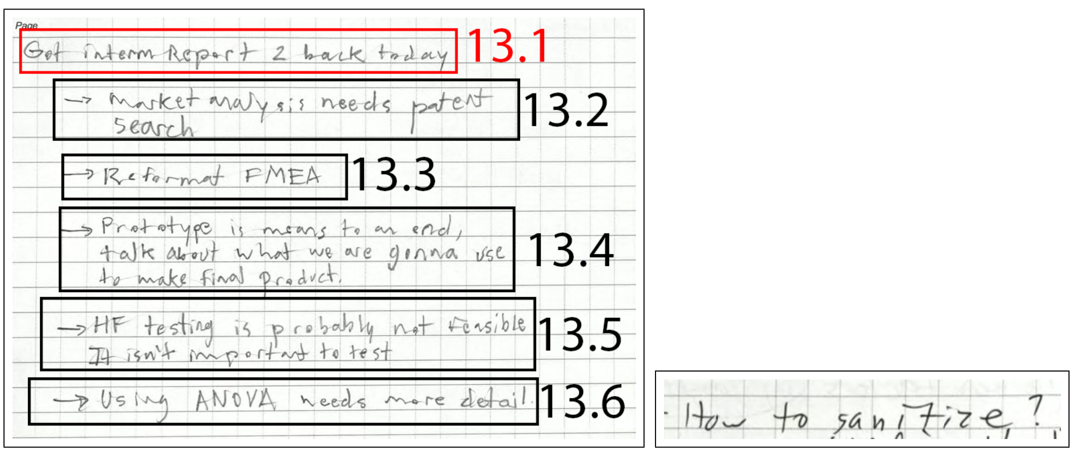
Table 4.1 – Summary of text analysis on each activity class

Class	**Total Words**	**Unique Words**	**Vocab Density**
Information Seeking & Noting	17,834	4,262	0.239
Problem Understanding	8,388	2,357	0.281
Idea Generation	9,749	2,583	0.265
Analysis	26,497	4,557	0.172
Decision Making	9,635	2,544	0.264
Project Management	22,171	3,592	0.162
Reflection	17,326	3,188	0.184
Other	409	232	0.567
All Classes	112,009	10,305	0.092

Table 4.1 summarizes high level findings of the text analysis on activity class segments. Included in this table are each corpus's number of total words, number of unique words, and vocabulary density. Vocabulary density for a corpus is simply the ratio of its unique word count to its total word count.

4.1.1 Information Seeking & Noting

Segments that are classified as *Information Seeking & Noting* accounted for 14.05% of segments on average. These segments are often are either a question with unknown answers at the time of writing or some piece of information which is being recorded for later use. Figure 4.1 contains a pair of examples taken from different journals.



(a) Feedback action (b) Questioning action

Figure 4.1 – Examples of Information Seeking & Noting

Figure 4.1 (a) is an example of the Feedback action. The first segment in this image, segment 13.1, is actually a different class, but the context from it is important in correctly classifying segments 13.2–13.6. Here a student is discussing receiving a returned report and then recording feedback they received for future reference. As such, segments 13.2–13.6 are all Feedback actions (action code# 32), a part of the *Information Seeking & Noting* class. Figure 4.1 (b) is an example of Questioning (action code# 11), one of the most common actions in this class, where the journal author has written an open ended question. Specifically in this example they are asking how to sanitize some part of their artifact.

Table 4.2 – Most common and most distinctive words for Information Seeking & Noting along with their total counts

	Word	*N*	**Distinctive Word**	*N*
1st	#fig_sketch	138	questions	42
2nd	design	96	#fig_line	62
3rd	need	76	prototype	52
4th	use	73	dr	15
5th	#fig_line	62	trace	9

4.1.2 Problem Understanding

Problem Understanding was the least frequent of the classes outside of *Other*, representing only 7.40% of segments on average. When segments do occur in this class it is usually earlier in the semester, and most typically is in the form of things such as criteria lists like the one seen in Figure 4.2.

Table 4.3 – Most common and most distinctive words for Problem Understanding along with their total counts

	Word	*N*	**Distinctive Word**	*N*
1st	#fig_chart	116	consumption	15
2nd	use	58	durability	13
3rd	user	53	daily	10
4th	easy	44	population	7
5th	weight	43	feels	7

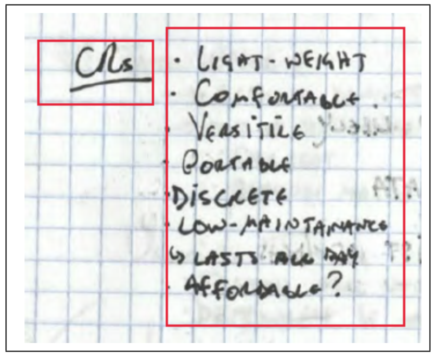


Figure 4.2 – Example of a Problem Understanding segment

4.1.3 Idea Generation

On average *Idea Generation* accounted for 16.09% of segments. At the start of this research it was expected to be the most dominant activity class but it was only the 3^{rd} most frequent. The most prolific type of activity in this class are concept sketches, and there were 709 segments containing sketches in this class as seen in Table 4.4.

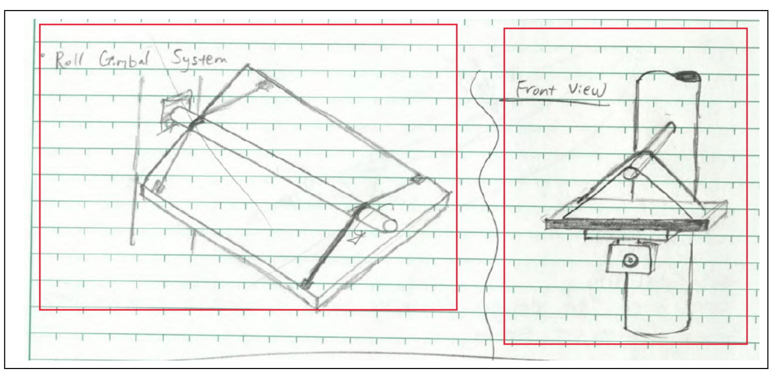


Figure 4.3 – Example of an Idea Generation segment

Table 4.4 – Most common and most distinctive words for Idea Generation along with their total counts

	Word	N	Distinctive Word	N
1st	#fig_sketch	709	kayak	21
2nd	concept	121	title	40
3rd	design	51	concept	121
4th	air	43	pros	8
5th	title	40	joysticks	5

4.1.4 Analysis

Analysis was on average the most frequent activity class in the study, with an average of 23.13% of segments. Figure 4.4 is an example of the Calculations action which heavily attributed towards *Analysis* totals. Other common segment examples of this class include students explaining thoughts by using reasoning, describing prototype testing procedures, or testing results.

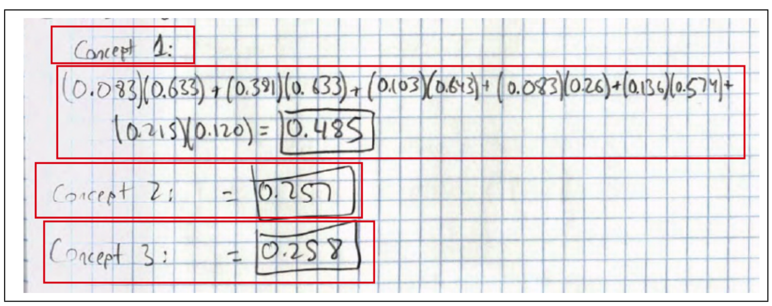


Figure 4.4 – Example of an Analysis segment

4.1.5 Decision Making

Decision Making was found to be very uncommon, occurring in only 9.23% of segments on average. One possibility is that this class is not well-captured by

Table 4.5 – Most common and most distinctive words for Analysis along with their total counts

	Word	N	Distinctive Word	N
1st	#fig_sketch	419	#fig_eng	102
2nd	#calculations	347	kayak	45
3rd	page	113	#fig_table	12
4th	design	110	tee	29
5th	user	107	shredded	9

journals. It is perhaps more likely to occur verbally during a group meeting. Often in journals the act of decision making occurs through omission rather than proclamation. For instance it is rare for a student to record "We have decided to stop working on Concept #23". Rather they will simply cease to record entries regarding that concept. Another possibility is that these classes have high value at specific points in the project's timeline and are less valuable for the remainder of it.

Table 4.6 – Most common and most distinctive words for Decision Making along with their total counts

	Word	N	Distinctive Word	N
1st	#fig_sketch	286	#fig_line	74
2nd	design	89	prototype	49
3rd	need	83	nest	6
4th	#fig_line	74	crow's	6
5th	final	54	confusion	6

4.1.6 Project Management

Project Management segments often involve individuals making itemized lists or tasks which need to be done. Figure 4.5 is representative of what students will regularly record in their journals.

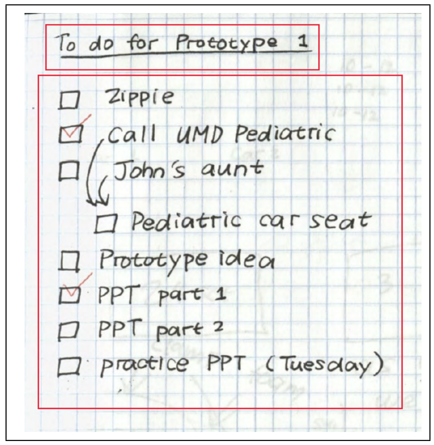


Figure 4.5 – Example of a Project Management segment

Table 4.7 – Most common and most distinctive words for Project Management along with their total counts

	Word	N	**Distinctive Word**	N
1st	report	218	report	42
2nd	need	179	(student name redacted)	29
3rd	design	164	prototype	155
4th	prototype	155	(student name redacted)	30
5th	concept	108	(student name redacted)	20

4.1.7 Reflection

Segments from *Reflection* are most typically Personal Notes. They are short prose written by the journal's author to recap something that has happened or their own personal thoughts. Figure 4.6 includes a pair of examples of the Personal Note action.

4.1.8 Other

Segments that are classified as *Other* are rather difficult to summarize. They are nearly always something unrelated to the journal author's project. Sometimes

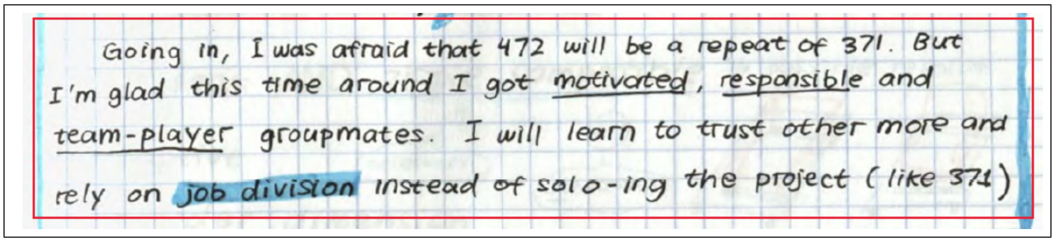


Figure 4.6 – Example of Reflection activity

Table 4.8 – Most common and most distinctive words for Reflection along with their total counts

	Word	N	**Distinctive Word**	N
1st	meeting	328	prototype	116
2nd	team	169	report	112
3rd	prototype	116	met	30
4th	design	113	working	40
5th	report	112	recap	20

these are doodles or notes unrelated to course work. On occasion a segment is simply too illegible to be classified as anything else and so is coded as *Other*.

Table 4.9 – Most common and most distinctive words for Other along with their total counts

	Word	N	**Distinctive Word**	N
1st	#fig_sketch	45	#illegible	23
2nd	#illegible	23	typing	2
3rd	pm	10	drunk	2
4th	#mistake	9	culmination	2
5th	#calculations	6	351	2

4.2 Individual Activity Class Frequencies

Once an individual's journal has been fully coded the number of segments belonging to each of the eight classes of design activity are tallied against the total number of segments in an individual's journal. This will result in eight percentage values which add up to account for all activity recorded in a journal. This can be represented visually as a radar plot or as a stacked bar graph, as seen in Figure 4.7.

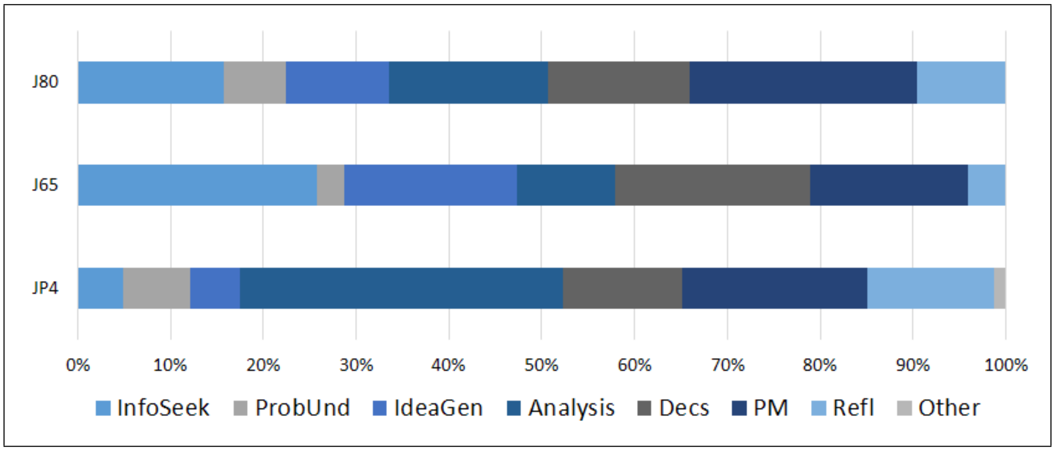


Figure 4.7 – Comparison of the class frequencies for three different participants (InfoSeek = Information Seeking & Noting, ProbUnd = Problem Understanding, IdeaGen = Idea Generation, Analysis, Decs = Decisions, PM = Project Management, Refl = Reflection, Other)

In total, 68 of the 83 students performed actions belonging to all 7 of the primary activities. An additional 13 students recorded segments in all but one of the primary activities, while the remaining 2 students performed all but two. As further detailed in Section 4.7, no activity class was the most frequent for all participants and all but *Other* were the most frequent class for at least one journal in the study. While there are definite patterns regarding the frequency of activity classes, it is clear that there is a large amount of variation between students. *Analysis* was the most frequent activity class and had the highest average frequency, accounting for nearly a quarter of all journal segments.

4.3 Study-Wide Journal Activity Averages

The average number of segments in a journal was 179 segments and the average class frequencies across all 83 journals were: 14.05% *Information Seeking & Noting*, 7.40% *Problem Understanding*, 16.09% *Idea Generation*, 23.13% *Analysis*, 9.23% *Decisions*, 17.62% *Project Management*, 11.30% *Reflection*, and 1.18% *Other*. Table 4.10 details the sample-wide values for the mean, median, and standard deviation for each activity class and segment count.

Table 4.10 – Study wide (N=83) summary statistics for total segment count and frequencies of segments per activity class

	Mean	**Median**	**StdDev**	**Skew**	**Kurtosis**
Segment Count	179.11	146.00	101.04	3.52	1.56
Information Seeking & Noting	14.05 %	13.82 %	8.84 %	1.96	0.41
Problem Understanding	7.40 %	7.16 %	5.12 %	3.31	2.92
Idea Generation	16.09 %	13.79 %	9.45 %	3.96	2.03
Analysis	23.13 %	20.59 %	12.72 %	2.32	-0.84
Decision Making	9.23 %	8.22 %	6.19 %	2.99	1.24
Project Management	17.62 %	15.97 %	9.41 %	2.62	0.58
Reflection	11.30 %	8.71 %	9.69 %	5.38	3.45
Other	1.18 %	0.27 %	2.01 %	6.08	4.04

4.4 Statistical Analysis of Individual Journals

The number of activity class and code instances was tabulated for each journal. The activity class data is used in this analysis. For all statistical tests performed in this section, a critical value $\alpha = 0.05$ was selected. All statistical testing that was performed was done with Python using the SciPy library [96].

Using the project-long activity proportion data from all 83 journals, the Shaprio-

Wilk test was conducted [97]. The null hypothesis of the Shapiro-Wilk test is that the distribution being tested comes from a normal distribution. Each class rejected the null hypothesis that the distribution was normal when using $\alpha = 0.05$. The p-value obtained for all eight classes was found to be below 0.05, and all but one (*Info Seeking & Noting*) had a p-value below 0.006 as seen in Table 4.11.

Table 4.11 – Shapiro-Wilk test *p*-value results for each class

	Shapiro-Wilk *p*-value
Segment Count	1.4397 E-04
Information Seeking & Noting	2.8046 E-02
Problem Understanding	6.4035 E-04
Idea Generation	1.5128 E-05
Analysis	1.7992 E-03
Decision Making	2.3069 E-03
Project Management	5.3792 E-03
Reflection	1.6514 E-09
Other	5.2017 E-13

The Kolmogorov-Smirnov statistical test was also performed to compare each of the class distributions to the normal distribution. In all cases the test returned p-values of 0.00, rejecting the hypothesis that the classes belonged to a normal distribution.

4.5 Segment Count Variation

Variation occurred in the type of activity recorded by students and in how frequently activities were recorded. Although students averaged 179 segments per journal, 11 journals were found to have over 300 (with an astonishing max of 513 segments) while 18 journals had less than 100 total. At the low end of total segments there is a degree of questioning the honest effort by the participants, however low segment count journals are not necessarily "bad". The Kruskal-Wallis test was performed and for all classes found no statistically significant difference between the class frequencies for students with segments totals of 100 and those of students with over 100 segments [98]. The Kruskal-Wallis test was used instead of ANOVA since the data previously had indicated to not follow a normal distribution.

To further compare the influence of segment count on class frequencies, three subgroups were made based on total segment count: the 5 journals with the highest totals ($J80$, $J44$, $J54$, $J55$, $J81$), the 5 journals in the middle of the scale ($J67$, $J112$, $J62$, $J108$, $J31$), and finally the 5 journals with the lowest totals ($J68$, $J79$, $J78$, $J105$, $J14$). The radar plots of their activity class frequencies can be seen in Figure 4.8.

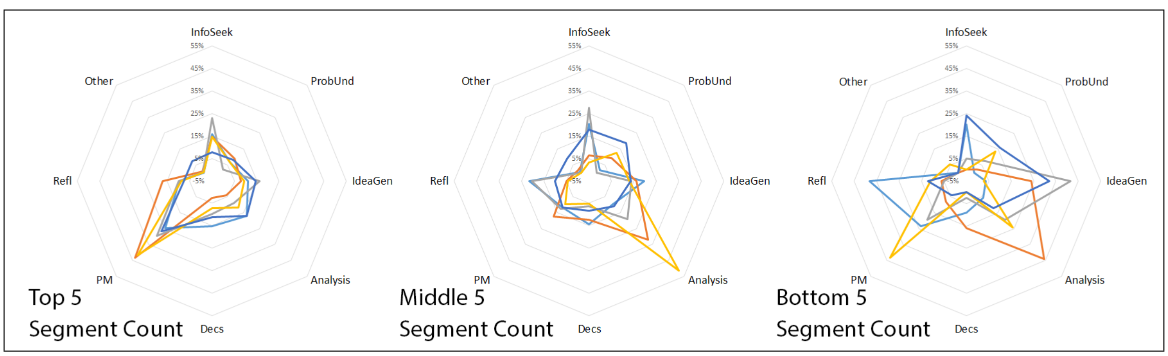


Figure 4.8 – Comparison of the class frequencies for the top 5, middle 5, and bottom 5 segment count journals

Some rather striking differences are immediately apparently in looking at these groups. All of the top 5 segment count journals have an extremely high number of *Project Management* entries. The relationship between high segment count and *Project Management* will be discussed further in Section 4.6. Journals in the middle group had a more uniform distribution of segments across the different activity classes. The one exception to this is one individual who had an extreme amount of *Analysis* entries. Other than that one individual, the other members of this middle group each had two or three activity classes which were recorded the most frequently in their journal. What is interesting about the bottom 5 group is that each individual focused on a different activity class. Their low segment totals could be simply making the relative amounts more misleading than they should be for the bottom group, but it is certain that journals in the middle group are less specialized in a single activity than those in either extreme group.

4.6 Correlations Between Classes

Determining whether correlations exist between pairs of activity classes was also of interest. If certain classes are commonly being employed together in the same journals it might suggest that there are certain activities most individuals adopt in their design work.

Spearman's correlation coefficient was measured between the frequency percentages for each pair of activity classes since the data was not normally distributed [99]. Spearman's r was used because it works well with all data types, including data which is discrete, ordinal, or continuous. Spearman's r was also calculated for each class compared to the total segment count to see if certain classes were favored by individuals who write more or less frequently. The Spearman coefficient ranges from -1, indicating a perfect negative relationship, to +1, indicating a perfect positive relationship. A value of 0 would indicate there is no linear correlation. Table 4.12 contains the coefficients for each activity class pair across the entire semester. Additionally it contains the correlation between each class and segment count.

Table 4.12 – Spearman correlation coefficients for class pairs and for each class compared to total segment count

Info								
0.168	**Prob**							
0.060	-0.001	**Idea**						
-0.531*	-0.190	0.205†	**Anlys**					
-0.090	-0.120	0.045	-0.022	**Decs**				
0.026	-0.033	-0.524*	-0.488*	-0.144	**PM**			
-0.009	-0.157	-0.505*	-0.419*	-0.064	0.286†	**Refl**		
0.160	0.250†	0.027	-0.019	-0.219†	-0.016	-0.187	**Other**	
0.264†	0.039	-0.208†	-0.177	0.121	0.325†	0.136	0.205†	**Segs**

*moderate, †weak

The coefficients in the table marked with a * are moderate strength correlations (values between 0.4-0.59), and coefficients marked with † are weak strength (values between 0.20-0.39). The remainder of values are very weak or no linear relationship was found. All of the moderate strength correlations were negative in nature. This means that for these class pairs, the larger of a percentage that one particular class was recorded in a journal the less the other one did. *Information Seeking & Noting* and *Analysis* had the strongest of all correlations, with a negative moderate relationship. *Idea Generation* and *Project Management* similarly had a negative correlation of moderate strength with each other. Finally *Reflection* had moderate-strength negative correlations with both *Idea Generation* and *Analysis*.

Analysis was observed to be the class with the strongest correlations. It had three different relationships that would be considered moderate and a fourth that would be considered weak which were all negative. This is partially explained by the fact that since *Analysis* was the most frequent class in journals, an increase in any other class will take away from it in most cases.

Total segment count had no strong correlations with any of the activity classes. The strongest correlation it did have was a weak-strength positive correlation with *Project Management*.

The relationship between total segment count and activity class frequency percentages for *Project Management*, *Information Seeking & Noting*, and *Idea Generation* may be indicative of a variety of issues. Students who journal less frequently or dislike writing may be primarily using their journal for ideation and sketching, which tend to be activities classified under *Idea Generation*. Students who have a proclivity for writing may also be individuals who prefer to stay very organized, often making to-do lists and other entries related to keeping on task (*Project Management* activities) or have a habit of record anything and everything that may be useful later on *Information Seeking & Noting* activities). A third possibility is that the average *Project Management* segment is much smaller than the average *Idea Generation* and so takes more total segments to record a comparable about of information.

4.7 Activity Class Ranks

The rank in which each class was featured within a journal was determined. For instance, *J54* had an activity breakdown of [0.23, 0.02, 0.16, 0.09, 0.10, 0.30, 0.10, 0.00]. Since *Project Management* was this journal's most prevalent class (30%) it is considered to be the top rank. One interpretation is that *J54* specialized in this class. Table 4.13 lists the results determined by tabulating the ranks for all 83 journals in this way. The bold faced number in each column indicates the most common rank for that class.

Table 4.13 – The frequencies with which each activity class were observed at each rank within journals

Class	**(most) 1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**(least) 8th**
Info. Seeking & Noting	12	17	14	12	9	8	11	0
Problem Understanding	2	0	9	14	17	14	24	3
Idea Generation	10	21	15	12	13	9	3	0
Analysis	36	14	12	9	5	3	4	0
Decision Making	1	8	9	14	14	16	19	2
Project Management	15	21	19	13	7	4	4	0
Reflection	9	6	5	12	16	21	12	2
Other	0	0	0	0	1	4	19	59

The results found in Table 4.13 indicate the variety between individuals. With the exception of *Other*, every class was the most prevalent for at least one student. This table also indicates a rough hierarchy of the classes. Half of the classes gravitate towards the top of the rankings: *Information Seeking & Noting*, *Idea Generation*, *Analysis*, and *Project Management*. Conversely, the other half are predominantly found to be the least common in journals: *Problem Understanding*, *Decision Making*, *Reflection*, and *Other*.

The reasons why certain classes gravitate towards the back end of rankings is not fully known at this time. It was naturally expected that *Other* would be very uncommon. For the other three least-common classes, it is possible that the information they represent is not particularly well captured by journals in comparison with the other classes. Other possibilities are discussed in their respective subsections of Section 4.1.

4.8 Activity Observed versus Perceived

If perceptions and coding values were found to be similar this would be a strong indicator of the scheme's capabilities. If perceptions were found to be different, it could help with refining the scheme or alternatively gain insight into what activities may appear to be disproportionately consuming to students. Other questions that were added were designed to discover participant disposition towards journalizing after partaking in the study and their opinion on the efficacy of using a design journal.

The first part of the survey asked students to allocate how much of their work out of 100% was in each of the activity classes. Students were not familiar with the segmenting process, the coding scheme used for journals, or any sort of formal definitions for these terms. The second portion of the survey asked students several questions assessing their team. The final section asked about the experience using a design journal. The survey in its entirety can be found in Appendix A.4.

In the Fall 2016 semester 10 participants were given this exit survey. Figure 4.9 contains the perceived and observed activity frequencies for $J92$.

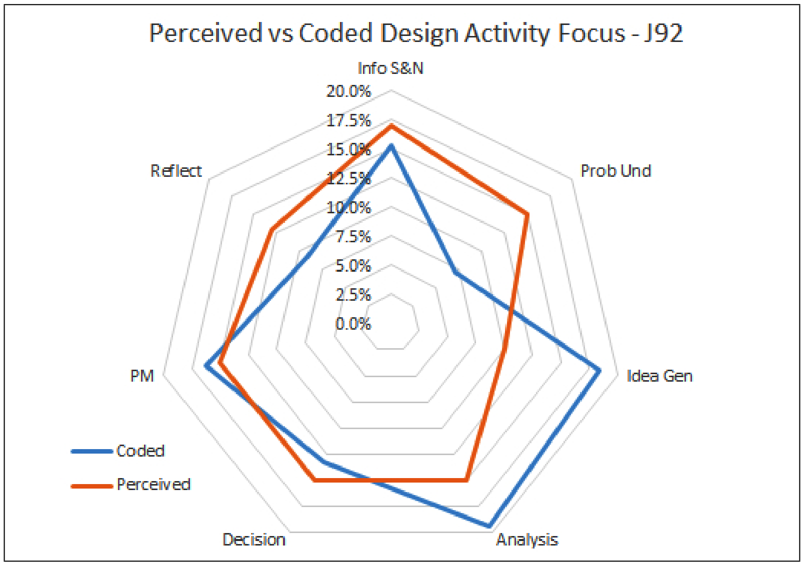


Figure 4.9 – Comparison of $J92$'s perceived and coded activity

While students were unable to identify the actual percentage of their journal segments, they were fairly decent at identifying their top ranked activity class. Of the 10, half correctly identified their most frequent class and 2 more of them were only off by 1 rank.

Spearman's correlation coefficient was calculated between the survey results and observed activity. Since Spearman's correlation also can be used successfully with ordinal systems both variables were input as their rankings. Spearman's r was also calculated between the observed and surveyed ranks for classes individually to identify certain activities were better represented by journal coding. As a whole the survey answers by students had a weak positive correlation with their observed activity. Specific classes though had notably different coefficients, as seen in Table 4.14.

Table 4.14 – Spearman's correlation coefficients between student survey perceived activity and observed activity

Info	Prob	Idea	Anlys	Decs	PM	Refl	Overall
-0.040	0.215*	-0.192	0.446†	-0.531†	-0.205*	0.386*	0.231*

**weak correlation, †moderate correlation*

Students were particularly strong at identifying *Analysis* which had a moderate-strength positive correlation. *Reflection* also had a positive correlation nearing moderate strength. *Decision Making* was by class students struggled the most with identifying. The most likely explanation for being off by such a wide margin is that the journals are simply not capturing *Decision Making* sufficiently.

4.9 Conclusions

Design journals were found to be a suitable method for gaining insight into the functional activities that individuals perform as part of an engineering design project. Students were observed making use of the gamut of activity classes. It was found that unique vocabularies exist for each class.

Key patterns that were found were that certain activity classes were more frequently recorded in journals and also more likely to be among the most frequently recorded by an individual. Some of these were more frequent than expected. It was not expected that *Analysis* would be more frequent than *Idea Generation*, let alone the most frequently recorded activity class.

The distributions of frequencies were found to be not normally distributed for all activity classes.

Certain pairs of activity classes were found to have moderate negative correlations with each other. This indicates that students who prefer *Analysis* activity are less likely to be frequent users of *Information Seeking & Noting*, *Project Management* or *Reflection*.

It was confirmed that a great deal of variation exists between journals, but commonalities do exist. The vast majority of students recorded activities in all classes.

Chapter 5: Segment Sequences

Now that the relative frequencies of activity classes have been discussed the next question in the research was to identify the patterns in which they occurred. This chapter is concerned with the patterns related to how individual activity is recorded sequentially in journals and Research Question 2. All analysis performed in this chapter stems from using the entire dataset of 83 individual journals. The work of the previous chapter identified a variety of information regarding the frequencies of the various activity classes. While the frequencies provide us with the building blocks that are being used, they do not provide any information of how they are assembled together. The goal of this chapter's work is to find the directions for how those blocks fit together.

This chapter begins with an overview of chapter-specific terminology in Section 5.1. In Section 5.2 the most frequent sequences of varying lengths observed and patterns related to those sequences will be discussed. Section 5.3 again looks at sequences of varying lengths but with a condensed version of the dataset that treats consecutive segments of the same activity class as one segment. Section 5.4 contains a look at the impact of total segment count on sequences. The chapter finishes with conclusions and limitations in Section 5.5.

5.1 Chapter Terminology

An activity sequence is the chronological order of classes which occur in a set of consecutive segments. For short hand, the segments within a sequence are referred to simply by the number associated with their activity class: 1)*Information Seeking & Noting*, 2)*Problem Understanding*, 3)*Idea Generation*, 4)*Analysis*, 5)*Decision Making*, 6)*Project Management*, 7)*Reflection*, and 8)*Other*. So if a segment was classified as being *Problem Understanding*, it would be simply labeled as "2" when writing out a sequence.

A sequence can be identified from any starting segment to any ending segment desired. For example, consider the excerpt from *J95* shown in Figure 5.1. There are three segments contained in this image. For the purpose of this explanation they have been labeled as a, b, and c. (*Note: while segments are typically coded numerically, here letters have been used in an attempt to reduce confusion.*) Considering just the segments in this image there are three different sequences which could be identified: one triple segment sequence (a,b,c), and two different segment pair sequences (a,b) and (b,c).

Suppose (b,c) is the sequence of interest. Segment b was coded as being *Idea Generation* (labeled as activity class 3) and segment c was coded as being *Analysis* (labeled as activity class 4). Thus the sequence for this pair of segments is referred to as (3,4).

In this sequence, *Idea Generation* is in the 1^{st} position of the sequence. It is the class that started off this particular sequence. *Analysis*, meanwhile, is in the 2^{nd}

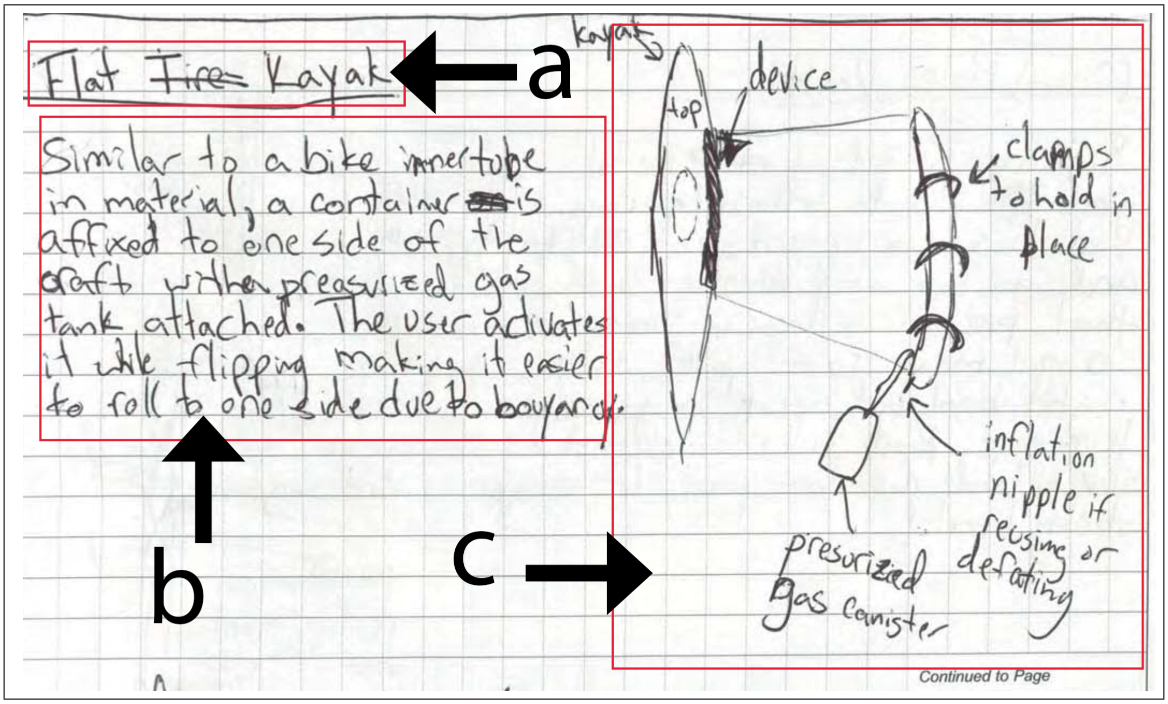


Figure 5.1 – Excerpt indicating a (Idea Generation, Analysis) sequence, or (3,4) sequence, occurring in segments (b,c)

position of the sequence.

5.2 Patterns in Activity Class Sequences

Journal class data was sorted to find common sequences to complement correlation findings. The first step taken was to combine all 83 journals into one dataset of 14,833 segments. A code was developed in Python to identify class activity sequences, which can be seen in Appendix C.2. The minimum and maximum sequence length can be designated within the code, so the code need only be run once to obtain the results for all desired sequence lengths. The code was run once to receive all the instances of sequences from 2 to 10 segments long. Table 5.1 contains the 10 most frequent sequences involving 2 to 5 segments (referred to as pairs, trios, quartets, and quintets).

The code works by first taking the 14,833 segments and slicing it into sequences of 2. By doing this, every segment except for the first and last are a part of two sequences. For example, if the first four segments in the overall dataset were 4, 3, 5, and 2 this would produce three pairs: (4,3) and (3,5) and (5,2). This is continued for the whole set and the instances of each 64 unique combinations of pairs is counted up. Next the code repeats this process but with slices of 3 segments. Those same first four segments would produce two triples: (4,3,5) and (3,5,2).

Since segments are counted in this manner, the relationship between the columns in Table 5.1 is complex. Longer length sequences contain chains of smaller sequences.

Table 5.1 – The most common activity class sequences for two, three, four, and five segments along with the number of instances (N) for each

Rank	N	Pairs	N	Trios	N	Quartets	N	Quintets
1st (most)	795	(6, 6)	441	(6, 6, 6)	271	(4, 4, 4, 4)	186	(4, 4, 4, 4, 4)
2nd	769	(4, 4)	428	(4, 4, 4)	255	(6, 6, 6, 6)	151	(6, 6, 6, 6, 6)
3rd	511	(1, 1)	269	(3, 3, 3)	160	(3, 3, 3, 3)	104	(4, 4, 3, 4, 4)
4th	502	(3, 3)	259	(3, 4, 4)	135	(4, 3, 4, 4)	103	(3, 3, 3, 3, 3)
5th	494	(3, 4)	225	(1, 1, 1)	131	(4, 4, 3, 4)	76	(1, 1, 1, 1, 1)
6th	414	(7, 7)	207	(7, 6, 6)	124	(1, 1, 1, 1)	75	(3, 4, 4, 3, 4)
7th	407	(7, 6)	203	(4, 3, 4)	108	(7, 6, 6, 6)	71	(7, 6, 6, 6, 6)
8th	391	(4, 3)	192	(4, 4, 3)	103	(3, 4, 4, 4)	59	(6, 6, 6, 6, 1)
9th	348	(6, 1)	178	(7, 7, 7)	100	(2, 2, 2, 2)	59	(4, 3, 4, 4, 3)
10th	330	(6, 7)	173	(6, 6, 1)	91	(6, 6, 6, 1)	55	(6, 6, 6, 6, 7)

Activity class legend:
1)*Information Seeking & Noting* 2)*Problem Understanding* 3)*Idea Generation* 4)*Analysis* 5)*Decision Making* 6)*Project Management* 7)*Reflection* 8)*Other*

Not surprisingly because of this overlap, 8 of the 10 most common sequences were simply pairs. The remaining 2 were trios. Results also indicated that a significant portion of the most common sequences involved repeated activity within the same class. The most common sequence was back-to-back *Project Management* segments, which occurred 795 times in the whole sample. An example of this (6,6) sequence can be seen in Figure 5.2. It is quite common to find sections of journals that contain a collection of short *Project Management* segments consecutively. These typically involve things which must be done next. Back-to-back *Analysis* segments were just behind with 769 occurrences, with a more noticeable drop off for the 3rd highest back-to-back *Information Seeking and Noting* segments with 511 occurrences.

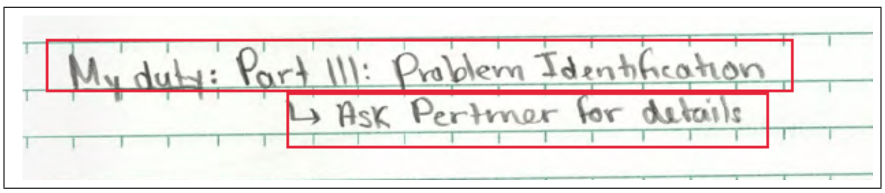


Figure 5.2 – Example of a (6,6) sequence

There were a few distinct breakpoints in this data. The largest drop off occurs after the top two sequences. Another noticeable drop occurs after the fifth, and again after the tenth and fourteenth. From there on it follows a more steady decline. The 50 most common sequences can be seen along with their frequencies in Figure 5.3. Meanwhile Table 5.2 contains how often segments belonging to each activity class were included in the 50 most common sequences. Each column lists the amount of times a class was recorded in specific position of a sequence. For example, the first column is the amount of times each class was recorded first in a sequence.

In 11 of the 50 most common sequences an *Analysis* segment was the first

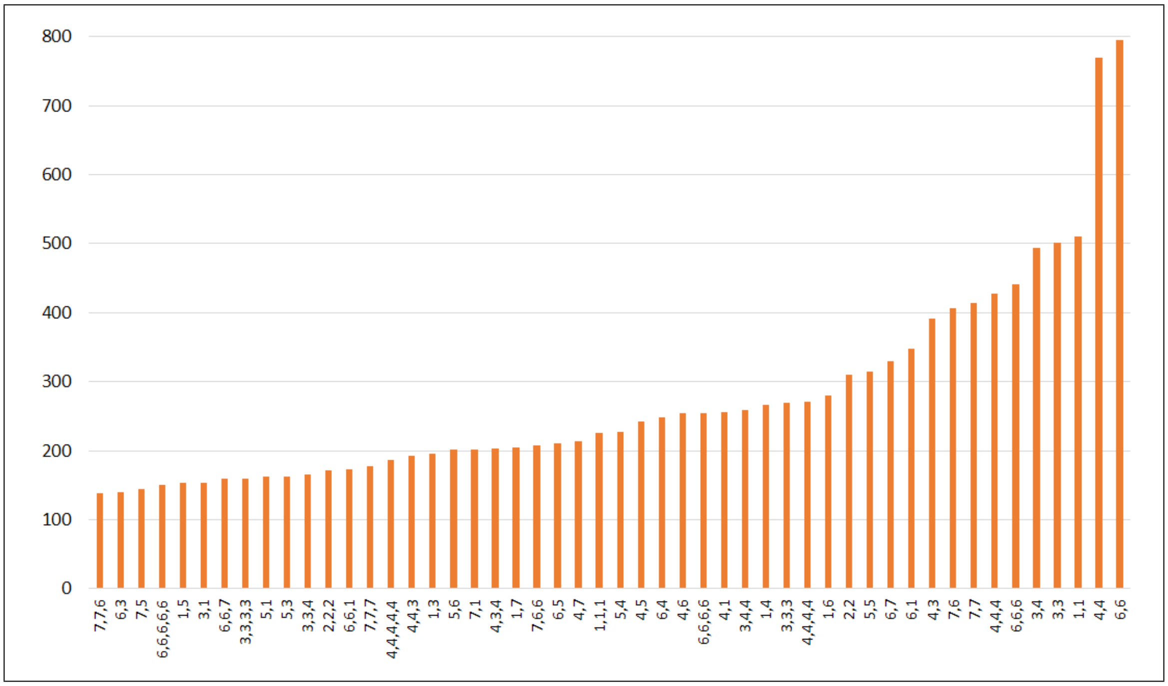


Figure 5.3 – Histogram of the 50 most common activity sequences

activity recorded. Similarly, *Decision Making* was the second action recorded in 5 of the 50 most common sequences. Also included in the table are the unique and total counts for each class. Unique count is number of times that a class was recorded at least once in a sequence, so in a sequence like (6,7,6) both *Project Management* (6) and *Reflection* (7) would have a unique count of 1. Total count on the other hand is the absolute count, so the same sequence would count twice for *Project Management* (6) and once for *Reflection* (7).

It was also observed that *Analysis* and *Project Management* were the classes which occurred most often in these sequences, both appearing in 17 of the 50 identified (not exclusively the same 17, though some overlap did exist). They also both were recorded the most in any position of a sequence, each having 30 appearances total. They were both equally likely to initiate a sequence. What is particularly

Table 5.2 – The number of instances that each activity class was performed at a specific sequence position (among the 50 most common sequences)

Class	Instances per Sequence Position						Unique Count	Total Count
Info. Seeking & Noting	7	7	2	0	0	0	13	16
Problem Understanding	2	2	1	0	0	0	2	5
Idea Generation	7	9	3	1	0	0	13	20
Analysis	11	10	6	2	1	0	17	30
Decision Making	5	5	0	0	0	0	9	10
Project Management	11	11	5	2	1	0	17	30
Reflection	7	6	2	0	0	0	11	15
Other	0	0	0	0	0	0	0	0
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**		
	Position within Sequence							

interesting about these two classes being so similar in this analysis method is that they shared one of the largest negative relationships in the Spearman correlation coefficient measurements. In conjunction with that information, the data corroborates that students are likely to either focus on runs of activity which involve some amount of *Analysis* or runs of activity involving *Project Management*, but not both. Only 2 of the 50 most common sequences contained both classes, which is quite remarkable considering both were a part of 17 of the 50 most common sequences.

No activity classified in the *Other* category occurred among these most frequent of sequences, which is not surprising considering how little of the total sample it accounts for. The least featured of the remaining classes was *Problem Understanding* which only a part of 2 sequences. Those sequences were simply the pair and trio of repeating *Problem Understanding* segments. In fact, sequences exclusively consisting of repetition of a single class were 18 of the 50 most frequent and 7 of the

10 most frequent sequences.

The amount that each class was present in the 50 most frequent sequences was largely the same as the average proportions for each class (from Table 4.10). This is worth noting because it indicates that even though certain classes seem to be so predominant in the very top end of sequences, they are actually consistent throughout the data. The largest difference from top sequence proportions to average proportions was *Project Management* which represented 6% more of the segments in the sequences than in the overall data. This indicates that *Project Management* has a particularly strong relationship with being a part of the most common sequences. One interpretation of this would be that *Project Management* activities are more likely to be recorded in conjunction with related neighboring segments than on its own.

5.3 Patterns in Condensed Activity Classes Sequences

Additional Python [93] code was developed [94] to address the heavy dominance of sequences which involve consecutive segments repeating the same activity class. This additional code can be found in Appendix C.3. In the new code segments are not registered until there is a change in activity class. In essence this is condensing the dataset to treat all consecutive segments with the same activity class instead as a singular segment.

As an example: if in the original dataset there was a sequence of (4,3,4), a sequence of (4,4,3,4), and a sequence of (4,3,3,4), these would all be counted as instances of (4,3,4) in this condensed dataset. Furthermore, another sequence of (4,4,3,3,4,4) would also be counted as an instance of (4,3,4).

By condensing all instances of consecutive repeated activity, the total amount of segments dropped by over half to 7,931 segments. The 10 most frequent sequences of any size were still dominated by pairs, which accounted for 8 of them. No classes were added or removed from inclusion in the upper echelon of sequences.

Table 5.3 – The most common activity class sequences for two, three, four, and five segments along with the number of instances (N) for each using the condensed dataset

Rank	N	Pairs	N	Trios	N	Quartets	N	Quintets
1st (most)	494	(3, 4)	277	(3, 4, 3)	230	(3, 4, 3, 4)	160	(3, 4, 3, 4, 3)
2nd	407	(7, 6)	271	(4, 3, 4)	175	(4, 3, 4, 3)	153	(4, 3, 4, 3, 4)
3rd	391	(4, 3)	178	(6, 7, 6)	86	(7, 6, 7, 6)	44	(6, 7, 6, 7, 6)
4th	348	(6, 1)	153	(7, 6, 7)	66	(6, 7, 6, 7)	35	(7, 6, 7, 6, 7)
5th	330	(6, 7)	133	(6, 1, 6)	55	(6, 1, 6, 1)	30	(4, 1, 4, 1, 4)
6th	280	(1, 6)	106	(1, 4, 1)	51	(1, 4, 1, 4)	30	(1, 4, 1, 4, 1)
7th	266	(1, 4)	103	(4, 1, 4)	49	(4, 1, 4, 1)	24	(7, 6, 7, 6, 1)
8th	256	(4, 1)	101	(1, 6, 1)	48	(6, 7, 6, 1)	23	(6, 7, 6, 1, 6)
9th	255	(4, 6)	94	(7, 6, 1)	44	(7, 6, 1, 6)	22	(6, 1, 6, 1, 6)
10th	248	(6, 4)	94	(4, 5, 4)	41	(5, 4, 5, 4)	21	(3, 4, 3, 4, 7)

Activity class legend:
1)*Information Seeking & Noting* 2)*Problem Understanding* 3)*Idea Generation* 4)*Analysis* 5)*Decision Making* 6)*Project Management* 7)*Reflection* 8)*Other*

The histogram for the 50 most common sequences in the condensed dataset can be found in Figure 5.4. For example the (2, 4) sequence was recorded just shy of 100 times.

The frequency of appearances among the most common sequences was tabulated and can be found in Table 5.4. Table 5.3 contains the most common two, three, four, and five part sequences. Perhaps most interesting in comparison of the two tables is how many of the values are either the same or very close to it. *Project*

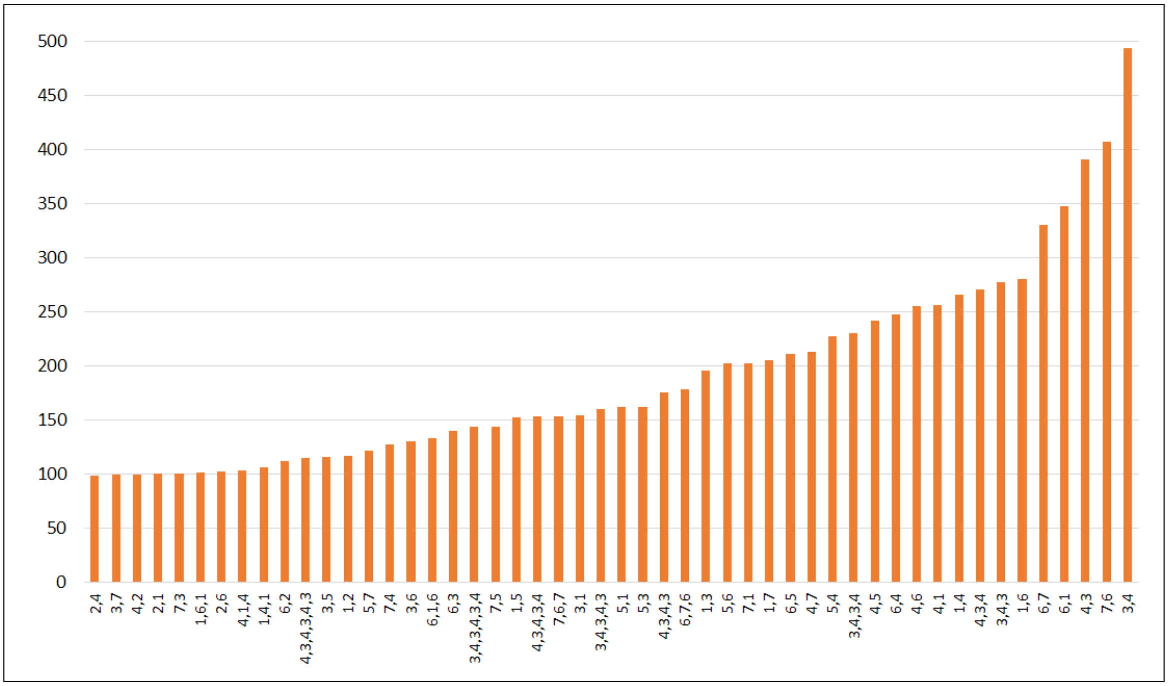


Figure 5.4 – Histogram of the 50 most common activity class sequences in the condensed dataset

Management fell from 23.8% to 14.3% of segments, while *Idea Generation* rose from 15.9% to 22.2%. The remainder of activity classes were quite consistent regardless of whether using the original or condensed dataset.

In the condensed data, *Analysis* is exclusively the most prevalent class and the most likely class to initiate the most common sequences. *Project Management* was affected the most by excluding repetition. There are much more noticeable differences from the average proportions of classes. *Idea Generation* had the largest change, holding a 6% larger proportion of activity in comparison to the data as a whole.

Table 5.4 – The number of instances that each activity class was performed at a specific sequence position in the condensed dataset (among the 50 most common sequences)

Class	Instances per Sequence Position						Unique Count	Total Count
Info. Seeking & Noting	8	8	2	0	0	0	16	18
Prob Understanding	3	3	0	0	0	0	6	6
Idea Generation	9	9	4	3	2	1	18	28
Analysis	11	11	5	3	2	1	22	33
Decision Making	5	5	0	0	0	0	10	10
Project Management	8	8	2	0	0	0	16	18
Reflection	6	6	1	0	0	0	12	13
Other	0	0	0	0	0	0	0	0
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**		
	Position within Sequence							

5.4 Impact from Segment Count

The sequence tracking code was also run using the same sample subgroups created for Section 4.5 to determine if different sequences of activity were being employed by individuals at different ends of the segment count spectrum. As before all sequences were fully explored but particular emphasis was placed on the 10 most frequent from each subgroup for comparative purposes which can be found in Table 5.5.

The findings were that the groups had more in common than not. The 10 most frequent sequences shared a large amount of overlap despite the vast differences in segment count. In the condensed dataset the groups deviated from each other a bit more, but still had some overlap.

Due to having a low segment count to begin with it is not surprising that the condensed dataset for the low segment count lacked many of the unique combinations

Table 5.5 – Impact of segment count on sequences

Rank	Segment Count Subgroup		
	Top 5	Mid 5	Bottom 5
1st (most)	(6, 6)*	(4, 4)*	(6, 6)*
2nd	(6, 6, 6)*	(6, 6)*	(4, 4)*
3rd	(6, 1)	(3, 4)*	(7, 7)*
4th	(7, 6)*	(3, 3)*	(3, 3)*
5th	(1, 1)*	(4, 4, 4)*	(7, 6)*
6th	(6, 6, 6, 6)	(4, 3)*	(6, 4)
7th	(1, 6)	(1, 1)*	(3, 3, 3)
8th	(6, 7)	(7, 7)*	(4, 6)
9th	(3, 3)*	(7, 6)*	(1, 1)*
10th	(7, 7)*	(5, 5)	(6, 7)

*also present in study-wide 10 most frequent sequences

found in the study-wide data. Largely though it seems that even these segment outlier journals follow many of the same patterns in activity.

5.5 Conclusions

By surveying journal data for common sequences in activity several determinations have been made. Chains of the same activity being repeated consecutively are dominant among sequences. Even repeating sequences made up of less frequent classes are among the most common sequences overall.

In particular consecutive *Project Management* segments were the most common, with consecutive *Analysis* segments being a close second. Consecutive *Analysis* segments were the most frequent when looking for longer sequences involving four or more segments. It is not surprising that consecutive segments are the most common sequences, especially *Project Management*. In journals *Project Management* segments were observed as rarely being isolated. It is typical to find a section of page containing several *Project Management* segments that are all concurrent.

Condensing consecutive segments which belonged to the same class into a single segment reduced the total segment count by nearly half. This may be an indication that the methodology for how journals are segmented should be adjusted. Under the current segmenting methodology, however, it indicates that repetition within the same activity class is a critical aspect of design for capstone students.

To an extent this goes against the findings of other design studies which have found expert designers made use of rapid shifts in activity to solve design problems [69–71]. Part of the difference could be the fact that the subjects in this study were all novices still in training and as such may not be making the most efficient pathways through their work. Assessing whether the most common activity sequences by expert designers is similar to capstone students in a future study could yield considerable information.

How prevalent activity classes were among top sequences was mostly unaffected whether viewing the original dataset or the condensed version. The only class whose presence among the most common sequences was notably affected was *Project Management*.

The frequency of activity sequences were also largely unaffected by a journal's total segment count. Students with the most, the least, and the median amount of segments were compared and it was found that the groups still utilized many of the same sequences. This validates low segment journals being included in the study sample.

One minor limitation of this approach is that there is no distinction made between when one session or journal ends and another begins. While this undoubtedly will have added some instances of sequences into the final numbers, it is expected to only represent a very small portion of the total sequences and not believed to have meaningfully changed the order of the top sequences.

Chapter 6: Team Analysis

The work discussed in this chapter is focused on answering part of Research Question 3, which asks what journals can indicate about how an individual's activity relates to their team. Throughout this chapter the journal data discussed will be a subset of the overall sample. The data used here is refined to the 13 teams, 5 which include journals from all members and 8 which are missing only one member's journal. These teams are comprised of a total of 66 journals.

Material detailed in this chapter was included in a paper to be presented at the 2018 ASME IDETC/CIE conference, and also is at the time of this writing currently under review with the Journal of Mechanical Design as part of their IDETC/CIE selected works special issue [85].

Section 6.1 pertains to a number of statistical tests which were performed using team averages. Section 6.2 details methods and findings for comparing members of the same team, while Section 6.3 involves methods and findings for comparing teams to other teams. Section 6.4 contains the conclusions for this data.

6.1 Team-Based Statistical Analysis

Work in Section 4.4 indicated that the frequency of journal segments by activity class in individual journals are non-parametric in nature. Averaging the class frequencies for the members of a team and repeating for each of the 13 teams produces a set of 13 samples. These can be used in conjunction with the central limit theorem to explore normal distributions for each activity class. The averages for each team can be found in Table 6.1. Also included are the To confirm normality, the Shapiro-Wilk test was performed on each class again using these 13 team averages. This time all 8 classes produced p-values greater than $\alpha = 0.05$, indicating no reason to reject the null hypothesis that the samples indeed belong to a normal distribution.

The values found in the "*Avg*" and "*StdDev*" rows of Table 6.1, along with the knowledge that the team averages were normally distributed, were used to make distributions for each class. The kurtosis values for each class's normal distribution were calculated and can also be found in Table 6.1. Figure 6.1 visualizes the class distributions, providing a look at just how much variation there is probabilistically for the frequency of each class. Note that the distribution for *Other* activity was left out of Figure 6.1 due its kurtosis value over 13 which negatively impacted the chart's visibility.

Table 6.1 – Average frequencies of activity class segments per journal for each team along with the overall sample average and standard deviation. The left most column indicates how many members of the team size were included in each team's average (n of m).

Team (n **of** m)	**Info** (%)	**Prob** (%)	**Idea** (%)	**Anlys** (%)	**Decs** (%)	**PM** (%)	**Refl** (%)	**Other** (%)
$T2$ (5 of 5)	22.82	13.54	19.62	21.46	3.98	8.66	8.03	1.89
$T3$ (4 of 5)	10.28	8.41	8.85	35.17	9.22	19.18	8.21	0.68
$T5$ (6 of 6)	11.63	11.18	15.18	19.45	11.16	18.28	10.91	2.20
$T6$ (6 of 6)	11.35	6.52	12.66	23.36	11.19	16.99	17.13	0.78
$T7$ (6 of 6)	22.20	9.51	9.03	11.94	6.08	28.36	12.34	0.56
$T8$ (5 of 6)	21.19	6.81	16.61	20.50	9.52	13.43	10.01	1.92
$T9$ (5 of 6)	17.95	4.75	22.70	12.42	8.31	26.09	6.49	1.29
$T11$ (5 of 6)	26.26	4.57	13.32	10.20	12.77	16.11	16.02	0.74
$T13$ (5 of 6)	6.92	4.71	13.61	30.63	18.24	17.96	5.54	2.39
$T14$ (6 of 6)	7.73	2.86	8.06	19.24	12.27	27.68	22.16	0.00
$T15$ (5 of 6)	5.03	1.29	20.17	34.15	9.13	9.21	20.56	0.46
$T17$ (4 of 5)	9.52	9.67	13.86	34.34	6.47	17.06	5.15	3.93
$T18$ (4 of 5)	5.65	10.63	16.22	39.82	7.54	13.05	6.45	0.64
Avg	13.73	7.27	14.61	24.05	9.68	17.85	11.46	1.35
StdDev	7.35	3.59	4.50	9.84	3.62	6.34	5.78	1.08
Kurtosis*	3.74	8.93	7.68	-0.40	8.88	5.18	5.96	13.13

**Kurtosis of the activity class's underlying normal distribution*

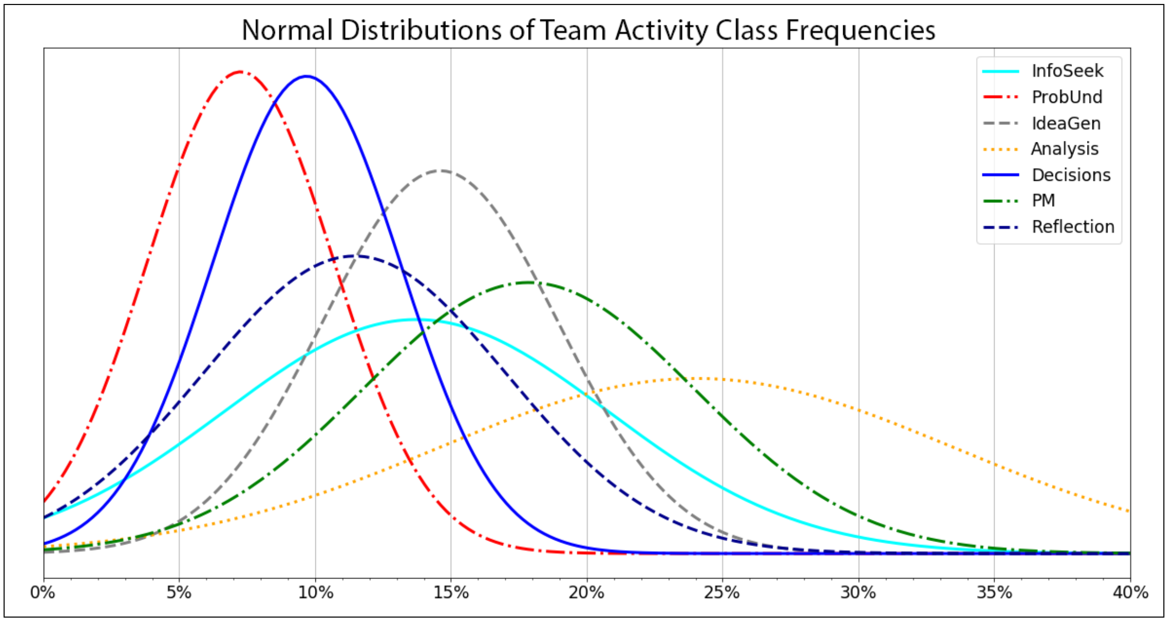


Figure 6.1 – Normal distributions based on the sample average and standard deviation for each of the design activity classes. *Other* has been left out due to extreme kurtosis.

6.1.1 Discussion of Results

The means made from the 13 team averages were very close to the averages derived from all 83 journals. Table 6.2 compares the averages and standard deviations for class frequencies for the teams, the study wide sample, and the journals that were not included in this chapter's team data. No class deviated from the sample wide average by more than 1.48%, and 7 of the 8 classes were within 1% if not a fraction of a percent.

From Table 6.1 and Figure 6.1 it can be observed that *Problem Understanding* (13.73% average) and *Decision Making* (9.68% average) were not only the two least common of the primary 7 classes, but also the two classes with the least amount of variation. *Problem Understanding* accounting for less than 10% of recorded sgements

Table 6.2 – Comparison in activity class averages and standard deviation for journals in teams, all journals, and journals not included in teams

Sample Subgroup	Stat	Info (%)	Prob (%)	Idea (%)	Anlys (%)	Decs (%)	PM (%)	Refl (%)	Other (%)
Journals from Teams	*Avg*	13.73	7.27	14.61	24.05	9.68	17.85	11.46	1.35
	StdDev	7.35	3.59	4.50	9.84	3.62	6.34	5.78	1.08
All Journals	*Avg*	14.05	7.40	16.09	23.13	9.23	17.62	11.30	1.18
	StdDev	8.89	5.15	9.51	12.79	6.23	9.46	9.75	2.03
Journals not from Teams	*Avg*	14.50	8.25	22.34	23.04	7.03	15.29	8.84	0.72
	StdDev	8.25	6.54	11.02	12.81	6.88	6.01	6.22	1.20

corroborates the findings in Atman's work which found students doing substantially less problem scoping than professional designers [73].

Reasons for why *Problem Understanding* is so low in students is that capstone students may be performing a non-trivial amount of problem understanding before deciding their project prior to the semester's start. It could simply be that as an activity class it primarily exists only in the beginning of the project (this will be discussed further in Chapter 8. All of these possibilities could further mean that once students have reached what they deem to be an sufficient amount of understanding they abandon the activity. On the other hand, *Decision Making* is very likely to suffer from journals simply being a poor medium for capturing that type of activity.

It was surprising that *Idea Generation* was found to be in the middle of the pack of activity proportions with an average of 14.61%. Before results were found it was thought that this would be the dominant class. Some *Idea Generation* takes place outside of journals in homework assignments. While some participants included some of this work inside of their journals, not all did. This may also indicate that journals are simply better at capturing activity from the remaining three classes or that perhaps *Idea Generation* segments have a higher information density, as a large deal of these segments involve sketches. As the saying goes "A picture is worth a thousand words", so fewer segments may not equate to less information when it comes to sketches and diagrams.

Project Management (17.85% average) and *Analysis* (24.05% average), not only had the highest maximums in terms of frequency but also had the highest minimums. This seems logical in that journals do well at capturing a large deal of activity in these areas such as task assignment and inventories for *Project Management* or calculations and testing procedures for *Analysis*. It is logical that *Project Management* is one of the most common activity classes observed in journals. Capstone courses, and the professional work they emulate, involve a great deal of project management from start to finish. It was unexpected to find that not only was *Analysis* the most common activity class, but that it was by a considerable enough margin. One potential explanation is that regardless of any possible role preferences individual students may have, the nature of engineering projects necessitates that all team members partake in a certain amount of analysis work.

6.2 Inter-team Comparisons

By calculating areas of focus (as discussed in Section 4.2) across an entire team it is possible to see whether and to what extent members of the same team performed different aspects of their project. This type of chart was created for every team in the study as a method to quickly compare members of a team.

An example of this can be seen in Figure 6.2, where all the members from the $T7$ have been superimposed over each other.

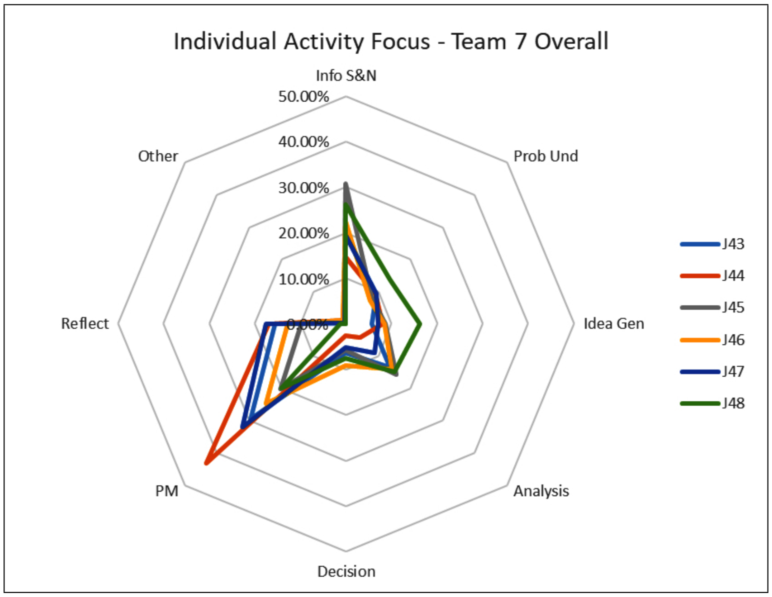
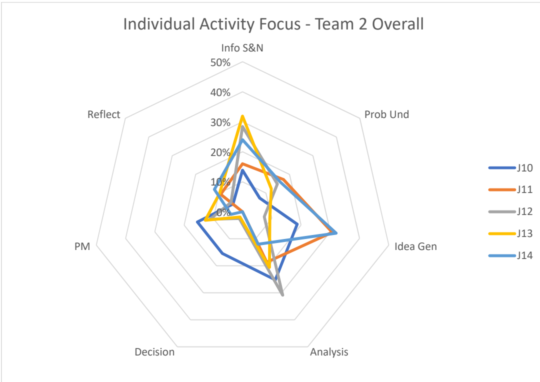


Figure 6.2 – Focus distributions for members of $T7$ superimposed on each other

Note once more that these values are all relative to each of their individual segment counts, so in doing this each member of a team is evaluated only by their own total segment count. For example, *Reflection* accounts for around 17% of segments for both $J44$ and $J47$. For $J44$ this was 80 segments of a possible 471. However, for $J47$ who recorded less total entries this was only 47 of a possible 268 segments.

The plots for all teams (and at all time intervals) can be found in the following pages.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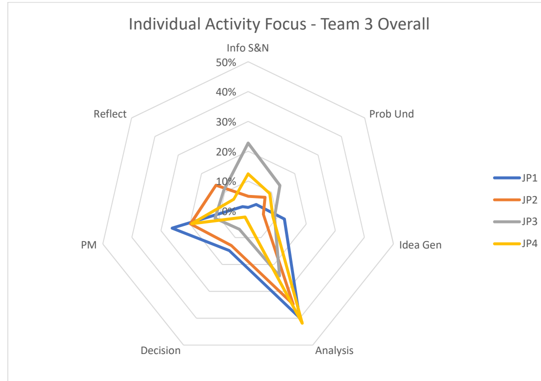
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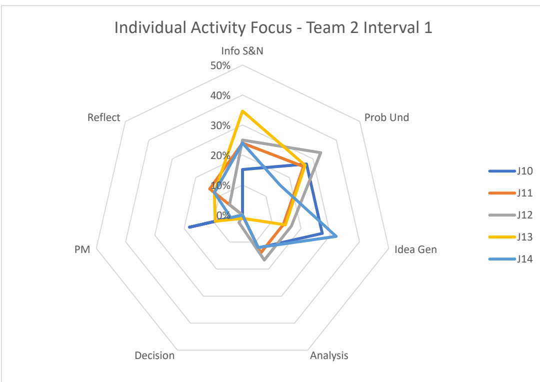
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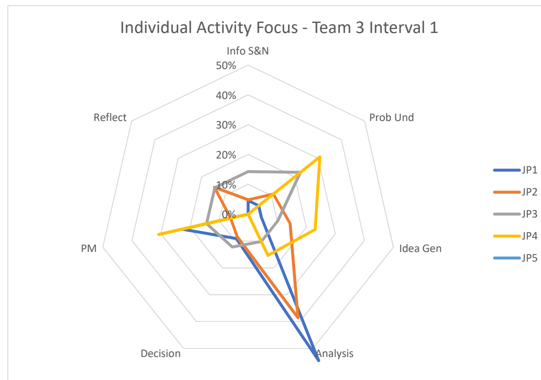
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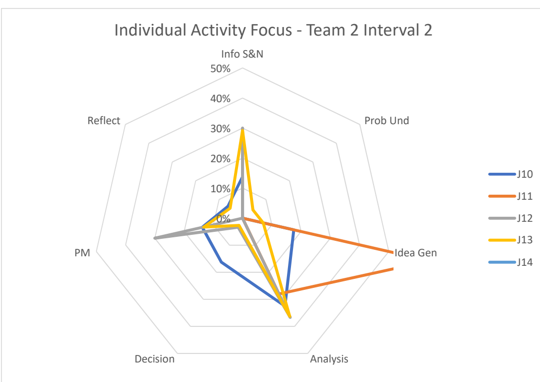
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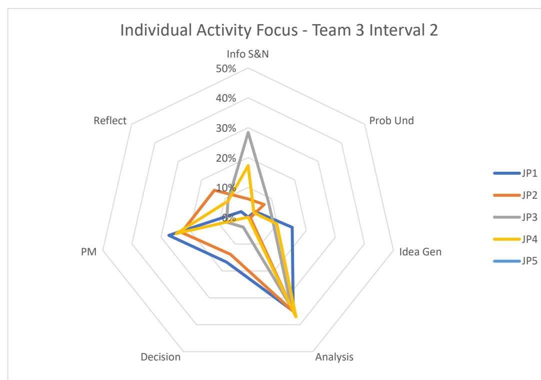
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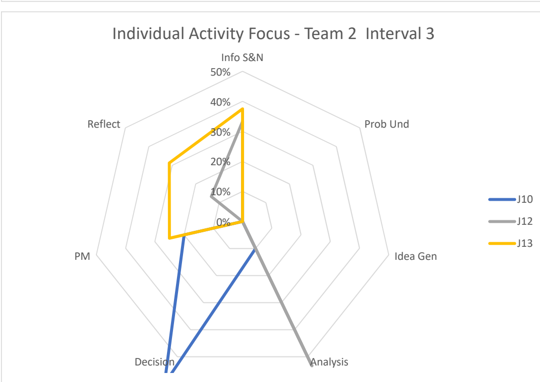
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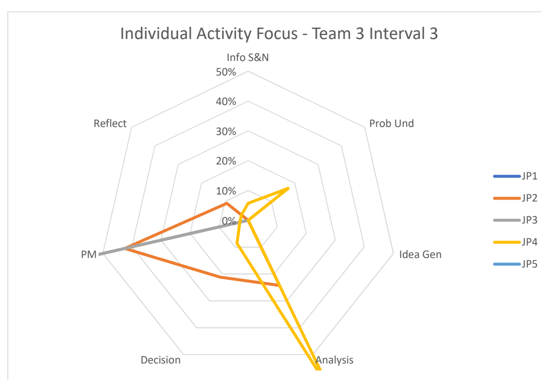
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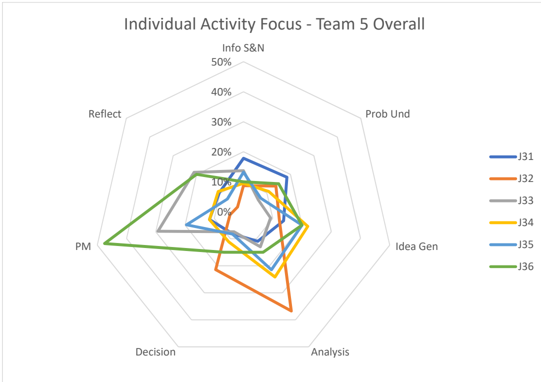
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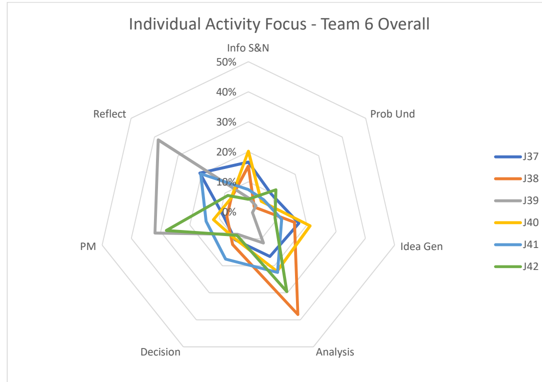
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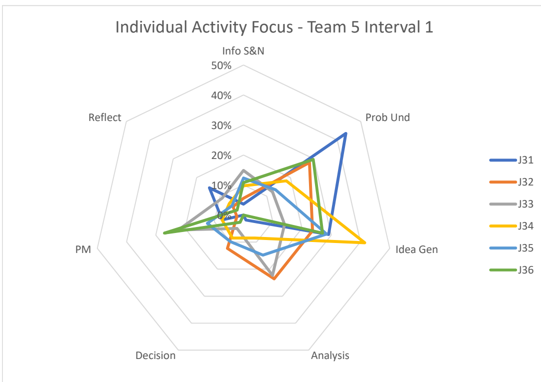
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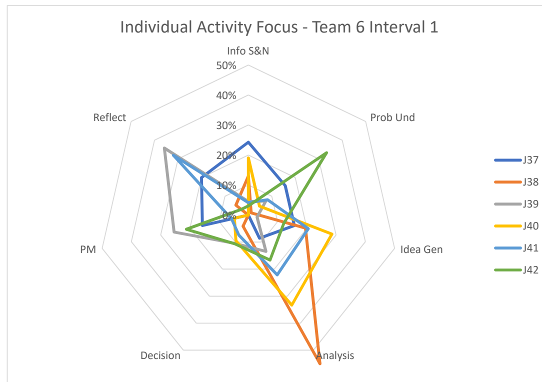
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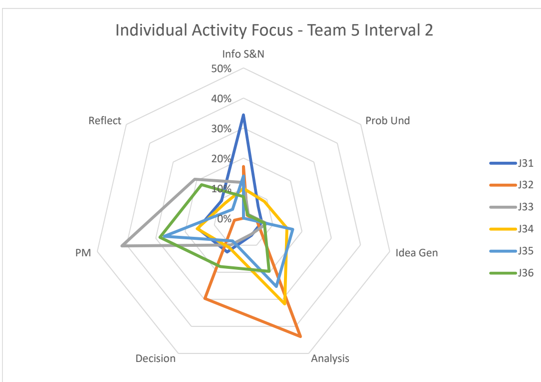
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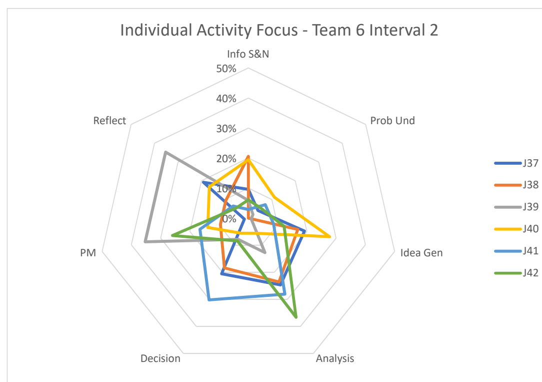
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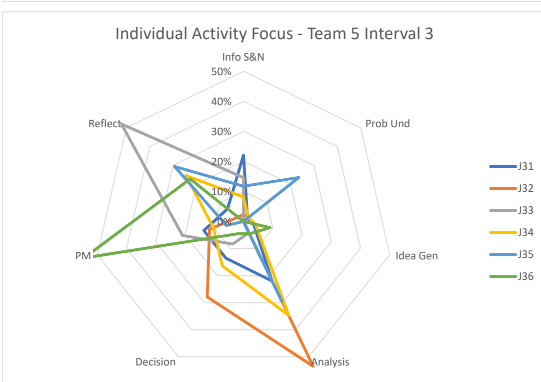
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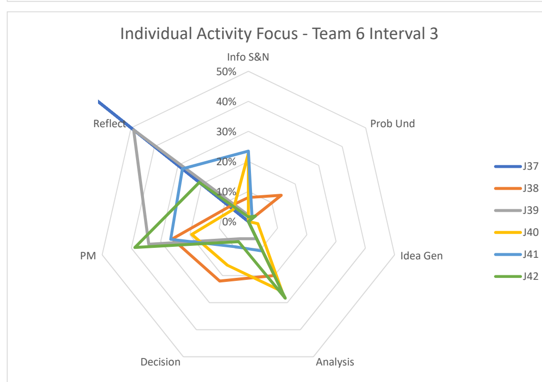
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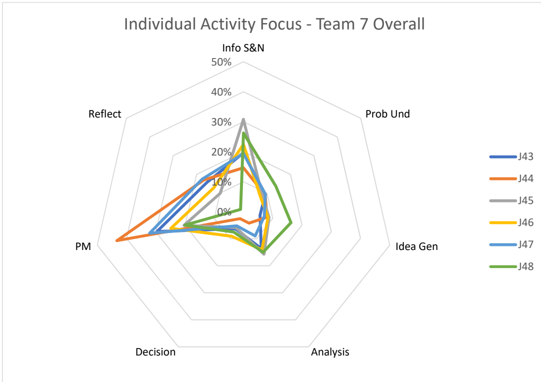
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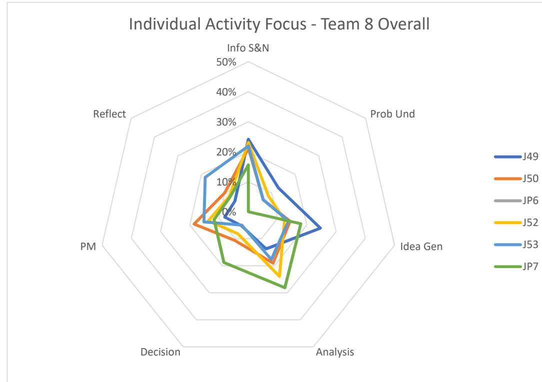
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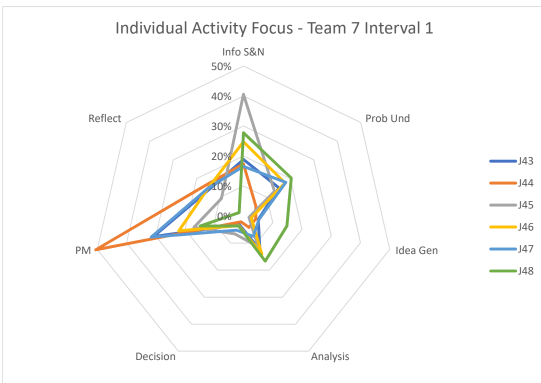
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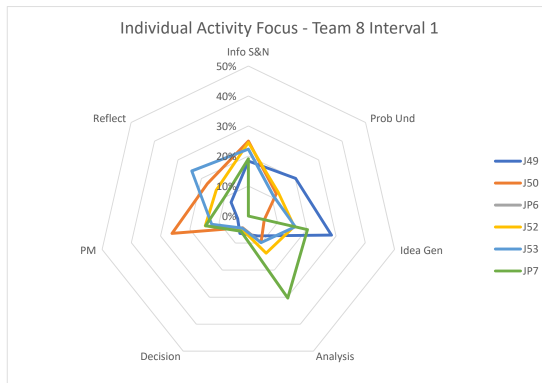
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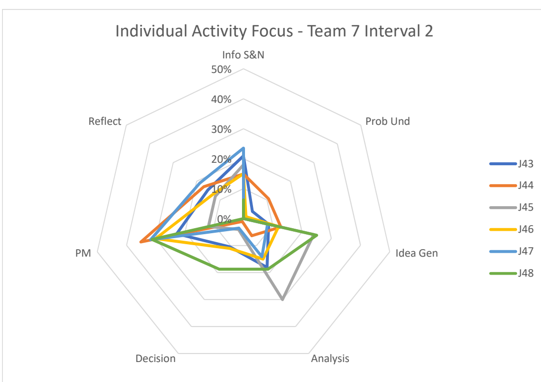
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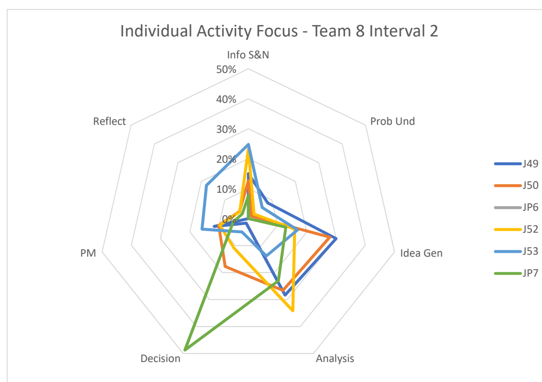
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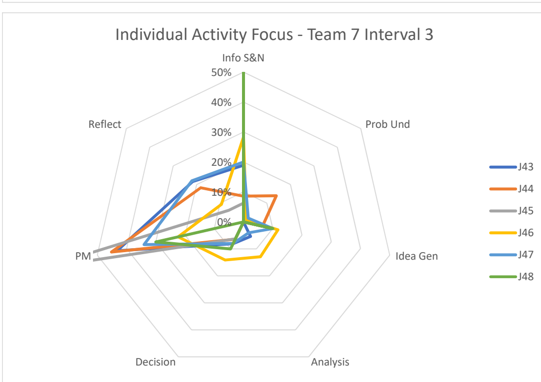
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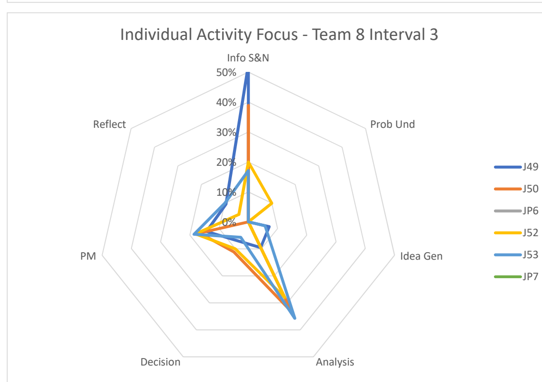
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Info S&N
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Analysis
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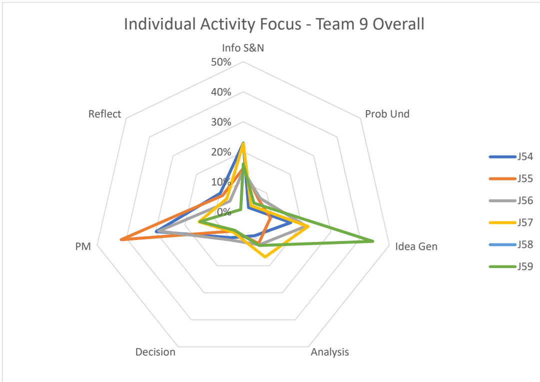
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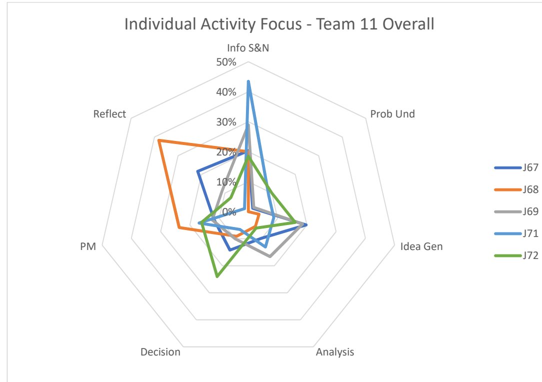
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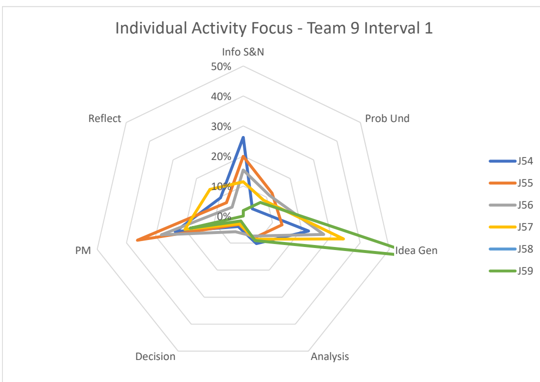
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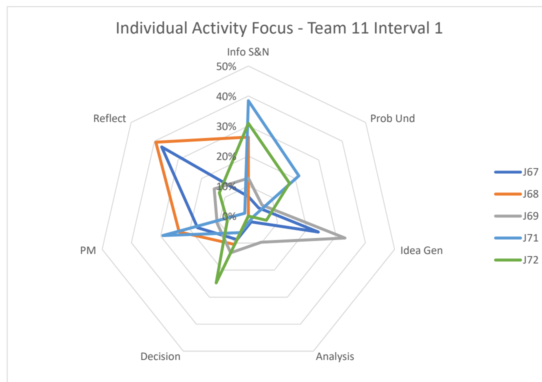
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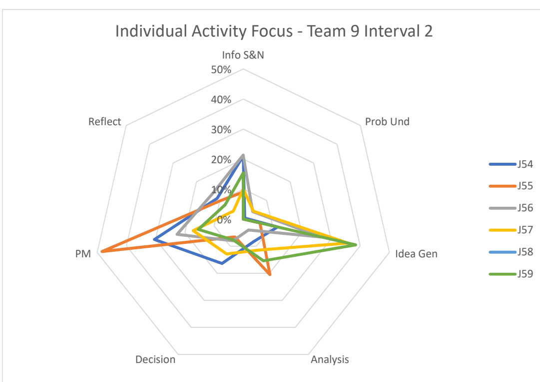
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Idea Gen
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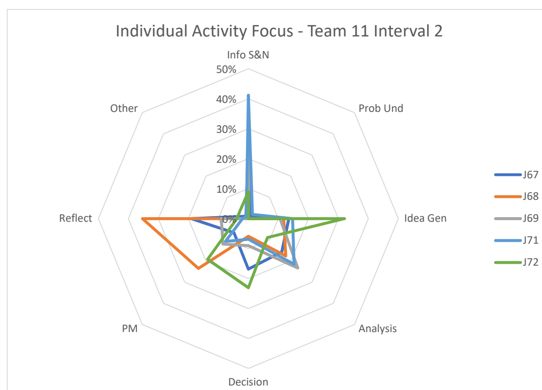
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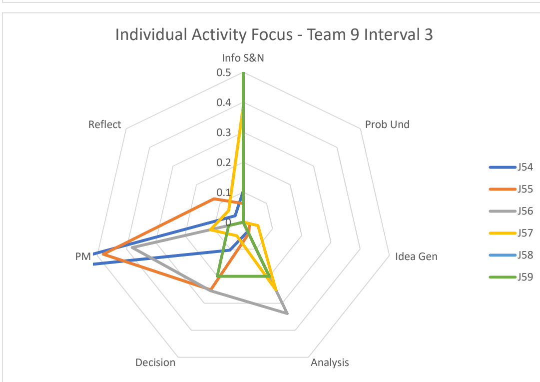
Individual Activity Focus - Team 9 Interval 3
Info S&N
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Analysis
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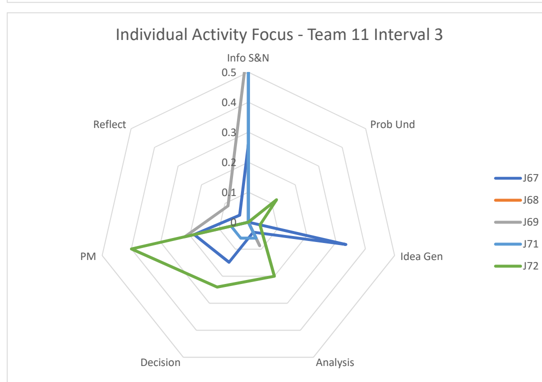
Individual Activity Focus - Team 11 Interval 3
Info S&N
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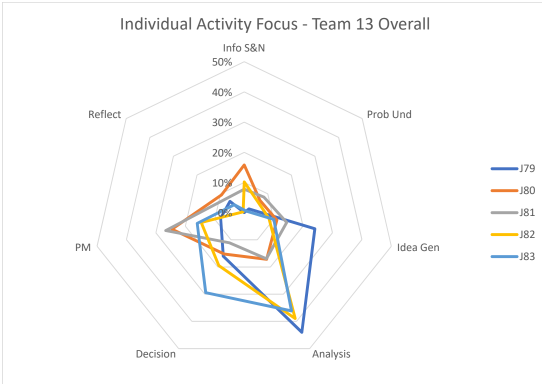
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Decision
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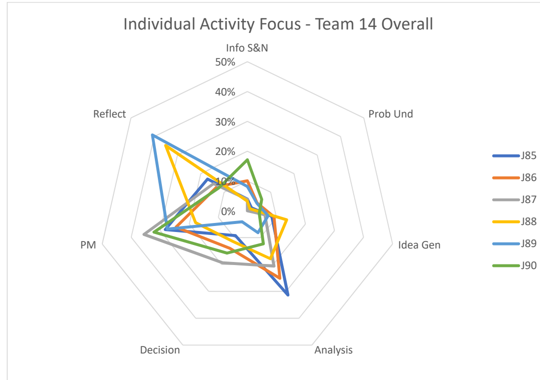
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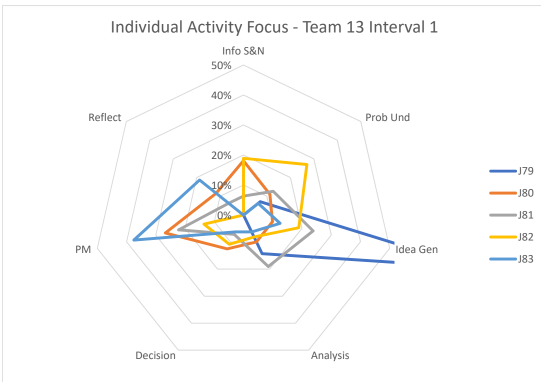
Individual Activity Focus - Team 13 Interval 1
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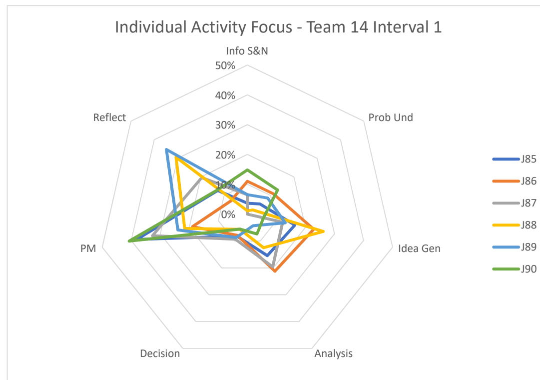
Individual Activity Focus - Team 14 Interval 1
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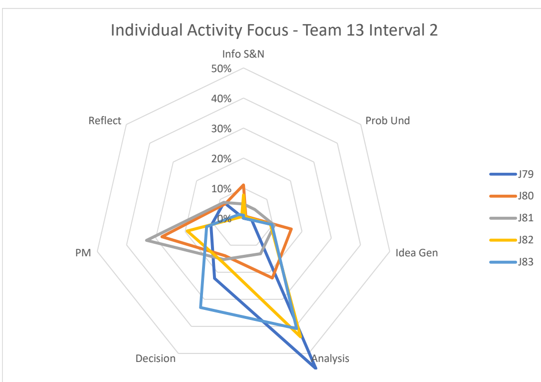
Individual Activity Focus - Team 13 Interval 2
Info S&N
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Idea Gen
Analysis
Decision
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Reflect
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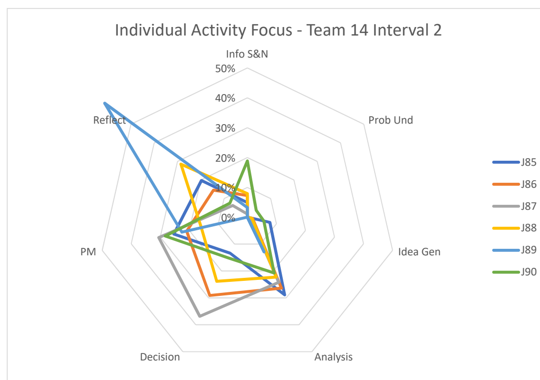
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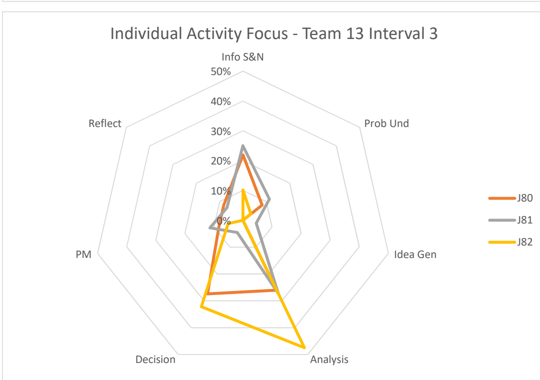
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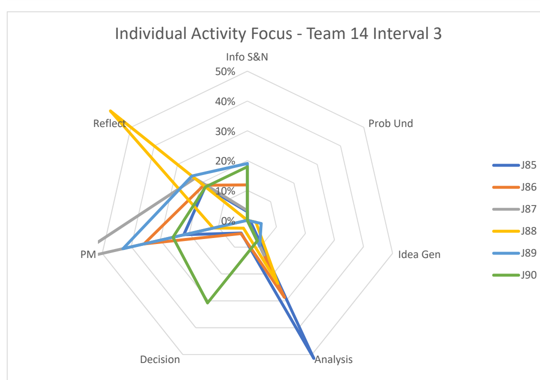
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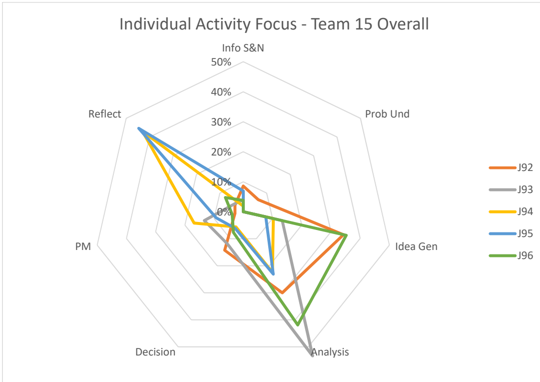
Individual Activity Focus - Team 15 Overall
Info S&N
Prob Und
Idea Gen
Analysis
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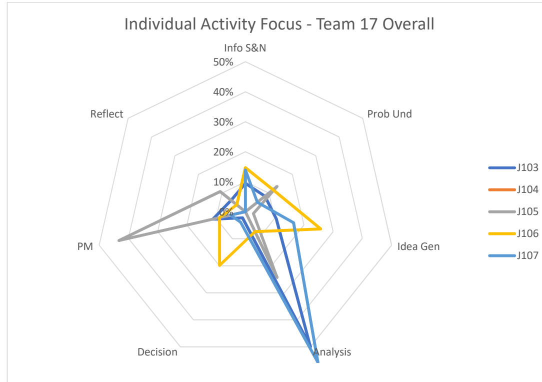
J93
J94
J95
J96


Individual Activity Focus - Team 17 Overall
Info S&N
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Idea Gen
Analysis
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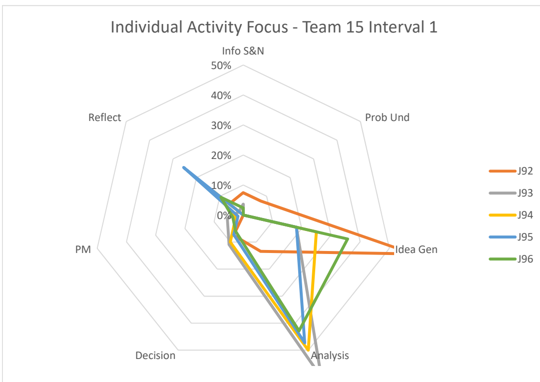
J103
J104
J105
J106
J107


Individual Activity Focus - Team 15 Interval 1
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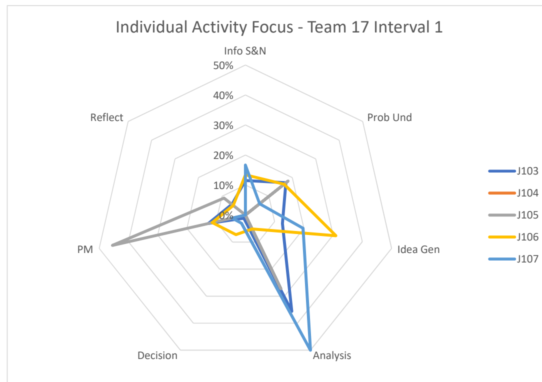
Individual Activity Focus - Team 17 Interval 1
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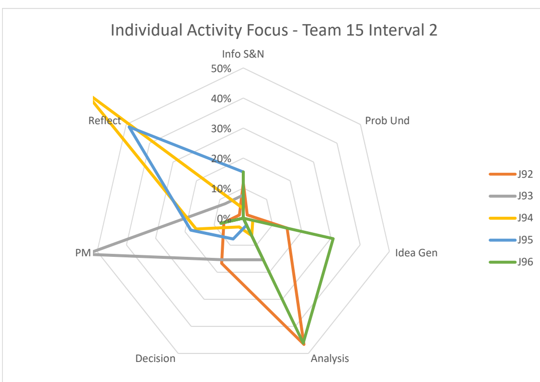
J104
J105
J106
J107


Individual Activity Focus - Team 15 Interval 2
Info S&N
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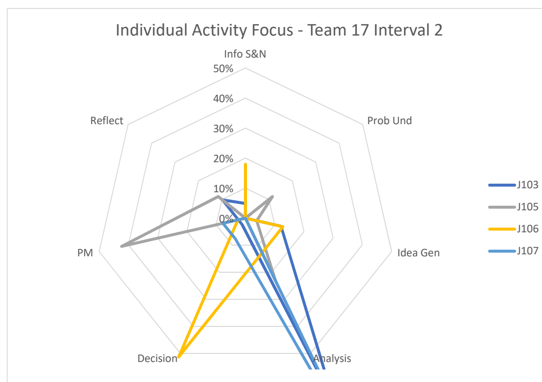
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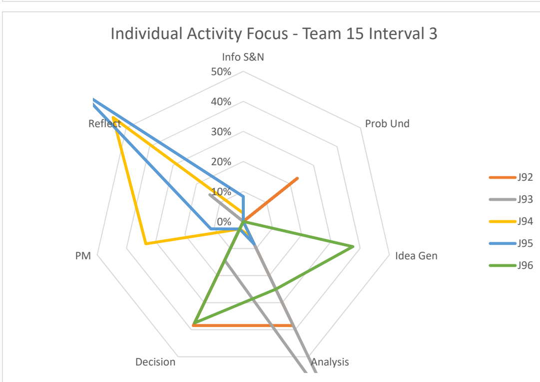
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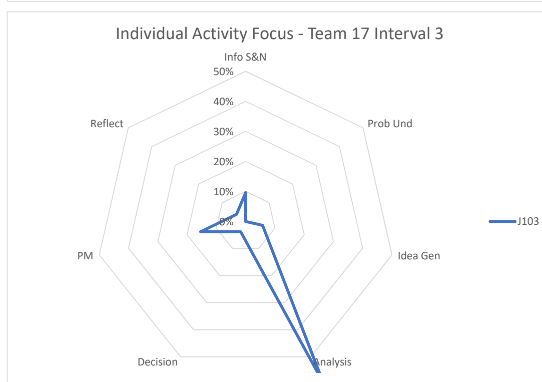
Individual Activity Focus - Team 17 Interval 3
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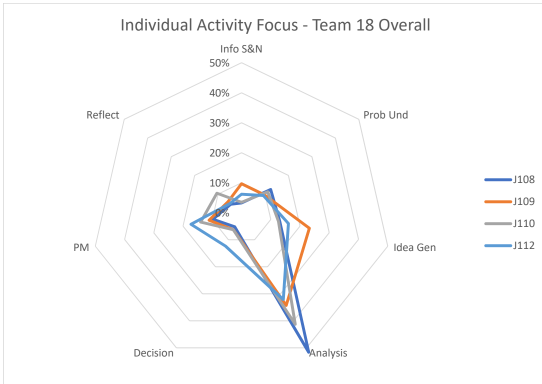
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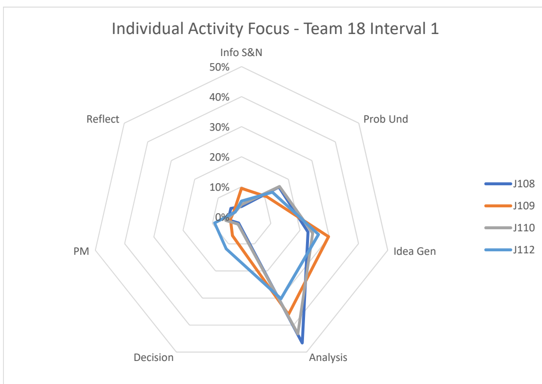
J112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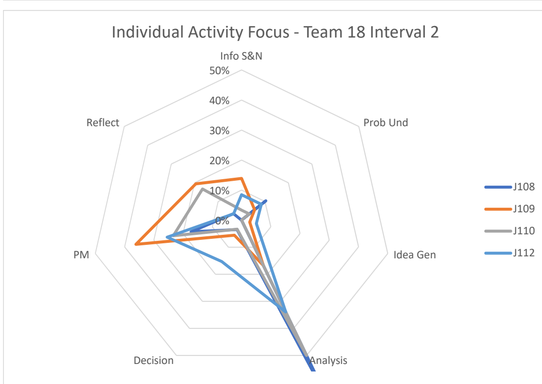
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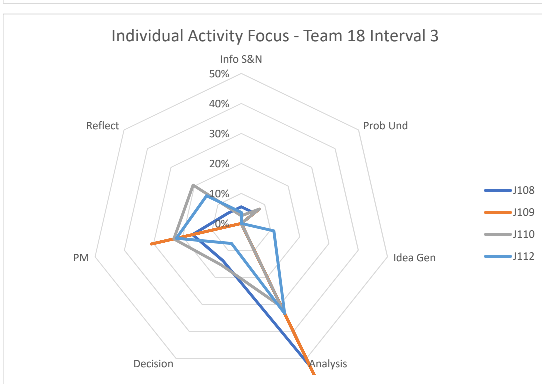
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J108
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6.3 Intra-team Comparisons

Just as the radar plots could be used to quickly draw comparisons between members of a single team, so too can they be used to quickly draw comparisons between multiple teams. Since these charts were already created, one simply need put them side by side as in Figure 6.3 to highlight the stark difference between some teams.

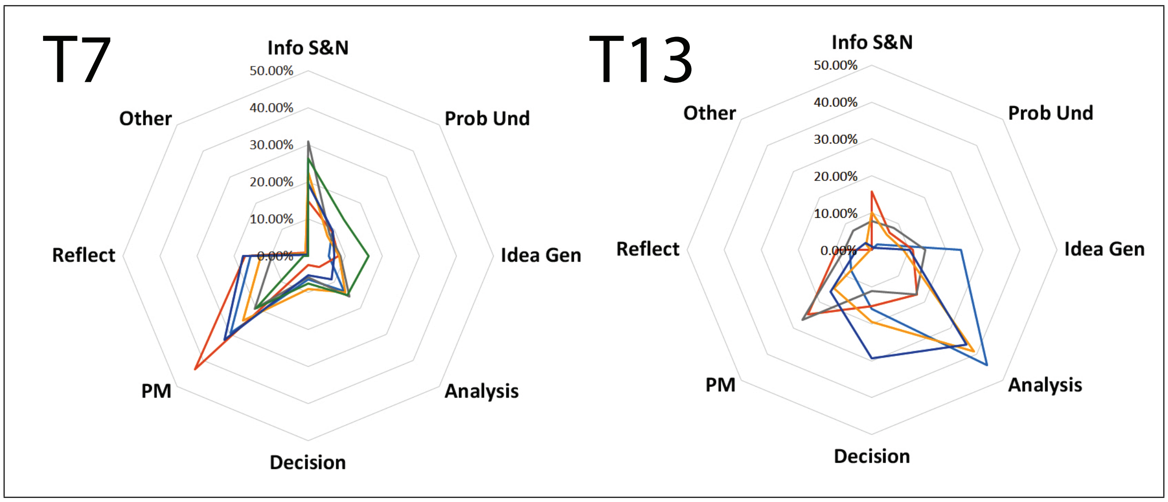

Figure 6.3 – Semester-long activity proportions for the members of two different teams, $T7$ and $T13$

In this comparison between $T7$ and $T13$ it is apparent that one team very closely mirrored each other in how they allocated their journal activity while the other had a few team members each focusing on a few different areas.

The team charts found in the previous section are also used to make these comparisons.

3 of the 13 teams exhibited the highly aligned team behavior demonstrated by $T7$. These teams did not align in the same way though. Another 3 exhibited

partial alignment, as in $T13$ where several members have utilized a similar The final 7 teams exhibited no noticeable alignment in recorded activity.

A chi-squared test was also performed to test whether a journal's class frequencies were independent of the team the journal belonged to. In other words, finding if there is a correlation between teams and activities recorded.

When setting up this test absolute segment counts are used instead of percentages, since in a chi-squared test the expected values per class are found relative to each team's total number of segments.

The results from this test were that 3 of the 8 classes exceeded the chi-squared critical value. This indicates that the frequency that an individual records *Information Seeking & Noting*, *Analysis*, and *Project Management* is dependent on the team they belong to. This could be due to the behavior of other team members or due to the team's selected project topic. This could be an indication of a team mental model existing which is influencing how team members are approaching their journal activity. The other 5 classes did not exceed the critical value for the chi-squared test. This means that the frequency that an individual records *Problem Understanding*, *Idea Generation*, *Decision Making*, *Reflection*, or *Other* segments is not influenced by their team.

6.4 Conclusions

It was hypothesized that teams would largely balance out differences between the activity class frequencies of individual members when observing the team as a whole. This was found to be partially true when looking at the averages of teams. Team activity averages were observed belonging to 3 profiles. Different composites of activity were identified which may average out similarly but get there in different ways. Other findings include:

- Team averages recorded in journal activity appear to be normally distributed.
- 3 rough profiles of team average activity exist.
- Probability distributions were created for the frequency of each activity class based on team averages, and the distribution for each class is different.
- The recorded frequency of 3 of the 8 design activity classes was found to be dependent on the team that the journal's author belonged to.
- 3 of the 13 teams were observed as having highly aligned patterns in member activity, and another 3 were observed having the activity of several but not all of their members aligned.
- The 3 team profiles were not all made of the same type of alignment. In other words, teams were observed as being able to arrive at the same average despite having markedly different combinations in individual behavior.

Chapter 7: Concept Tracking

Team concept tracking forms the second part of Research Question 3 and is the subject of this chapter. The data that forms the backbone of this chapter is comprised of all journals that are not listed as individuals in Table 3.3.

Even partial teams (teams missing more than one member) are included in this chapter's data, bringing the number of journals up to 79 and the number of teams to 17.

The equations that govern referencing ratios were initially defined and explained in the Methodology chapter in Section 3.9. In this chapter the 4 referencing ratios for all 79 journals included in this analysis can be found in Section 7.1. In Section 7.2, correlations are drawn between referencing ratios and journal activity. Section 7.3 discusses the ability of journals to monitor concepts spreading between a team. Conclusions and limitations for this chapter are in Section 7.4.

7.1 Concept Referencing

The concept work for each team was tracked using the Python code described in Section 3.9. A copy of the code used can be found in Appendix C.1. Table 7.1 contains all concept referencing ratios results. Each of the values in this table are proportion ratios, as defined in Section 3.9. Histograms were also generated to observe the frequency distribution of each of the ratios, taken as proportions, as seen in Figures 7.1 - 7.4.

Table 7.1 – The concept ratios for all 79 journals belonging to the 17 team sets (both partial and full). All values are proportion ratios.

Team	Journal	Self Referencing Ratio ($r^s_{J_i}$)	Other Referencing Ratio ($r^o_{J_i}$)	Team Referencing Ratio ($r^t_{J_i}$)	Final Referencing Ratio ($r^*_{J_i}$)
$T1$	J4	3:3	0:3	3:4	16:21
	$J6$	1:3	2:3	3:4	0:11
	$J7$	0:2	2:2	2:4	17:23
$T2$	J10	4:4	0:4	4:9	7:16
	$J11$	4:5	1:5	5:9	0:17
	$J12$	0:1	1:1	1:9	0:2
	$J13$	0:2	2:2	2:9	0:5
	$J14$	1:1	0:1	1:9	0:6
$T3$	JP1	3:3	0:3	3:11	6:10
	$JP2$	8:11	3:11	11:11	17:40
	$JP3$	0:6	6:6	6:11	4:10
	$JP4$	0:3	3:3	3:11	5:12
$T5$	J31	1:5	4:5	5:15	3:9
	$J32$	5:5	0:5	5:15	8:28
	$J33$	6:6	0:6	6:15	5:36
	$J34$	3:10	7:10	10:15	5:22
	$J35$	0:6	6:6	6:15	1:13
	$J36$	0:8	8:8	8:15	1:23
$T6$	J37	8:8	0:8	8:17	3:15
	$J38$	4:7	3:7	7:17	14:27
	$J39$	0:3	3:3	3:17	1:9
	$J40$	3:6	3:6	6:17	9:24
	$J41$	2:5	3:5	5:17	26:40
	$J42$	0:6	6:6	6:17	14:20
$T7$	J43	4:4	0:4	4:10	3:9
	$J44$	2:5	3:5	5:10	2:10
	$J45$	1:3	2:3	3:10	1:3
	$J46$	1:2	1:2	2:10	0:6
	$J47$	2:5	3:5	5:10	1:10
	$J48$	0:4	4:4	4:10	8:13

Continued on next page

Table 7.1 – continued from previous page

Team	Journal	Self Referencing Ratio ($r^s_{J_i}$)	Other Referencing Ratio ($r^o_{J_i}$)	Team Referencing Ratio ($r^t_{J_i}$)	Final Referencing Ratio ($r^*_{J_i}$)
$T8$	J49	11:11	0:11	11:12	11:21
	$J50$	0:1	1:1	1:12	6:6
	$J52$	1:4	3:4	4:12	5:16
	$J53$	0:2	2:2	2:12	17:19
	$JP7$	0:2	2:2	2:12	7:18
$T9$	J54	4:4	0:4	4:6	6:29
	$J55$	0:2	2:2	2:6	11:24
	$J56$	2:5	3:5	5:6	14:35
	$J57$	0:3	3:3	3:6	4:8
	$J59$	0:2	2:2	2:6	3:6
$T10$	J61	1:1	0:1	1:10	7:7
	$J62$	9:10	1:10	10:10	3:21
	$J64$	0:2	2:2	2:10	6:8
	$J65$	0:1	1:1	1:10	10:10
$T11$	J67	2:2	0:2	2:2	15:16
	$J69$	0:2	2:2	2:2	15:17
	$J71$	0:1	1:1	1:2	1:1
	$J72$	0:1	1:1	1:2	6:6
$T12$	J73	6:6	0:6	6:8	16:30
	$J74$	1:5	4:5	5:8	10:18
	$J77$	1:5	4:5	5:8	14:30
	$J78$	0:2	2:2	2:8	3:5
$T13$	J79	6:6	0:6	6:12	2:8
	$J80$	4:9	5:9	9:12	11:22
	$J81$	2:7	5:7	7:12	9:30
	$J82$	0:4	4:4	4:12	3:11
	$J83$	0:3	3:3	3:12	10:14
$T14$	J85	6:6	0:6	6:9	33:47
	$J86$	1:6	5:6	6:9	20:43
	$J87$	2:7	5:7	7:9	11:28
	$J88$	0:6	6:6	6:9	12:35
	$J89$	0:3	3:3	3:9	0:5
	$J90$	0:2	2:2	2:9	7:9
$T15$	J92	11:11	0:11	11:33	6:28
	$J93$	10:10	0:10	10:33	0:22
	$J94$	8:10	2:10	10:33	0:20
	$J95$	2:7	5:7	7:33	1:21
	$J96$	2:11	9:11	11:33	6:58

Continued on next page

Table 7.1 – continued from previous page

Team	Journal	Self Referencing Ratio ($r^s_{J_i}$)	Other Referencing Ratio ($r^o_{J_i}$)	Team Referencing Ratio ($r^t_{J_i}$)	Final Referencing Ratio ($r^*_{J_i}$)
$T16$	J97	5:5	0:5	5:8	11:19
	$J98$	0:1	1:1	1:8	1:1
	$J99$	1:4	3:4	4:8	5:29
	$J100$	2:4	2:4	4:8	3:23
$T17$	J103	1:1	0:1	1:10	4:4
	$J106$	8:9	1:9	9:10	12:39
	$J107$	1:5	4:5	5:10	0:23
$T18$	J108	5:5	0:5	5:12	3:41
	$J109$	3:7	4:7	7:12	0:43
	$J110$	3:8	5:8	8:12	1:24
	$J112$	1:5	4:5	5:12	4:21

Some surprising results were obtained from calculating these concept ratios. On average students were observed to be considerably more likely to record a team member's concepts than their own. Only 41.4% of the average set of concepts in a journal were concepts originated by that journal author, compared to 58.6% which originated in another journal. These means, however, were incredibly skewed by individuals belonging to the two extremes as can be seen in Figure 7.1. Of the 79 students analyzed, 28 had a self referencing ratio of 0% and an other referencing ratio of 100%. Another 20 students had the opposite extreme of 100% and an other referencing ratio of 0%, meaning that over half of the sample fell into one of these two categories. Students belonging to either of these groups is discouraging. On the surface it suggests that they are either only working on their own ideas or are doing no concept generation of their own.

For the 31 students not belonging in either extreme there was a slight preference towards referencing others over themselves. Interestingly the average of the remaining 31 students was a self referencing ratio of 41.0% and an other referencing ratio of 59.0%, which is practically the same averages found when including the 48 all-or-nothing students. This suggests that those averages are meaningful and not just the result of two groups of opposite extremes.

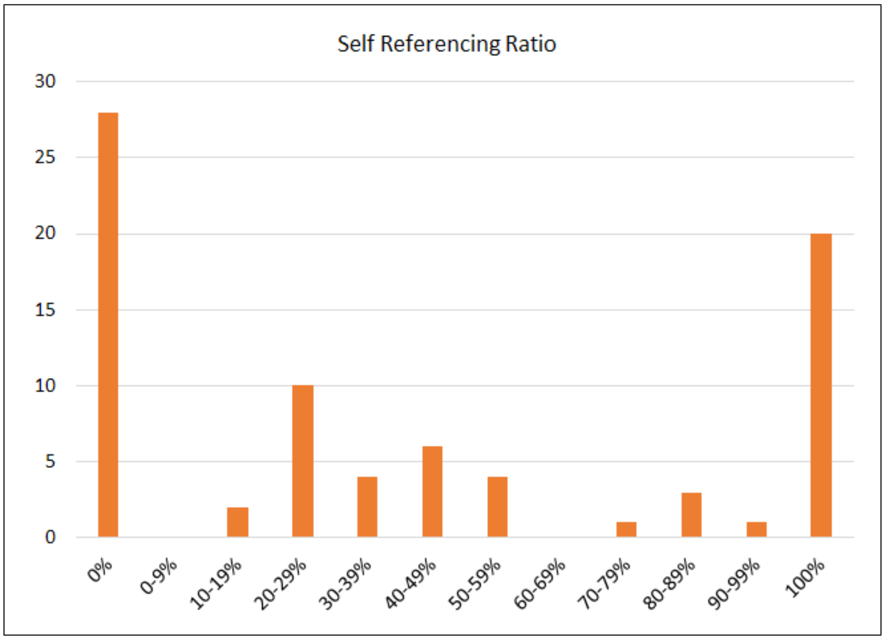

Figure 7.1 – Frequency distribution for the self referencing ratio ($r^s_{J_i}$)

Team referencing ratio can be thought of as breadth of involvement with concepts. It is an indication of how aware and engaged students are with the concepts of their team. The average found here among all students was 45.7%. Figure 7.3 shows that this average is much more representative of students than the previous ratio averages. Students who with values towards 100% in this category are likely the ones creating all of their team's concepts. For many teams it was noticed that some concepts have a lifespan of just a single session. While it can't be determined why all of those concepts had such short windows of existence, the impact that makes on team referencing ratios for teammates can be clearly seen. For future work it may be wise to only track concepts which have a certain longevity in this measure.

The team concept list and date information can be combined visually to examine the life spans of all concepts considered. In doing so, it is possible to see several pieces of information such as when the last time an alternative was considered and how many concepts were created before the eventual final concept emerged. An example of this can be seen in visual form in Figure 7.2, taken from $T3$ [11].

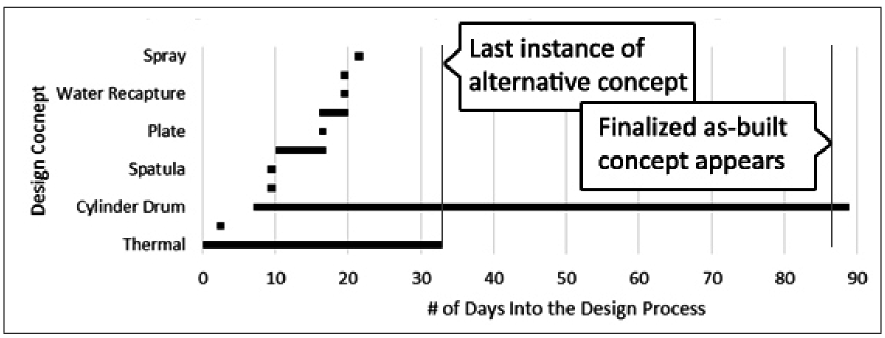

Figure 7.2 – The lifecycles for all concepts from $T3$ [11]

Students with other reference ratios of 100% had an average team reference ratio of 34.2%, while those with self reference ratios of 100% had an average team reference ratio of 47.8%. This indicates that the students who are only referencing themselves are also recording information on a lot of the team's total concepts.

The final concept referencing ratio is unique from the other ratios in that it accounts for total occurrences in a journal. It is not necessarily a good thing if an individual obtains a 100% on this measure since that suggests that they were locked into a singular concept throughout their project. Overall the average student referenced their team's final concept in 40.1% of the times they referenced any concept.

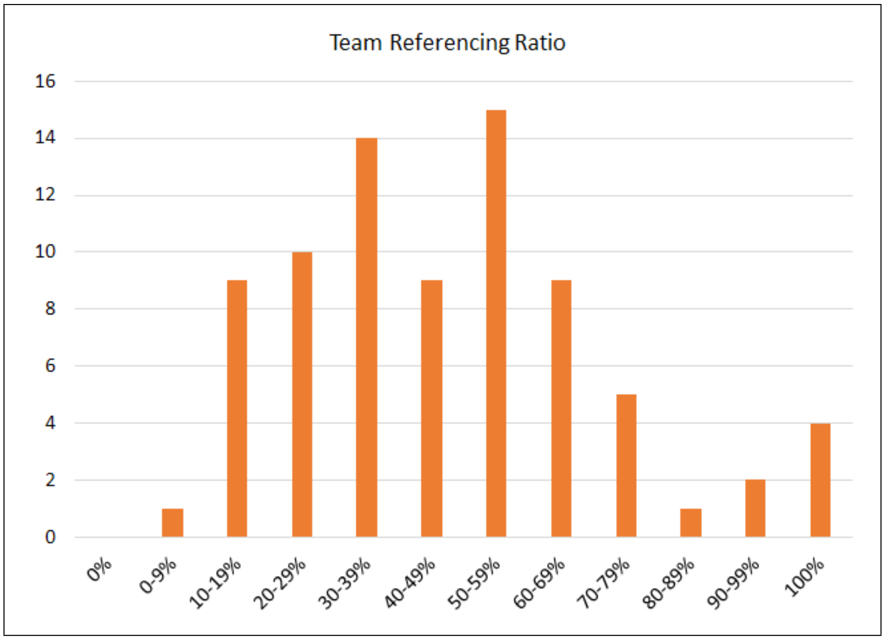

Figure 7.3 – Frequency distribution for the team referencing ratio ($r^t_{J_i}$)

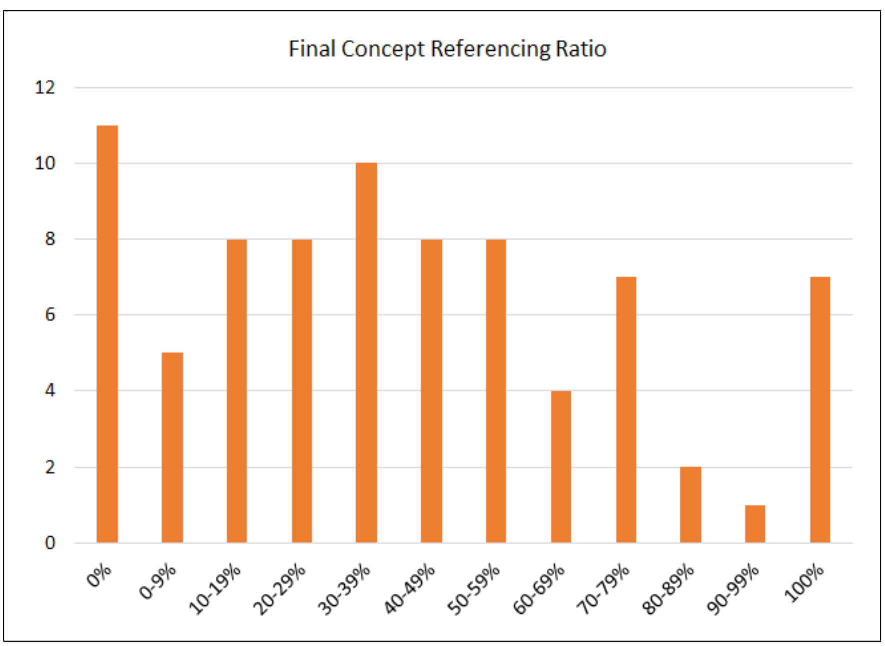

Figure 7.4 – Frequency distribution for the final concept referencing ratio ($r^*_{J_i}$)

Students with other reference ratios of 100% had an average final concept referencing ratio of 54.2%, while students with a self referencing ratio of 100% had an average final concept referencing ratio of 43.9%. The likeliest reason for this is students who only reference themselves are generating a lot of their team's ideas. Because of that, their final concept referencing ratio is being diluted by all the segments dedicated to the unused concepts.

7.2 Reference Ratio Correlations

Spearman correlation coefficients were calculated to determine if any correlations existed between the concept referencing ratios of individuals and their segment count or their activity frequencies, found in Table 7.2. Note that other referencing ratio correlations are simply the inverse of self referencing ratio.

Table 7.2 – Spearman correlation coefficients between concept referencing ratios, segment count, and activity class frequency

	$r^s_{J_i}$ **(Self)**	$r^t_{J_i}$ **(Team)**	$r^*_{J_i}$ **(Final)**	**Concepts Created**
$r^t_{J_i}$ (Team Referencing Ratio)	*0.231	n/a	0.010	*0.377
$r^*_{J_i}$ (Final Referencing Ratio)	-0.134	0.010	n/a	*-0.234
Segment Count	-0.016	0.146	0.065	0.062
Info. Seeking & Noting	-0.181	-0.113	0.055	*-0.255
Problem Understanding	0.023	0.005	-0.100	-0.041
Idea Generation	0.147	*0.245	0.046	0.170
Analysis	0.149	-0.04	-0.052	*0.230
Decision Making	0.033	-0.038	*0.244	0.085
Project Management	-0.192	0.036	0.065	*-0.224
Reflection	-0.029	0.039	-0.064	-0.036
Other	0.005	0.054	-0.114	0.010

** weak correlation*

Correlation testing between referencing ratios and class frequencies largely found no relationship between the two. The strongest correlation was a weak one between team referencing ratio and *Idea Generation*, which makes sense intuitively. If an individual is referencing more of the ideas a team has created they are likely to be performing above average amounts of *Idea Generation* segments. Final concept referencing ratio and *Decision Making* shared a correlation that was just about the same strength. This was one of the most unexpected results throughout this dissertation. Self referencing ratio and team referencing ratio also shared a weak positive correlation. As postulated earlier, students who favor referencing themselves seem to also be responsible for a larger number of concepts.

To further analyze this possibility, the Spearman correlation coefficient was calculated for the number of concepts created per journal compared to the self reference ratio. A value of 0.902 was obtained indicating a strong positive relationship. The number of concepts created by a journal also had a near-moderate weak positive correlation with team referencing ratio, a weak positive relationship with *Analysis*, and negative weak relationships with final concept referencing ratio, *Information Seeking & Noting*, and *Project Management*.

While they are weak correlations, the interplay between the number of concepts created and activity classes is interesting because it suggests that individuals who are more heavily associated with *Information Seeking & Noting* and *Project Management* are less active in creating concept ideas.

7.3 Concept Propagation

Concept referencing data was also looked at in a chronological perspective through visual representation. Figure 7.2 contains all exchanges in concepts across $T3$ [11]. The vertical axis lists the members of the team ($JP1 - JP5$), while the horizontal axis is a timeline from the first to last entries by $T3$. The 11 plotted lines each represent a unique concept. A concept moving along the vertical axis indicates that a different member of the team has made the next chronological appearance of this concept. This offers a big picture view of the propagation of concepts through a team. In this example it is visibly apparent that many of the team's concepts, especially their final design, were referenced quite a bit by all members.

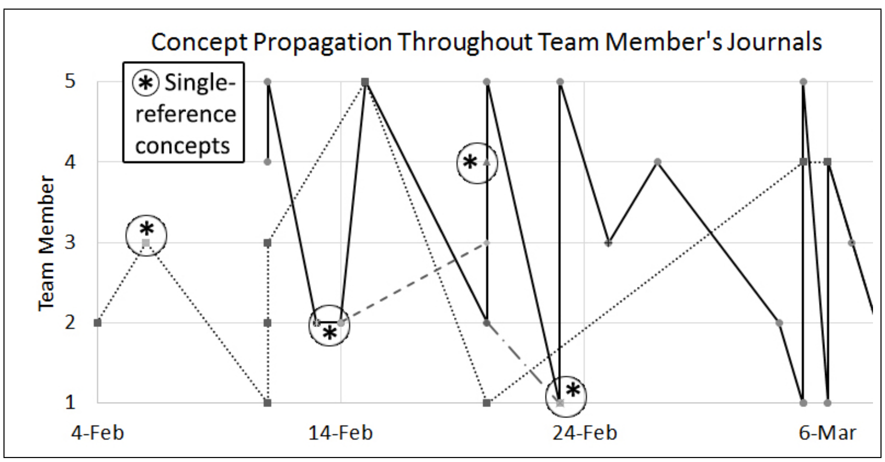

Figure 7.5 – Concept propagation for $T3$ [11]

7.4 Conclusions

Calculating concept referencing ratios found that individuals were likely to be either responsible for 100% of a team's total concepts or less than 30% if not 0.

Combined with measuring the number of concepts that are created by individuals, the data indicates that most teams have one or two individuals creating the bulk of their team's concepts. This might be an indication of the presence of the "idea person".

While nearly 1/3 of students were observed not creating any of their team's ideas, the majority of students are still engaging with a variety of concepts. Only 7 of the 79 students observed were found to exclusively work on the final concept. All other students worked on concepts which did not end up being selected. This is a good indicator that students are not locking into a single idea.

It was hoped that the referencing ratios would provide a good method of evaluating whether or not and to what degree a student is engaging with their team's concepts. Team referencing ratio specifically was found to have merit but it remains to be seen if the other ratios hold real value. Future work is required to reevaluate their use.

There are some limitations specific to this chapter which warrant further discussion. Of all of the analysis done in this entire research, concepts are perhaps the most influenced by the issue of variety in capstone project topics. Some student teams select projects with a narrow scope, while others attempt very grand projects which lead to a higher number of concepts or a number of subsystems which each have their own trees of concepts. Additionally, there is a degree of subjectivity on the coders behalf as to when to a concept has diverged sufficiently from previous ideas such that it should be considered a new concept and not simply a revision.

The largest limitation is that some sets of journals are unclear on who is being credited as the creator of a concept. It is possible that some concepts are being conceived outside of the journal during a meeting or another medium. It may be more accurate to consider the journal which first includes a concept as being the “first to report” rather than the creator of it. While these limitations do exist, the ratios are still meaningful. In particular the team referencing ratio and the final concept referencing ratio hold tremendous value. Error in crediting who developed a concept first does not affect either of these ratios.

Chapter 8: The Impact of Time on Journal Activity

The final research question asked by this dissertation is how does journal activity change over the course of a capstone project. To identify the answer to this, many facets of this research were reevaluated using time periods established by the dates for interim reports.

This chapter begins with an overview of the interval dates for each semester of the study's journal collection in Section 8.1. Next in Section 8.2, the results of using intervals on individual activity are discussed. Section 8.3 discusses the use of intervals on study wide data, and Section 8.4 uses intervals to look at team data. Section 8.5 contains conclusions for this chapter.

8.1 Interval Dates

Since the study sample comes from multiple semesters it is not possible to set one set of dates to apply to all individuals. Course deadlines are practically the same every semester however and so the deadlines for key course submissions have been used to subdivide each semester. The key dates for each of the semesters when data collection occurred can be found in Table 8.1

The period of time from the start of the semester until the first interim report

Table 8.1 – Interval dates for each semester, defined by the beginning of the semester and deadlines for interim and final reports

Semester	Starting Date	Interim Report 1	Interim Report 2	Final Report
Spring 2014	Jan. 27, 2014	Feb. 27, 2014	Apr. 17, 2014	May 13, 2014
Spring 2015	Jan. 26, 2015	Mar. 03, 2015	Apr. 16, 2015	May 12, 2015
Fall 2015	Aug. 31, 2015	Oct. 06, 2015	Nov. 12, 2015	Dec. 10, 2015
Spring 2016	Jan. 25, 2016	Mar. 03, 2016	Apr. 14, 2016	May 10, 2016
Fall 2016	Aug 29, 2016	Oct. 06, 2016	Nov. 10, 2016	Dec. 08, 2016

is considered “Interval 1”. Likewise the period of time between the first and second interim report is “Interval 2”, while the time from the second interim report to the final report is “Interval 3”.

Whenever intervals are mentioned, they can be considered as being roughly equal thirds of the capstone course. Spring cohorts are subject to time off for spring break, which occurs in Interval 2. Fall cohorts have Thanksgiving break, which is shorter. For the purposes of this work it is assumed that volunteers either do not perform journal work or only perform a negligible amount during holidays.

In the sections that follow, the sample being used will change. In all cases it follows the same sample used in previous chapters for the same type of work, i.e. team data involves only the 66 journals that are part of the 13 filled out teams.

8.2 Individual Data

To evaluate individual focus using project intervals, class activity is simply split measured for each interval instead of using the entire range of journal entries. By doing so it is possible it see changes in activity over time. On an individual level this shows shifts in areas of focus. The changes in focus for $J48$ can be seen in Figure 8.1.

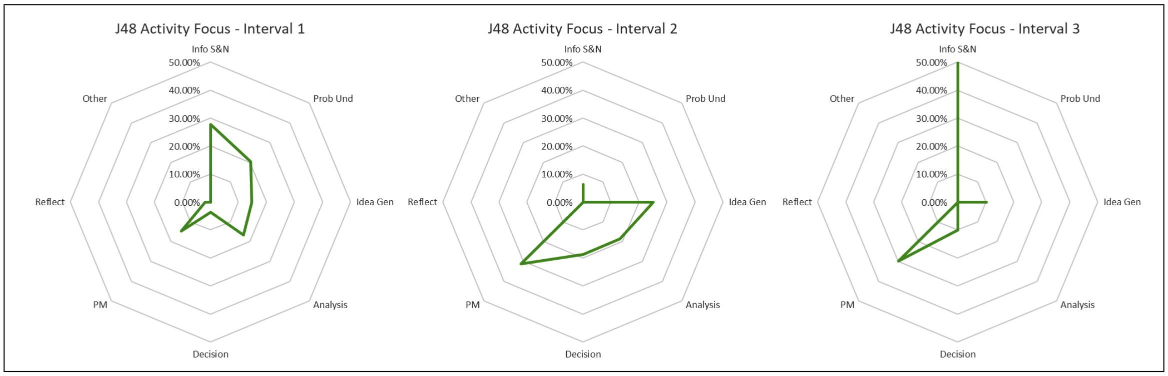

Figure 8.1 – The individual activity class frequencies for $J48$ during each project interval (Interval 1, Interval 2, Interval 3, respectively)

Individuals acted differently through the intervals. 35 of the 83 participants had two changes in the class that they recorded the most frequently over the semester. 30 participants changed their most recorded activity class once between intervals. The final 18 students made no change to their most recorded activity class between intervals. Instead these participants had one activity class that they recorded the most segments in all semester.

8.3 Study-Wide Trends

There were notable changes in segment amounts per interval. The total number of segments belonging to each class were tabulated for each interval. In Table 8.2 they are listed along with the percent they represent of the semester-wide segment total for that class.

There are distinct changes in segment activity. Intervals 1 and 2 are not very

Table 8.2 – The number of segments per interval and the percentage across each interval for each class

Class	Segment Count (Percent of Class Total)					
	Interval 1		Interval 2		Interval 3	
Info. Seeking & Noting	981	(45.54%)	807↓	(37.47%)	366↓	(16.99%)
Problem Understanding	776	(74.47%)	196 ↓	(18.81%)	70↓	(6.72%)
Idea Generation	1,253	(59.02%)	764 ↓	(35.99%)	106↓	(4.99%)
Analysis	1,207	(37.33%)	1,465↑	(45.31%)	561↓	(17.35%)
Decision Making	393	(27.07%)	761↑	(52.41%)	298↓	(20.52%)
Project Management	1,146	(38.60%)	1,228↑	(41.36%)	595↓	(20.04%)
Reflection	722	(42.12%)	636↓	(37.11%)	356↓	(20.77%)
Other	48	(26.82%)	80↑	(44.69%)	51↓	(28.49%)
Total	6,526	(43.90%)	5,937↓	(39.94%)	2,403↓	(16.16%)

Arrows indicate change from previous interval

far off in size difference, combined they account for 84% of the segments. Not all classes simply decreased each interval and in fact half of the activity classes increased from the first to second interval. *Analysis*, *Decision Making*, *Project Management*, and *Other* all increased during the second interval. The most dramatic change between intervals is *Problem Understanding.* Nearly 75% of all *Problem Understanding* segments occur during the first interval. Another finding is how much total segmenting drops during the third interval. This may be due to a combination of factors, but it is suspected that the major reason is that journals become less useful in later stages of a project when work has transitioned from conceptual to tangible.

To make additional inferences between the intervals, team data was used to enable the use of testing methods which require normal distributions.

8.4 Team Data

The means of the 13 team averages were also calculated within each of the project's time periods marked by interim and final report submissions. Analysis of variance testing was also performed on the three time periods using the 13 team averages for each class. Both of these results can be found in Table 8.3.

Table 8.3 – Average frequencies of design journal activity among teams during each project time interval and the ANOVA results between the periods. (*) indicates that the test found statistically significant differences between the means.

Class	Int 1 (%)	Int 2 (%)	Int 3 (%)	ANOVA *p*-value
Info. Seeking & Noting	13.09	12.66	15.76	0.6160
Problem Understanding	13.51	2.72	3.12	1.9713 E-07*
Idea Generation	20.00	12.48	3.63	1.0813 E-06*
Analysis	19.25	27.22	26.33	0.2251
Decision Making	6.10	12.49	12.60	9.9754 E-04*
Project Management	16.28	19.79	23.10	0.1611
Reflection	10.70	11.39	13.50	0.6651
Other	1.06	1.25	2.06	0.0838

From Table 8.3 it can be observed that certain classes maintain a fairly consistent proportion of journal activity, while others fluctuate to a much greater extent depending on the location of the project's timeline. *Problem Understanding* exists predominantly in the first third of the project and becomes increasingly less common over time. Similarly, *Idea Generation* steadily declines from being the most common activity to being middle of the pack, and then to one of the least common activities during the final interval. *Decision Making* follows an opposite trend, going from barely present to becoming more common as a project matures. In contrast to these time-affected changes, *Information Seeking & Noting* as well as *Reflection* feature notably lower variation over time. Logically these observations make sense. *Problem Understanding* and *Idea Generation* are both front loaded tasks in design projects. Conversely, *Reflection* is likely to be more influenced by an individual's own work style preferences than by the place in a project's timeline.

Also included in Table 8.3 are the results from analysis of variance testing. It was found that three classes (*Problem Understanding*, *Idea Generation*, and *Decision Making*) had statistically significant differences between project time periods. The remaining classes all were found to have no statistically significant differences between project time periods, even though some had noticeable changes to the average.

8.5 Conclusions

Time plays a key role in journal activity and the changes that occur in activity can be found at each level of the study.

On an individual level it was determined that time played a major role in what activities were being performed by students. While certain classes were found to be more likely at certain project intervals, it was not found to be a hard rule for all individuals. This can be further seen in Appendix D.

While the majority of individuals were found to be fluid in what activity they recorded the most frequently, 18 participants completely specialized in a certain activity over all project intervals. 35 students changed their most recorded class each interval, while the final 30 changed after only one of the two intervals.

Although total segment count decreased at each interval, several classes were recorded more frequently during the second interval than the first. *Problem Understanding* had the most drastic change in frequency between intervals, which in part explains why the activity class has such a low overall frequency.

Not only did individuals often change their primary activities, but team members regularly traded off being the primary contributor for a certain activity class.

With the team data that previously was used to construct probability distributions for the activity classes, the interval averages of each class were determined. ANOVA testing found that some classes had statistically significant changes in frequency, more specifically *Problem Understanding* (776 to 196 to 70 segments per interval), *Idea Generation* (1,253 to 764 to 106 segments per interval), and *Decision Making* (393 to 761 to 298 segments per interval). This shows that not only do the frequencies of these activity classes vary over time but that it is beyond just random chance.

Chapter 9: Final Conclusions and Future Work

Design journals offer a unique potential but have not been thoroughly studied to date and so this work also exists in part to further advance the field. In total journals maintained by 83 mechanical engineering capstone students across 17 teams were examined. Journal content was codified and tested. Discoveries were made not only about the activity frequencies but how much those frequencies varied from person to person and team to team. Work presented here was heavily reliant on statistical analysis. The foundation for the coding scheme used in this work was created by Westmoreland [2], with refinement and updating done by the dissertation's author. Journals were found to be an under utilized source of data that could play a key role in better understanding design thinking.

9.1 Summary of Research Question Results

1. **What can engineering design journals reveal about the specific activities an individual performs in a design project?**

    - A wide variety exists between student records but there are clear commonalties in how journals are used.

    - The activities recorded in journals can be used to analyze the type of work an individual is performing.

- *Analysis*, *Project Management*, and *Idea Generation* were identified as being the most common activity classes performed and also found to be more likely to be an area of focus for students.
- Students did not universally focus on the same activities, however, and even the least common activities were the most commonly performed by at least one student in the study.
- Some specialization in activity was apparent.
- Negative correlations were found between certain pairs of classes, indicating that students who perform lots of *Analysis* are less likely to be involved with *Project Management*.

2. **Do distinct design activity sequences exist can be identified by analyzing design journals?**

    - Distinct activity sequences in journals were identified.
    - *Project Management* and *Analysis* were the most commonly featured activity classes in the most frequently occurring sequences.
    - When journal data was condensed to find only sequences without repetition, *Analysis* was the most commonly featured activity class.

3. **What do design journals indicate about the interaction an individual has with their team and their team's concepts?**

- Teams were found to have comparable average class activity frequencies.
- Different teams exhibit different member patterns. All of the members on some teams mirror the same activity. Other teams have members that each focus on different activity classes.
- Probability distributions were created for the frequency of each activity class. They were found to be very different from each other.
- Journals were also successfully used to track concepts within a team.
- Concept referencing ratio analysis within this work did not provide strong evidence of individual engagement with teams.
- 48 of 79 students referenced either only concepts they were first to report or only concepts that other members were first to report on. Most teams had one or two members being credited with almost all of the team's concepts.

4. **How does design journal activity differ as a project advances?**

- Time plays a major role in journal activity.
- As a project's timeline advances certain classes like *Problem Understanding* became less frequent while others like *Decision Making* became more frequent. These changes in frequency were determined to be statistically significant.
- Some individuals were found to focus on the same activity classes throughout a project but most students were observed to use classes different in

each interval.

9.2 Contributions of this Research

At the time of writing it is the most comprehensive study of design journals to date. This work has contributed to the following areas of engineering design research:

1. Refining and validating a previously established journal coding scheme to construct the most information rich design journal dataset to be studied.
2. Obtaining a better understanding of what occurs in the mind of the designer by measuring the frequencies of the activity they perform.
3. Measuring the amount of activity variation that exists between different individual designers as well as the activity variation between different teams.
4. Identifying patterns in activity sequences that occur in journal recordings.
5. Collection of a highly detailed dataset which can be further harvested by researchers.

9.3 Opportunities for Future Research

For each answer this research has sought out, several new questions have arisen that could form the basis of future work. After more work in this area is performed, it is hoped that more specific recommendations can be made. Some of the key areas for future work are:

- Studying questions related to specific actions rather than the broader activity classes. This could provide more specific information regarding the sequences that occur.

- Recreating work with professional designers instead of capstone students should either validate the findings here or indicate measurable differences in how experts and novices work.

- Deeper research on the effect of project topic on recorded activities. This dissertation briefly touched upon the fact that there is tremendous range in mechanical capstone project topics, and it is likely that this is a non-trivial variable influencing activity on both an individual and team basis.

- Automated classification is another area that would be beneficial to explore. Attempts were made during this work but with only moderate success. Automating the coding process would enable researchers to work on journal data with greater ease and eliminate any concerns about inter-coder reliability.

- Linking the data and methodology presented in this work with project outcomes. This really represents the ultimate goal of this research in being able to identify what patterns of activity lead to the best designs. What patterns are best may also be influenced on the project topic as noted before. It is not easy to assess the quality of outcomes for different projects on the same scale, so using a basic approach with simple outcome possibilities (exceptional, good, average, poor, etc) to start may be a worthwhile pursuit.

Appendix A: Study Documentation

This appendix includes copies of several important pieces of study documentation. Appendix A includes all project IRB approvals of the study for initiating the research study and continuing reviews. Appendix A.2 is a copy of the consent form used for the study. The only thing which differed is that in some semesters the total compensation was $75 and others it was $100. Appendix A.3 is the instructions provided to participants, in part taken from Sobek's instructions [87]. Finally Appendix A.4 is a copy of the exit survey provided to participants in the fall 2016 semester.

A.1 IRB Approvals

UNIVERSITY OF MARYLAND

INSTITUTIONAL REVIEW BOARD

1204 Marie Mount Hall
College Park, MD 20742-5125
TEL 301.405.4212
FAX 301.314.1475
irb@umd.edu
www.umresearch.umd.edu/IRB

DATE:	May 15, 2014
TO:	Linda Schmidt, PhD
FROM:	University of Maryland College Park (UMCP) IRB
PROJECT TITLE:	[599393-1] Journal Research Study
REFERENCE #:	
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	May 15, 2014
EXPIRATION DATE:	May 14, 2015
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *6 & 7*

Thank you for your submission of New Project materials for this project. The University of Maryland College Park (UMCP) IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this committee prior to initiation. Please use the appropriate revision forms for this procedure which are found on the IRBNet Forms and Templates Page.

All UNANTICIPATED PROBLEMS involving risks to subjects or others (UPIRSOs) and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this office.

This project has been determined to be a Minimal Risk project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of May 14, 2015.

Please note that all research records must be retained for a minimum of three years after the completion of the project.

UNIVERSITY OF MARYLAND
INSTITUTIONAL REVIEW BOARD

1204 Marie Mount Hall
College Park, MD 20742-5125
TEL 301.405.4212
FAX 301.314.1475
irb@umd.edu
www.umresearch.umd.edu/IRB

DATE:	May 6, 2015
TO:	Linda Schmidt, PhD
FROM:	University of Maryland College Park (UMCP) IRB
PROJECT TITLE:	[599393-2] Journal Research Study
REFERENCE #:	
SUBMISSION TYPE:	Continuing Review/Progress Report
ACTION:	APPROVED
APPROVAL DATE:	May 6, 2015
EXPIRATION DATE:	May 14, 2016
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *6 & 7*

Thank you for your submission of Continuing Review/Progress Report materials for this project. The University of Maryland College Park (UMCP) IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

Prior to submission to the IRB Office, this project received scientific review from the departmental IRB Liaison.

This submission has received Expedited Review based on the applicable federal regulations.

This project has been determined to be a Minimal Risk project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of May 14, 2016.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Unless a consent waiver or alteration has been approved, Federal regulations require that each participant receives a copy of the consent document.

Please note that any revision to previously approved materials must be approved by this committee prior to initiation. Please use the appropriate revision forms for this procedure.

All UNANTICIPATED PROBLEMS involving risks to subjects or others (UPIRSOs) and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this office.

UNIVERSITY OF MARYLAND
INSTITUTIONAL REVIEW BOARD

1204 Marie Mount Hall
College Park, MD 20742-5125
TEL 301.405.4212
FAX 301.314.1475
irb@umd.edu
www.umresearch.umd.edu/IRB

DATE:	July 1, 2015
TO:	Linda Schmidt, PhD
FROM:	University of Maryland College Park (UMCP) IRB
PROJECT TITLE:	[599393-3] IUSE: Exploration of Journaling to Assess Design Learning
REFERENCE #:	NSF 1504964
SUBMISSION TYPE:	Amendment/Modification
ACTION:	APPROVED
APPROVAL DATE:	July 1, 2015
EXPIRATION DATE:	May 14, 2016
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # 7

Thank you for your submission of Amendment/Modification materials for this project. The University of Maryland College Park (UMCP) IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

Prior to submission to the IRB Office, this project received scientific review from the departmental IRB Liaison.

This submission has received Expedited Review based on the applicable federal regulations.

This project has been determined to be a Minimal Risk project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of May 14, 2016.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Unless a consent waiver or alteration has been approved, Federal regulations require that each participant receives a copy of the consent document.

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1204 Marie Mount Hall
College Park, MD 20742-5125
TEL 301.405.4212
FAX 301.314.1475
irb@umd.edu
www.umresearch.umd.edu/IRB

DATE:	May 16, 2016
TO:	Linda Schmidt, PhD
FROM:	University of Maryland College Park (UMCP) IRB
PROJECT TITLE:	[599393-4] IUSE: Exploration of Journaling to Assess Design Learning
REFERENCE #:	NSF 1504964
SUBMISSION TYPE:	Continuing Review/Progress Report
ACTION:	APPROVED
APPROVAL DATE:	May 16, 2016
EXPIRATION DATE:	May 14, 2017
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *6 & 7*

Thank you for your submission of Continuing Review/Progress Report materials for this project. The University of Maryland College Park (UMCP) IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

Prior to submission to the IRB Office, this project received scientific review from the departmental IRB Liaison.

Please Note: Any changes made to the protocol, including the number of participants, must be approved by the IRB prior to their implementation in the project.

This submission has received Expedited Review based on the applicable federal regulations.

This project has been determined to be a Minimal Risk project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of May 14, 2017.

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1204 Marie Mount Hall
College Park, MD 20742-5125
TEL 301.405.4212
FAX 301.314.1475
irb@umd.edu
www.umresearch.umd.edu/IRB

DATE:	November 29, 2016
TO:	Linda Schmidt, PhD
FROM:	University of Maryland College Park (UMCP) IRB
PROJECT TITLE:	[599393-5] IUSE: Exploration of Journaling to Assess Design Learning
REFERENCE #:	NSF 1504964
SUBMISSION TYPE:	Amendment/Modification
ACTION:	APPROVED
APPROVAL DATE:	November 29, 2016
EXPIRATION DATE:	May 14, 2017
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # 7

Thank you for your submission of Amendment/Modification materials for this project. The University of Maryland College Park (UMCP) IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

Prior to submission to the IRB Office, this project received scientific review from the departmental IRB Liaison.

This submission has received Expedited Review based on the applicable federal regulations.

This project has been determined to be a Minimal Risk project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of May 14, 2017.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Unless a consent waiver or alteration has been approved, Federal regulations require that each participant receives a copy of the consent document.

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1204 Marie Mount Hall
College Park, MD 20742-5125
TEL 301.405.4212
FAX 301.314.1475
irb@umd.edu
www.umresearch.umd.edu/IRB

DATE:	April 21, 2017
TO:	Linda Schmidt, PhD
FROM:	University of Maryland College Park (UMCP) IRB
PROJECT TITLE:	[599393-6] IUSE: Exploration of Journaling to Assess Design Learning
REFERENCE #:	NSF 1504964
SUBMISSION TYPE:	Continuing Review/Progress Report
ACTION:	APPROVED
APPROVAL DATE:	April 21, 2017
EXPIRATION DATE:	May 14, 2018
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # 7

Thank you for your submission of Continuing Review/Progress Report materials for this project. The University of Maryland College Park (UMCP) IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

Prior to submission to the IRB Office, this project received scientific review from the departmental IRB Liaison.

This submission has received Expedited Review based on the applicable federal regulations.

This project has been determined to be a Minimal Risk project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of May 14, 2018.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Unless a consent waiver or alteration has been approved, Federal regulations require that each participant receives a copy of the consent document.

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A.2 Consent Forms

University of Maryland College Park

 Initials______ Date_____

Project Title	Capture & Analysis of Design Records
Purpose of the Study	This research is being conducted by Dr. Linda Schmidt at the University of Maryland, College Park. We are inviting you to participate in this research project because you are currently enrolled in ENME 472, a course which includes a major design project. The purpose of this research project is to identify and analyze design thinking as recorded in situ (whatever setting the work is completed).
Procedures	Each study participant will be given a design journal and asked to record all design tasks, thoughts, analysis, and reflections about their current project. Journals will be reviewed periodically by the researchers to track level and appropriateness of usage. Subjects whose journals lack sufficient content will be asked to leave the study. The expectation of the investigators is that participants will be making at least several thorough pages of content a week. This should require about 15 minutes a day. Throughout the semester pages may be scanned for interim analysis. At the end of the semester, students will turn in journals to the research team. Some participants will be given a smartpen and journal for digital upload of their records. The first full team to volunteer for the study will be selected as the smartpen group.
Potential Risks and Discomforts	There are no risks to this study. Participants may find the recording responsibility tedious. At any time participants may freely chose to withdraw from the study.
Potential Benefits	There are no direct benefits to participants. Possible benefits include improved understanding of the design process through reflection on journal entries. Subjects in a similar study have reported general benefit to their projects from maintaining ongoing documentation of their work.
Confidentiality	The identities of subjects will be revealed to the research team as a requirement for joining the study. Each journal has a unique ID number, so when analysis begins participants will only be identified by that to help protect confidentiality. Any other potential loss of confidentiality will be minimized by storing journals in a locked cabinet within a locked office. Any digital data will be stored on a password protected computer. If the investigators write a report or article about this research project, your identity will be protected to the maximum extent possible. Raw data, both physical and digital, will only be viewed by the investigative team. Your information may be shared with representatives of the University of Maryland, College Park or governmental authorities if you or someone else is in danger or if we are required to do so by law.
Compensation	You will receive three installments of $25 Amazon.com gift cards for every 4 weeks of successful participation. There be a maximum of payments totaling $75. You will be responsible for any taxes assessed on the compensation. ☐ Check here if you expect to earn $600 or more as a research participant in UMCP studies in this calendar year. You must provide your name, address and SSN to receive compensation. ☐ Check here if you do not expect to earn $600 or more as a research participant in UMCP studies in this calendar year. Your name, address, and SSN will not be

	collected to receive compensation.	
Right to Withdraw and Questions	Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time. If you decide not to participate in this study or if you stop participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify. If you are a student at the University of Maryland, your grades or standing with the university will not be positively or negatively affected by your decision to participate or not participate in this research project. If you decide to stop taking part in the study, if you have questions, concerns, or complaints, or if you need to report an injury related to the research, please contact the investigator: **Dr. Linda Schmidt** 2104B Glen L. Martin Hall, University of Maryland College Park, MD 20742-3035 Phone: 301-405-0417 Email: lschmidt@umd.edu **Werner Born** Phone: 301-405-4518 Email: wcborn@umd.edu	
Participant Rights	If you have questions about your rights as a research participant or wish to report a research-related injury, please contact: **University of Maryland College Park** **Institutional Review Board Office** **1204 Marie Mount Hall** **College Park, Maryland, 20742** **E-mail: irb@umd.edu** **Telephone: 301-405-0678** This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human subjects.	
Statement of Consent	Your signature indicates that you are at least 18 years of age; you have read this consent form or have had it read to you; your questions have been answered to your satisfaction and you voluntarily agree to participate in this research study. You will receive a copy of this signed consent form. If you agree to participate, please sign your name below.	
Signature and Date	**NAME OF PARTICIPANT [Please Print]**	
	SIGNATURE OF PARTICIPANT	
	DATE	

A.3 Design Journal Guidelines

First off, thanks for volunteering to be a part of this study! If you at any point have any questions or concerns, feel free to contact either Werner Born or Dr. Linda Schmidt.

Your design journal should be used to serve as a complete record for all activity related to your capstone project. When it is finished, it should provide a look at the evolution of your design project and your thinking on it. If in doubt, put it in! Beyond the context of the study, this should be a tool to help you work through your capstone project. Some additional guidelines:

1) **DO include the date every time you start a new entry**. Each page in your journal has a section on the bottom of the page to list the date. This is very critical!
2) **DO** bring your notebook to lecture on Thursdays. Once it has been checked for progress, I will sign the last page you had work on.
3) **DO** plan on spending a few minutes each day working on your journal.
4) **DO** label entries as needed to provide context (identify when things are meeting notes or personal thoughts, etc)
5) **DO** label sketches / diagrams / drawings
6) **DON'T** remove or skip pages.
7) **DON'T** backfill pages. The books are plenty big, so once you move to a new page don't fill in blank spaces on previous pages.
8) **DON'T** use the book for anything that does not pertain to progressing your project. This includes things like 472 lecture notes with no clear connection to your work or projects from other classes.
9) **DO** include any of the following and anything else that might cross your mind as you solve your problem:

• Notes from site visit	• Work-in-progress	• Design review feedback
• Meeting notes	• Scratch work	• Decision criteria
• Data collection	• Class notes	• Decision process/results
• Sketches & doodling	• Customer requirements	• Decision rationale
• Brainstorming	• Internet research	• Evaluation results
• Half-baked ideas	• Specifications	• Analysis results
• Sources of ideas	• Math calculations	

Lastly, here are some ideas that might help give you a jumpstart on when are good times to use a journal:

If you just finished…	Ask yourself…
A meeting,	➢ What were the main outcomes of the meeting? ➢ Was the meeting productive, and why? ➢ What are/should be the next steps? ➢ Is the team heading in the right direction?
Brainstorming,	➢ Do we have a large enough set of ideas? ➢ Which ideas seem most feasible, and why? ➢ How could we have made the session better?
Analyzing data,	➢ What were the most important findings? ➢ What do the results mean? How should we apply them?
Designing (by hand or in CAD),	➢ What did I learn about the problem or solution possibilities? ➢ What problems did we resolve, and which still need to be addressed? ➢ How does this piece integrate with the whole?
An internet search,	➢ Do we have a complete picture? Are there other sources we should pursue? ➢ What key information did I find? Why is it key? How does it help us achieve our objectives?

Excerpts taken from Design Journal Instructions from Sobek, University of Montana, EIND 499

A.4 Participant Exit Survey

Personal Assessment

1. Please allocate **your** contribution to your team's project across the following categories, **for the time period covering the start of the semester until Interim Report 1**. These should total up to 100%.

____% Information Seeking & Noting

____% Problem Understanding

____% Project Ideas

____% Analysis

____% Decision Making

____% Project Management

____% Reflection

2. Please allocate **your** contribution to your team's project across the following categories, **for the time period covering Interim Report 1 until Interim Report 2**. These should total up to 100%.

____% Information Seeking & Noting

____% Problem Understanding

____% Project Ideas

____% Analysis

____% Decision Making

____% Project Management

____% Reflection

3. Please allocate **your** contribution to your team's project across the following categories, **for the time period covering Interim Report 2 until the end of the semester**. These should total up to 100%.

____% Information Seeking & Noting

____% Problem Understanding

____% Project Ideas

____% Analysis

____% Decision Making

____% Project Management

____% Reflection

4. Please allocate **your** contribution to your team's project across the following categories, **for the semester as a whole**. These should total up to 100%.

____% Information Seeking & Noting (examples)

____% Problem Understanding

____% Project Ideas

____% Analysis

____% Decision Making

____% Project Management

____% Reflection

5. Do you think that other team members had similar distributions to yours? If not, please expand as to why you believe yours was different.

Team Assessment

For the following questions please indicate how strongly you agree or disagree with the statement presented.

1. Your team worked together effectively on this project.

   Strongly Disagree Disagree Neutral Agree Strongly Agree

2. Members of the team split workloads evenly.

   Strongly Disagree Disagree Neutral Agree Strongly Agree

3. You performed more work than the average on your team.

   Strongly Disagree Disagree Neutral Agree Strongly Agree

Design Journals

For the following questions please indicate how strongly you agree or disagree with the statement presented.

1. Your engineering design project benefited from you maintaining a design journal.

   Strongly Disagree Disagree Neutral Agree Strongly Agree

2. In the future you would voluntarily keep a design journal when working on an engineering design project.

   Strongly Disagree Disagree Neutral Agree Strongly Agree

3. You predominantly used your design journal at the end of the day to record your efforts.

   Strongly Disagree Disagree Neutral Agree Strongly Agree

4. You predominantly used your design journal "live", i.e. you recorded things as you worked on them.

   Strongly Disagree Disagree Neutral Agree Strongly Agree

5. Your journal entries reflect the distribution of design behavior you defined in section 1 of this survey.

   Strongly Disagree Disagree Neutral Agree Strongly Agree

6. You looked back to your earlier journal entries as the semester progressed.

   Strongly Disagree Disagree Neutral Agree Strongly Agree

7. Was there a point in the design process that made journaling seem more difficult or less beneficial, if so when? Please expand.

Appendix B: Design Activity Code Glossary

Action Class	Specific Design Action	Cue / Description
1. Information Seeking and Noting	1. Search	Looking for information relating to the design project at any stage of the design process
	5. References	Source of information such as books, blogs, person, tables, and charts that needs to be available for future reference
	11. Questioning	Requesting information about the project that is not at the time known, usually ending statements with a question mark
	26. Price Quotes	An estimate from a vendor or company related to the price of products or services
	32. Feedback	Information received from an external source in response to prior work. Typically comes from a professor or industry expert. Includes assessment of grades received for the project.
	36. Definitions	The meaning of a word
	38. Categorization or Labeling	Contextual information provided typically to group several related segments.
2. Problem Understanding	2.Customer Requirements	Describing the product requirements from the perspective of the customer
	3. Problem Statement Clarification	Making the problem statement clearer by explaining it in greater detail
	17. Criteria Lists	List of things that must be considered when making a decision or judgment about the project
	37. Engineering Characteristics	A solution-neutral way of describing the customer requirements.
	39. Market Consideration	Information regarding the target market of the concept. Including but not limited to locations where the product could be used, descriptions of socio-economic classes, etc.
3. Idea Generation	4. Project Ideas	Variations of the project ideas for selection, different options considering, and project concepts
	6. Material Options	Choices of materials to use for the project
	8. Analogical Reasoning	Use of words “like”, “similar”, “as”, etc. Using text or visuals to compare components of the project
4. Analysis	7. Estimates	Rough assessments of various parts of the project
	9. Assumptions	Suppositions made and accepted to be true without prior confirmation
	10. Calculations	Involving math, physics, and engineering diagrams (free body, electrical circuits, thermodynamics diagrams, etc.). Number and formulas used with mathematical operators
	12. Testing Procedures	Establishing testing specifications and methods for the project. Comments that indicate an area of the project which requires evaluation.
	13. Variables	Project components that is liable to change before the project is completed
	16. Explanations	To establish by reasoning
5. Decisions	14. Recommendations	Suggestion to what is a good or beneficial thing to do for the project. Thoughts on internal team direction. “Need to…” a common queue word.

	15. Conclusions	The outcome of some action or the outcome of the project. A decision made after some analysis for the design project. Includes major pivots along the project's evolution or agreed upon direction. Stated as more of a hard fact than a recommendation.
	18. Design Changes	A difference in the design from a previous version of the design
6. Project Management	21. Task	Item(s) that need to be completed for the project. Includes general / team-wide activities.
	24. Task Assignment	The assignment of an action item to a specific member of the team. Typically just a team member's name written next to a specific task.
	25. Inventory	Things obtained for the project such as computer programs, materials, and other parts
	27. Task Completion	Recording the act of completing something for the project
	28. Project Milestones	Significant dates and accomplishments in the history of the project
	29. Field Trip Notes	Notes about a trip to any place related to the project and how it is related to the project
7. Reflection	19. Personal Notes	Informal notes about various parts of the project including feelings about the design
	20. Progress Assessment	Related to how well the design artifact is progressing in the stages of the design process
	22. Revelations	A new thought or idea about the project that was not previously known
	23. Meeting Minutes	An unofficial record of what is said or done during a meeting
	30. Mistakes	Recorded error made in the design journal
	31. Cross References	Notation directing the writer or reader of the design journal to look elsewhere for more details or updated design notes
8. Other	33. Illegible Entries	Journal entry that is not legible and therefore not able to be coded
	34. Designer Signature	Designers name signed in the journal entry
	35. No Evidence of Cognitive Activity	No clear evidence of the cognitive process from the given text or pictures.

Appendix C: Python Code

C.1 Concept Ownership and Ratio

```
class datas:
  def __init__(self,a,b,c):
    self.concept = a
    self.journal = b
    self.date = int(c)

lastconcept = -1
lastdate=0
lista = []
dicta = {}
dict2 = {}
cowner = {}
owncount = {}
useown = {}
lastcount = {}
totjourn = {}
usefinal = {}
ownusecount = {}
f = open('teamX.txt', 'r')

for line in f:
  a = line.split()
  dat =  datas(a[0], a[1], a[2])
  lista.append(dat)
  if int(a[2]) > int(lastdate):
    lastdate = a[2]
    lastconcept = a[0]
```

Continued on next page

```
for data in lista:
  if data.concept not in cowner:
    cowner[data.concept] = data.journal
    if data.journal not in owncount:
      owncount[data.journal] = 1
      ownusecount[data.journal] = 0
    else:
      owncount[data.journal] = owncount[data.journal] + 1

print ('total concepts - '+ str(len(cowner)))
print ('Concept Owners - ' + str(cowner))
print ('Ownership Counts -' + str(owncount))

for data in lista:
  if(data.journal == cowner[data.concept]):
    ownusecount[cowner[data.concept]] = ownusecount[cowner[data.concept]] + 1
  if data.journal in dicta:
    totjourn[data.journal] = totjourn[data.journal] + 1
    if(data.concept == lastconcept):
      if data.journal in lastcount:
        lastcount[data.journal] = lastcount[data.journal] + 1
      else:
        lastcount[data.journal] = 1
    if data.concept not in dicta[data.journal]:
      dicta[data.journal] = dicta[data.journal] +' '+ data.concept
      dict2[data.journal] = dict2[data.journal] + 1
  else:
    dicta[data.journal] = data.concept
    dict2[data.journal] = 1
    totjourn[data.journal] = 1
    if(data.concept == lastconcept):
      lastcount[data.journal] = 1

for key in dict2:
    if key in ownusecount:
        useown[key] = str(ownusecount[key]) + '/'+str(totjourn[key])
    else:
        ownusecount[key] = str(0)
    if key in lastcount:
        usefinal[key] = str(lastcount[key]) + '/' + str(totjourn[key])
    else:
        usefinal[key] = '0/' + str(totjourn[key])

print ('Self concept referencing ratio' +  str(useown))
print ('Team concept referencing ratio' + str(dict2))
print ('Final concept referencing frequency' + str(usefinal))
```

C.2 Activity Class Sequence Tabulation

```python
import numpy as np
import pandas as pd
from collections import Counter

RawClassData = open('SequencerFull.txt', 'r')
ClassData = RawClassData.read().splitlines()
SegmentClasses = np.asarray(ClassData)

Counter(ClassData)

def checkEqual(iterator):
   return len(set(iterator)) <= 1

arr = SegmentClasses
cut = 2
theMap = {}
while cut < 7:
  i = 0
  while i < len(arr) - cut:
    lst = []
    for k in range(cut):
      lst.append(arr[i+k])
    i = i + 1
    if(checkEqual(lst) and (i + k + 1) < len(arr) and arr[i+k+1] == lst[0]):
      continue
    if tuple(lst) not in theMap:
      theMap[tuple(lst)] = 1
    else:
      theMap[tuple(lst)] = theMap[tuple(lst)] + 1
  cut = cut + 1

for key, value in sorted((value,key) for (key,value) in theMap.items()):
  print ("%s: %s" % (key, value))
```

C.3 Extra Sequence Tabulation Code to Condense Segments

```
raw = SegmentClasses
trimmed = ''

for x in raw:
    if trimmed == '' or x != trimmed[len(trimmed)-1]:
        trimmed += x

arr = trimmed
```

Appendix D: Study Data

All Semester										
Cohort	Team	Journal	Info. Seeking & Noting	Problem Understanding	Idea Generation	Analysis	Decision Making	Project Management	Reflection	Other
Participant ID			Segment Count							
Spring 2014	1	4	2	10	30	12	1	5	4	1
		6	18	4	13	5	1	18	11	0
		7	14	8	35	41	1	7	10	0
	2	10	17	9	23	31	19	19	5	0
		11	12	13	23	14	0	0	7	6
		12	23	12	6	25	2	9	4	0
		13	65	25	19	42	4	26	20	3
		14	6	4	8	3	0	1	3	0
	3	P1	1	3	11	35	13	23	2	0
		P2	12	18	13	86	32	49	34	3
		P3	30	18	12	32	9	15	14	2
		P4	16	12	11	54	3	25	8	0
Spring 2015		30	36	6	53	10	1	24	10	0
Fall 2015	5	31	26	27	20	16	12	17	15	13
		32	17	27	24	72	42	9	5	0
		33	37	17	25	35	20	79	57	0
		34	22	25	51	56	26	27	25	0
		35	27	15	41	44	17	40	14	7
		36	8	12	16	12	12	38	16	1
	6	37	24	14	25	24	15	12	30	1
		38	54	9	56	135	43	26	26	6
		39	10	7	3	25	18	69	83	1
		40	22	6	23	24	11	13	8	2
		41	24	21	37	73	57	47	66	0
		42	11	31	24	78	23	74	23	0
	7	43	59	28	17	41	19	89	47	1
		44	69	43	38	20	12	204	80	5
		45	53	14	15	27	10	35	17	1
		46	67	22	25	42	27	74	38	3
		47	52	25	19	24	14	86	47	1
		48	21	11	13	12	6	16	1	0
	8	49	51	27	52	29	11	17	12	12
		50	40	12	27	36	20	35	19	0
		52	54	20	29	56	19	32	19	5
		53	62	18	39	50	14	43	52	5
		JP7	20	0	23	36	24	15	10	0

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All Semester										
Cohort	Team	Journal	Info. Seeking & Noting	Problem Understanding	Idea Generation	Analysis	Decision Making	Project Management	Reflection	Other
Participant ID			Segment Count							
Spring 2016	9	54	93	9	66	36	39	121	40	2
		55	53	24	34	43	26	153	32	1
		56	46	24	72	41	35	97	19	1
		57	42	6	41	31	14	28	13	10
		59	14	4	39	11	6	13	1	0
		60	15	14	15	27	15	8	11	1
	10	61	8	6	5	3	18	15	19	0
		62	43	0	22	30	10	20	32	0
		64	29	12	29	9	14	21	11	1
		65	44	5	32	18	36	29	7	0
	11	67	33	3	32	16	23	19	35	1
		68	11	0	2	3	5	13	21	0
		69	75	6	48	43	26	32	29	0
		71	80	16	16	24	12	31	3	2
		72	37	20	32	12	48	32	15	4
	12	73	1	11	29	45	11	14	9	0
		74	13	16	21	57	10	22	1	1
		77	6	5	21	32	0	7	4	0
		78	2	3	17	8	1	8	2	0
	13	79	0	1	12	22	8	4	3	0
		80	81	34	57	88	78	126	49	0
		81	28	30	52	61	40	96	27	26
		82	23	13	19	88	44	33	1	5
		83	1	1	12	43	35	19	5	3
	14	85	14	6	30	112	33	101	61	0
		86	34	14	31	85	47	83	44	0
		87	9	0	14	48	45	83	34	0
		88	6	2	25	33	21	33	65	0
		89	8	4	7	8	4	27	40	0
		90	25	9	6	18	23	47	18	0
Fall 2016	15	92	12	9	48	42	20	4	5	0
		93	3	0	10	40	9	10	3	0
		94	2	0	11	24	6	18	46	0
		95	9	0	10	30	8	12	58	3
		96	4	0	37	44	8	4	8	0
	16	97	17	0	24	27	3	19	3	1
		98	16	29	10	19	6	9	11	0
		99	31	15	36	81	17	77	19	13
		100	16	8	20	60	6	25	6	4
	17	103	17	15	19	90	4	20	11	4
		105	0	5	1	9	0	16	4	2
		106	20	16	35	10	27	12	5	11
		107	11	4	13	44	3	4	0	0
	18	108	5	19	20	79	8	15	7	0
		109	20	20	48	71	13	23	12	0
		110	5	16	18	59	9	20	15	1
		112	10	15	26	52	20	28	8	3

Interval 1										
Cohort	Team	Journal	Info. Seeking & Noting	Problem Understanding	Idea Generation	Analysis	Decision Making	Project Management	Reflection	Other
Participant ID			Segment Count							
Spring 2014	1	4	1	7	7	2	0	1	3	0
		6	4	2	3	4	0	7	7	0
		7	4	7	12	4	0	1	1	0
	2	10	5	9	9	4	0	6	0	0
		11	12	13	7	7	0	0	7	4
		12	9	12	6	6	1	0	2	0
		13	26	20	11	1	1	7	9	0
		14	6	4	8	3	0	1	3	0
	3	P1	1	1	1	12	2	5	0	0
		P2	4	9	12	32	7	5	12	2
		P3	7	11	5	5	6	7	7	1
		P4	0	4	3	2	0	4	0	0
Spring 2015		30	10	0	12	7	0	9	4	0
Fall 2015	5	31	2	24	16	1	0	4	8	0
		32	5	25	21	21	11	2	4	0
		33	18	15	17	27	6	27	11	0
		34	8	15	34	7	7	6	5	0
		35	10	11	23	12	8	10	4	3
		36	4	11	10	0	1	10	1	0
	6	37	17	11	11	6	0	11	14	0
		38	22	2	33	93	7	0	9	3
		39	3	5	2	9	7	17	24	0
		40	8	2	12	14	4	2	0	0
		41	5	10	25	27	9	7	39	0
		42	2	22	8	11	7	14	2	0
	7	43	30	24	8	20	5	49	23	0
		44	33	10	8	8	4	96	31	0
		45	43	14	2	12	7	18	10	0
		46	28	20	3	16	4	25	17	0
		47	22	24	7	10	7	42	20	1
		48	15	11	8	9	2	8	1	0
	8	49	20	22	31	8	7	4	8	9
		50	23	11	5	9	4	24	16	0
		52	25	13	16	14	5	15	14	0
		53	25	12	18	11	5	14	27	0
		JP7	17	0	18	27	5	13	9	0

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Interval 1										
Cohort	Team	Journal	Info. Seeking & Noting	Problem Understanding	Idea Generation	Analysis	Decision Making	Project Management	Reflection	Other
Participant ID			Segment Count							
	9	54	54	8	46	21	8	48	20	1
		55	39	24	26	16	6	71	14	0
		56	29	21	52	14	11	53	9	0
		57	4	3	12	3	1	7	5	0
		59	1	4	34	5	1	10	0	0
		60	6	13	11	7	3	3	0	0
	10	61	0	0	0	0	0	2	8	0
		62	33	0	20	10	0	14	20	0
		64	4	0	4	2	0	0	3	0
		65	16	2	9	0	13	11	5	0
	11	67	3	2	11	1	4	8	17	0
		68	10	0	0	0	4	9	15	0
		69	13	6	34	10	14	11	15	0
		71	25	14	1	1	4	19	1	0
		72	30	17	6	0	24	7	12	1
	12	73	1	8	18	32	4	6	2	0
		74	10	10	19	38	5	17	0	1
		77	3	4	20	28	0	6	4	0
		78	0	2	12	5	0	6	1	0
	13	79	0	1	11	2	0	0	0	0
		80	42	26	23	23	29	62	27	0
		81	8	16	30	24	9	28	8	3
		82	7	10	7	3	4	5	0	1
		83	0	1	2	1	1	6	3	2
	14	85	4	6	18	17	9	42	14	0
		86	14	14	29	27	10	24	9	0
		87	7	0	13	21	10	35	21	0
		88	1	2	23	11	5	19	27	0
		89	3	4	6	2	4	11	16	0
		90	8	7	3	4	3	22	7	0
Fall 2016	15	92	5	5	39	9	5	0	4	0
		93	2	0	10	33	6	3	1	0
		94	0	0	10	20	4	1	5	0
		95	0	0	10	26	4	1	14	0
		96	2	0	30	36	5	3	8	0
	16	97	17	0	24	6	3	19	3	1
		98	7	22	4	3	1	8	9	0
		99	28	15	20	38	4	23	17	0
		100	12	6	15	22	2	4	2	0
	17	103	10	15	11	31	1	11	5	3
		105	0	2	0	3	0	5	1	0
		106	13	16	30	5	7	11	5	10
		107	11	4	13	33	2	3	0	0
	18	108	3	14	20	41	2	4	4	0
		109	15	17	47	57	11	6	5	0
		110	3	12	18	32	2	4	2	1
		112	4	10	20	23	9	7	2	1

Interval 2										
Cohort	Team	Journal	Info. Seeking & Noting	Problem Understanding	Idea Generation	Analysis	Decision Making	Project Management	Reflection	Other
Participant ID			Segment Count							
Spring 2014	1	4	1	3	19	7	1	2	1	1
		6	9	0	10	1	1	11	4	0
		7	10	1	22	31	1	6	9	0
	2	10	11	0	14	26	13	11	5	0
		11	0	0	16	7	0	0	0	2
		12	9	0	0	11	1	9	0	0
		13	33	5	8	41	3	15	6	2
		14	-	-	-	-	-	-	-	-
	3	P1	0	2	10	23	11	18	2	0
		P2	8	9	1	46	18	30	19	0
		P3	23	7	7	27	3	6	7	1
		P4	14	2	8	30	0	20	7	0
Spring 2015		30	25	6	24	2	0	15	5	0
Fall 2015	5	31	11	2	2	2	4	5	3	3
		32	11	1	3	28	19	2	0	0
		33	12	2	8	6	10	42	21	0
		34	10	9	15	32	11	16	8	0
		35	15	0	18	27	9	29	5	4
		36	4	1	4	11	10	16	10	0
	6	37	7	3	14	18	15	1	14	1
		38	28	0	23	32	25	13	13	2
		39	6	2	1	13	8	36	36	0
		40	7	4	10	2	2	5	6	0
		41	4	10	12	39	42	23	9	0
		42	8	7	16	48	11	34	7	0
	7	43	22	4	9	19	11	24	16	0
		44	28	20	24	12	2	66	32	4
		45	9	0	12	15	2	6	6	0
		46	15	1	12	15	11	30	13	3
		47	20	0	7	12	3	27	16	0
		48	1	0	4	3	3	5	0	0
	8	49	9	5	18	17	1	7	0	3
		50	10	1	22	21	14	8	3	0
		52	19	2	13	28	9	8	3	0
		53	25	6	17	14	5	16	18	0
		JP7	3	0	5	9	19	2	1	0

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Interval 2										
Cohort	Team	Journal	Info. Seeking & Noting	Problem Understanding	Idea Generation	Analysis	Decision Making	Project Management	Reflection	Other
Participant ID			Segment Count							
	9	54	36	1	20	14	28	52	19	1
		55	11	0	7	25	8	59	12	0
		56	16	3	20	3	6	17	10	0
		57	7	3	25	8	9	12	3	3
		59	2	0	5	2	1	2	1	0
		60	9	1	4	17	8	4	10	1
	10	61	5	6	4	3	18	6	11	0
		62	8	0	2	18	9	5	9	0
		64	17	12	23	6	6	11	7	0
		65	15	3	8	13	14	13	1	0
	11	67	23	1	12	14	15	6	17	1
		68	1	0	2	3	1	4	6	0
		69	48	0	14	31	12	16	12	0
		71	42	2	15	22	7	11	2	1
		72	7	0	25	7	18	15	3	3
	12	73	0	3	11	13	5	8	7	0
		74	3	6	2	19	5	5	1	0
		77	3	1	1	4	0	1	0	0
		78	2	1	5	3	1	2	1	0
	13	79	0	0	1	20	8	4	3	0
		80	23	2	34	46	29	58	16	0
		81	9	9	20	25	29	63	16	19
		82	10	1	12	57	21	25	1	3
		83	1	0	10	42	34	13	2	1
	14	85	7	0	11	41	19	36	28	0
		86	8	0	2	29	32	23	16	0
		87	1	0	1	23	35	29	6	0
		88	5	0	1	14	15	10	18	0
		89	1	0	0	4	0	7	19	0
		90	10	2	3	11	8	15	4	0
Fall 2016	15	92	7	1	9	28	10	4	1	0
		93	1	0	0	2	2	7	1	0
		94	1	0	1	2	1	5	21	0
		95	6	0	0	1	3	7	19	3
		96	2	0	4	6	0	1	0	0
	16	97	0	0	0	21	0	0	0	0
		98	9	7	6	16	5	1	2	0
		99	2	0	16	38	5	36	2	11
		100	2	2	5	29	1	17	2	4
	17	103	2	0	5	28	1	1	4	0
		105	0	3	1	6	0	11	3	2
		106	7	0	5	5	20	1	0	1
		107	0	0	0	11	1	1	0	0
	18	108	0	3	0	19	1	5	1	0
		109	5	2	1	6	2	13	7	0
		110	1	1	0	15	1	7	5	0
		112	5	5	3	20	9	15	2	0

Interval 3										
Cohort	Team	Journal	Info. Seeking & Noting	Problem Understanding	Idea Generation	Analysis	Decision Making	Project Management	Reflection	Other
Participant ID			Segment Count							
Spring 2014	1	4	0	0	4	3	0	2	0	0
		6	5	2	0	0	0	0	0	0
		7	0	0	1	6	0	0	0	0
	2	10	1	0	0	1	6	2	0	0
		11	-	-	-	-	-	-	-	-
		12	5	0	0	8	0	0	2	0
		13	6	0	0	0	0	4	5	1
		14	-	-	-	-	-	-	-	-
	3	P1	-	-	-	-	-	-	-	-
		P2	0	0	0	8	7	14	3	1
		P3	0	0	0	0	0	2	0	0
		P4	2	6	0	22	3	1	1	0
Spring 2015		30	1	0	17	1	1	0	1	0
Fall 2015	5	31	13	1	2	13	8	8	4	10
		32	1	1	0	23	12	5	1	0
		33	7	0	0	2	4	10	25	0
		34	4	1	2	17	8	5	12	0
		35	2	4	0	5	0	1	5	0
		36	0	0	2	1	1	12	5	1
	6	37	0	0	0	0	0	0	2	0
		38	4	7	0	10	11	13	4	1
		39	1	0	0	3	3	16	23	1
		40	7	0	1	8	5	6	2	2
		41	15	1	0	7	6	17	18	0
		42	1	2	0	19	5	26	14	0
	7	43	7	0	0	2	3	16	8	1
		44	8	13	6	0	6	42	17	1
		45	1	0	1	0	1	11	1	1
		46	24	1	10	11	12	19	8	0
		47	10	1	5	2	4	17	11	0
		48	5	0	1	0	1	3	0	0
	8	49	22	0	3	4	3	6	4	0
		50	7	0	0	6	2	3	0	0
		52	10	5	0	14	5	9	2	5
		53	12	0	4	25	4	13	7	5
		JP7	-	-	-	-	-	-	-	-

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Interval 3

Cohort	Team	Journal	Info. Seeking & Noting	Problem Understanding	Idea Generation	Analysis	Decision Making	Project Management	Reflection	Other
Participant ID			Segment Count							
	9	54	3	0	0	1	3	21	1	0
		55	3	0	1	2	12	23	6	1
		56	1	0	0	24	18	27	0	1
		57	31	0	4	20	4	9	5	7
		59	11	0	0	4	4	1	0	0
		60	0	0	0	3	4	1	1	0
	10	61	3	0	1	0	0	7	0	0
		62	2	0	0	2	1	1	3	0
		64	8	0	2	1	8	10	1	1
		65	13	0	15	5	9	5	1	0
	11	67	7	0	9	1	4	5	1	0
		68	-	-	-	-	-	-	-	-
		69	14	0	0	2	0	5	2	0
		71	13	0	0	1	1	1	0	1
		72	0	3	1	5	6	10	0	0
	12	73	0	0	0	0	2	0	0	0
		74	-	-	-	-	-	-	-	-
		77	-	-	-	-	-	-	-	-
		78	-	-	-	-	-	-	-	-
	13	79	-	-	-	-	-	-	-	-
		80	16	6	0	19	20	6	6	0
		81	11	5	2	12	2	5	3	4
		82	6	2	0	28	19	3	0	1
		83	-	-	-	-	-	-	-	-
	14	85	3	0	1	54	5	23	19	0
		86	12	0	0	29	5	36	19	0
		87	1	0	0	4	0	19	7	0
		88	0	0	1	8	1	4	20	0
		89	4	0	1	2	0	9	5	0
		90	7	0		3	12	10	7	0
Fall 2016	15	92	0	3	0	5	5	0	0	0
		93	0	0	0	5	1	0	1	0
		94	1	0	0	2	1	12	20	0
		95	3	0	0	3	1	4	25	0
		96	0	0	3	2	3	0	0	0
	16	97	-	-	-	-	-	-	-	-
		98	-	-	-	-	-	-	-	-
		99	1	0	0	5	8	18	0	2
		100	2	0	0	9	3	4	2	0
	17	103	5	0	3	31	2	8	2	1
		105	-	-	-	-	-	-	-	-
		106	-	-	-	-	-	-	-	-
		107	-	-	-	-	-	-	-	-
	18	108	2	2	0	19	5	6	2	0
		109	0	1	0	8	0	4	0	0
		110	1	3	0	12	6	9	8	0
		112	1	0	3	9	2	6	4	2

WERNER C. BORN

EDUCATION

Ph.D. in Mechanical Engineering August 2018
University of Maryland, College Park, MD

M.S. in Mechanical Engineering May 2018
University of Maryland, College Park, MD

B.S. in Mechanical & Aerospace Engineering May 2010
Rutgers University, New Brunswick, NJ
Studied abroad in Berlin, Germany

KNOWLEDGE & SKILLS

Interests	Design, product development, human factors, machine learning, rapid prototyping, optimization, analytics, team behavior
Software	Solid Works, Inventor, AutoCAD, Fusion 360, Pro-E, SketchUp, Tinkercad, PTC Creo, 123D Design, Photoshop, Illustrator, Repetier Acrobat, Office, LaTeX, HTML, CSS, Mathematica, Audacity
Programming Languages	Python, MATLAB, C/C++, Java
Other Skills	Writing, 3D printing, CNC cutting, mold making & casting, talented artist

PROFESSIONAL EXPERIENCE

Graduate Research Assistant University of Maryland, College Park, MD August 2013 - Present

- Researched the cognitive activity which occurs during the product design process and the interactions between members of an engineering team over the course of a project
- Developed methods to interpret and analyze thousands of pages of design records kept by engineers
- Created algorithms to automate classification and analysis using machine learning techniques including neural networks, naive Bayes, and clustering ***(Python, Matlab)***

Graduate Teaching Assistant University of Maryland, College Park, MD August 2013 - Present

- Handled grading, communications, and general course problem solving for UMD's mechanical engineering capstone design course, managing over 150 students per semester
- Coordinated "Design Day" department capstone showcase event every semester

Freelance Product Design Work Self employed, Largo, MD 2013 - Present

- Recruited clients and negotiated contracts for freelance design work
- Designed products ***(Inventor, Fusion 360)*** to be manufactured with 3D printing and CNC laser cutting
- Produced a range of products by learning industry-specific requirements, including marine components for individual consumers as well as scale buildings for board game companies

Assistant Project Manager Egg Electric, Inc., New York, NY October 2010 - June 2011

- Managed multi-million dollar construction projects, handling all project documentation and submissions
- Performed all bidding and purchasing for job sites, including both daily material and capital purchases
- Designed AutoCAD drawings for proposals, construction guides, and as-built records

LEADERSHIP EXPERIENCE

Sigma Phi Delta, International Engineering Fraternity August 2011 - Present
Eastern Regional Director

- Elected voting executive board member of international non-profit social and professional engineering fraternity
- Dealt with university administrators for matters including colonizing outreach and problem response
- Managed all operations within the eastern region of North America, both undergraduate and alumni
- Coordinated international conventions, regional retreats, and local events

Rutgers University Student Assembly May 2009 - May 2010
President

- Led student government for a university with 30,000 undergraduate students
- Revamped student governing structure drastically to a model that is still in place today
- Met with university and city officials regularly as the primary representative of the student body
- Distributed a million dollar budget to over 330 student organizations
- Recognized for achievements with Rutgers University Extraordinary Service Award 2010

ACTIVITIES

Warhammer 40,000 September 2011 - Present
Playtester & Competitor

- Consulted on all rules for the flagship tabletop miniatures game from a $32M company
- Captained the most successful North American competitive team for 2016 & 2017
- Selected as coach for the 2018 US team for international competition

Semi-professional artist

PUBLICATIONS

W. Born, L. Schmidt. "Evaluating the Project Activity Differences in Capstone Design Students via Journals." *ASME 2018 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, 2018.

W. Born, L. Schmidt. "An Observational Study on Functional Behavior in Team Design." *ASME 2016 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, 2016.

W. Born, L. Schmidt. "A Case Study Exploring the Use of Journals to Support Student Engagement." *International Conference for Engineering Design*, 2015.

J. Nagel, L. Schmidt, and W. Born. "Fostering Diverse Analogical Transfer in Bio-Inspired Design." *ASME 2015 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, 2015.

(Additional manuscripts currently under review.)

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[1] Rivka Oxman. Cognition and design. *Design Studies*, 17(4):337–340, 1996.

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