AN ABSTRACT OF THE DISSERTATION OF

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Title: An Investigation of Student Cognitive Engagement in the STEM Classroom—A Compilation of Faculty and Student Perspectives

Abstract approved:

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Shane A. Brown

Student engagement has been the focus of much engineering education research, in large part due to its ties to student learning. Widely considered to be a meta-construct, student engagement is often broken down into behavioral, emotional, and cognitive components. Reasons for ongoing research on student cognitive engagement are twofold: educators often have difficulty assessing students' cognitive engagement due to its inherently unobservable qualities, and cognitive engagement has been seen as a predictor of deep learning and success in students. In the body of works that make up this dissertation, I researched student cognitive engagement from multiple vantage points. First, I worked to develop an instrument to measure student cognitive engagement. The outcome was the Student Course Cognitive Engagement Instrument (SCCEI), which showed evidence of validly measuring five distinct modes of cognitive engagement. The SCCEI aimed to allow instructors to evaluate the sophistication of the student cognitive engagement in their class. To support this aim, I analyzed student interviews to deepen my understanding of how students interpret

items probing cognitive engagement. This allowed the SCCEI to be modified to more accurately represent the realities of students' engagement experience. Included was the measurement of engagement inside and outside the classroom; evidence was found that students report statistically different on their modes of engagement depending on the context (inside or outside the classroom). I also interviewed students to gain a more holistic understanding of their engagement. These high-achieving, upper division engineering students provided insight on the major factors that shaped their engagement throughout college. Finally, I utilized our instrument, the SCCEI, in tandem with an instrument to measure instructional practices to explore the relationship between the two constructs. The results of these works broadly suggest that student cognitive engagement can indeed be measured by self-report, and instructors play a critical role in shaping their students' engagement. Furthermore, findings suggest that instructional practices are indeed correlated with modes of student cognitive engagement. Compiled, this body of work adds to the growing literature on student cognitive engagement, and how the engineering discipline can continue to move towards the betterment of students.

An Investigation of Student Cognitive Engagement in the STEM Classroom— A Compilation of Faculty and Student Perspectives

by

Allyson Jo Barlow

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APPROVED:

Major Professor, representing Civil Engineering

Head of the School of Civil and Construction Engineering

Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Allyson Jo Barlow, Author

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reminding me that statistics are not the enemy. I love you, and you will always be my most treasured outcome of this entire process.

CONTRIBUTION OF AUTHORS

Shane Brown was involved with the scoping and design of the studies that comprise this work. He offered feedback and review throughout the writing and publication of each work. Ben Lutz was offered his review and intellectual contributions to the works in both Chapter 2 and Chapter 3. Nicole Pitterson also offered her review to Chapter 2. Nathaniel Hunsu and Olusola Adesope assisted in the statistical analysis of Chapter 2, contributing their background knowledge of the subject and careful review of the manuscript. I, Allyson Barlow (Ironside), am the primary author of all the work in this dissertation, as well as the substantive driver behind the data collection, analysis, and processing for each work.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

1 – INTRODUCTION

The emergent field of engineering education has made repeated claims on the benefits of student engagement (e.g. see Freeman et al., 2014; Prince, 2004). Meaningful levels of student engagement have been associated with learning gains (S. Freeman et al., 2014), greater persistence in the discipline (Sinatra, Heddy, & Lombardi, 2015) and higher self-efficacy (Christopher, Walker, Greene, & Mansell, 2005). It has therefore become increasingly relevant for engineering education researchers to both define and measure student engagement.

Engagement is a multi-dimensional construct (Sinatra et al., 2015), meaning it is more clearly defined in the consideration of its relevant components. Commonly, student engagement is broken into three primary components: behavioral, emotional, and cognitive (Fredricks, Blumenfeld, & Paris, 2004). Behavioral engagement is defined by student conduct, involvement in academic tasks, and participation (Fredricks et al., 2004). An educator can observe the actions of their students' behavioral engagement, making the construct accessible to them once defined. Emotional engagement is somewhat less observable, defined by students' reaction to course features. This includes both displays and internal feelings of interest, boredom, happiness, and sadness (Fredricks et al., 2004). It has been noted that student's complex emotions and their relationship with academic performance can be mediated by cognitive engagement (Pekrun & Linnenbrink-Garcia, 2012). Yet, cognitive engagement has historically remained the most difficult component of engagement to define (Sinatra et al., 2015). It involves unobservable, less concrete factors including psychological investment and strategic learning (Fredricks et al., 2004).

The distinctions between components of student engagement are carried over into how each is measured by educators and researchers. Behavioral engagement can be measured by observation or self-report instruments; an educator could simply observe her classroom as a litmus for the students' behavioral engagement, or a researcher could attend a course lecture and note the apparent behavioral engagement of the students. Likewise, an educator or researcher can develop simple self-report metrics to ask students about their responses to a particular activity or assignment. Emotional engagement is more nuanced, and is ideally measured with validated instruments. Items that measure emotional engagement have been validated in the National Survey on Student Engagement (NSSE) (i.e. *indicate the quality of your interactions with [students, academic advisors, professors, etc.] at your institution*), among others. Yet, since its distinction from other forms of engagement cognitive engagement has been both difficult to distinguish and measure. Recently, Greene noted that self-report is a reasonable method for examining cognitive engagement, but urges the field to not rely exclusively on such measures (2015). One prominent work that goes beyond self-report is the well-cited work of Chi and Wylie (2014). They developed an observational schema to use the overt behaviors of students to determine their modes of cognitive engagement. The ICAP framework, as it was dubbed, made the measurement of cognitive engagement much more accessible to an educator observing their own classroom. Yet, as of the start of this work, the novel relationship between behaviors and modes of cognitive engagement

ICAP established had yet to be transitioned into a measurement tool usable by educators and researchers seeking to more broadly explore cognitive engagement within a course.

It was therefore important to my research team to develop such a tool. The measurement of cognitive engagement remains important for several reasons. Indeed, if classrooms are to be transitioned to the active learning environments suggested by current engineering education research, educators will greatly benefit from the ability to test the modes of cognitive engagement among their students. While observational metrics are useful in such cases, they are limited by the finite ability of educators to individually see each student's behaviors (thereby allowing them to infer their cognition via the ICAP framework). Beyond this, research has shown that educators are resistant to implementing changes such as active learning in their courses (Borrego, Froyd, & Hall, 2010; Dancy & Henderson, 2008). Some of this resistance develops from a lack of understanding how such changes are intended to be implemented in a specific course's context (Dancy & Henderson, 2008). In this case, educators need more information about their particular students and course in order to understand how their practices might be modified to align with best practices for engagement.

The need for reliable measurement of student cognitive engagement persists; beyond this, there exists a need to connect measurement tools to their broader meaning and context. Due to the often-isolated use and development of measurement tools, a comprehensive understanding of student cognitive engagement in STEM contexts is missing from the literature. One piece of understanding yet uncovered is how students are shaped by a complex set of factors that result in them engaging in a particular manner in a given context. Specifically, there is little known about how engagement varies for a single student across their STEM courses, and what causes it to vary in such a manner. Additionally, when new instruments are developed they are often used in isolation from those already existing in the literature. For instruments that measure cognitive engagement, it is important to explore how it may or may not relate to instruments that measure related constructs. As educators are often targeted to implement instructional changes to increase student engagement, exploring such a relationship is particularly important. Missing from the literature is the use of multiple instruments in tandem to explore engagement and instructional practices from the student and instructor perspective, respectively. Such exploration would generate empirical relationships between instructional practices and student engagement that could be used to infer what changes in instructional practices might have the greatest benefit to student learning.

As the need to measure and understand cognitive engagement persists, the primary aim of our work is to provide educators and researchers a holistic perspective of student cognitive engagement within STEM students with regards to a single course. I have invested myself in this work, the fruit of which is presented in this document. Here, I present a compilation of the work I have conducted throughout the course of this doctoral degree. My work approaches the question of how students are cognitively engaged from multiple angles: first through the development of self-report instruments, then through exploration of individual high-achieving students, and finally through an exploration of how student cognitive engagement is correlated with instructional practices. The work herein is my own, and is representative of the intellectual effort put forth by myself and my research team. The assembling of this work in dissertation format is unique, as it allows for the viewing of cognitive engagement from robust quantitative and qualitative perspectives. The dissertation is written in manuscript form, with each chapter representing a different peer-reviewed article either published or in review. Below is a summary of each chapter and the role I played in conducting of the relevant research and manuscript development.

1.1 Ch 2. Development of the Student Course Cognitive Engagement Instrument (SCCEI)

Over the course of multiple years, I aided in the development of Student Course Cognitive Engagement Instrument (SCCEI). The instrument shows evidence of validity when measuring students' in-class cognitive engagement. The SCCEI is based on the modes of engagement proposed in the ICAP framework, and has undergone many rounds of iterations and development. I was involved in several key item development and refinement meetings over the course of several rounds of pilot testing. I was tasked with managing the data collection via Qualtrics (2005), the online platform from which the survey was deployed. I recruited faculty and worked with them directly as they implemented the instrument in their course. The primary publication resulting from this work is *Development of the Student Course Cognitive Engagement Instrument (SCCEI)* (Barlow et al., in review), which was recently re-submitted to the Journal of Engineering Education upon request for revisal. This work details how survey development procedures were followed to generate an instrument with evidence of validity to measure student cognitive engagement in the classroom. The work is primarily a methods piece, presenting Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) results that provide evidence for validity of the five constructs of cognitive engagement being measured. I was the primary author of the work, and conducted my own EFA and CFA analyses. This work is foundational to my later work, and is the culmination of several supporting efforts.

1.2 Ch. 3 Student Perspectives on Cognitive Engagement: Preliminary Analysis from the Course Social and Cognitive Engagement Surveys

A supporting work to the aforementioned is Student Perspectives on Cognitive Engagement: Preliminary Analysis from the Course Social and Cognitive Engagement Surveys (A. Ironside, Lutz, & Brown, 2018), which provides data on student interviews essential to our survey development process. I did not conduct the interviews, rather analyzed the data for publication in American Society of Engineering Education (ASEE) 2018 Annual Conference Proceedings. I utilized data from these interviews to inform item development decisions, including the choice to simultaneously measure engagement both inside and outside the classroom. Data analysis of this work shaped the outcome of the SCCEI, and is evidence of my early fusion of quantitative and qualitative data sources for well-supported outcomes.

1.3 Ch. 4 WIP: Measuring Student Cognitive Engagement Using the ICAP Framework In and Outside of the Classroom

Upon the completion of the work on the development of the SCCEI, we sought to better understand how the instrument could be used outside the classroom. Using data collection during the SCCEI development, I conducted additional analysis and published *WIP: Measuring Student Cognitive Engagement Using the ICAP Framework In and Outside of the Classroom* (Barlow & Brown, 2019) at the ASEE 2019 Annual Conference. This work builds on the SCCEI development, indicating that our instrument differentiates between in-class and out-of-class engagement. While we posited this to be the case based on student interviews, paired t-tests on over 500 respondents indicated significant differences in the means of cognitive engagement reported by students in-class and out-of-class. I authored the work and ran data analysis.

1.4 Ch. 5. Discovering Upper-Division Students' Cognitive Engagement across Engineering Courses—An Interpretive Phenomenological Analysis Approach

Experiences from the development process of the SCCEI led to questions regarding what shapes student cognitive engagement in engineering courses. To explore this phenomenon, I conducted an in-depth qualitative study. Participants were five upper-division civil engineering students who were willing to discuss with a researcher (myself) their engagement experiences across their engineering courses. Interview data was transcribed and analyzed using Interpretive Phenomenological Analysis (IPA). The IPA approach has recently gained traction in engineering education contexts. IPA allowed for the individual participant experience to inform our understanding of the broader phenomenon of student engagement. The sample was purposefully selected to include high-achieving students of the same major, at the same institution, at approximately the same point in their academic career. By eliminating potentially confounding variables, I was able to postulate what shaped participant's cognitive engagement in their particular context. Findings suggested that participants were influenced by their own engagement values, their future goals, the instructor's engagement posture, and by strategies they deemed efficient and effective. Of particular importance to the education community is the role instructors play on shaping the engagement of even high-achieving students. While these findings are not intended to represent the universal of all engineering students, they begin to provide insight into how educators may seek to engage their students more meaningfully. I conducted all of the interviews and data analysis, with feedback solicited from the research team to ensure credibility and trustworthiness. I prepared the manuscript for publication, which at the time of this work is in review with Emerging Issues in Engineering Education.

1.5 Ch 6. Correlations between Modes of Student Cognitive Engagement and Instructional Practices in Undergraduate STEM Courses

My work with development of the SCCEI and student interviews discussing their cognitive engagement culminated with a study of the correlation between student modes of engagement and instructional practices. The SCCEI was developed as a means for instructors to assess their students' cognitive engagement and modify their instruction accordingly. One part of uncovering how the SCCEI might be useful to instructors was to gather the perspective of students on what shaped their engagement (Ch. 5). A second component of understanding the usefulness of the SCCEI was to empirically relate it to instructional practices in the classroom. To do so, we looked to existing research to select two instruments to use in tandem. We elected to use the SCCEI due to our familiarity and its unique measure of modes of engagement. The SCCEI was paired with an instrument to measure instructional practices, the Postsecondary Instructional Practices Survey (PIPS). Instructors were recruited to take the PIPS and provide their students with the opportunity to take the SCCEI. Underlying factors measured by either instrument were correlated using partial correlation analysis. Results showed that significant correlations existed between the two instruments. This work contributed both a novel use of multiple instruments with evidence of validity and a deeper understanding of how student cognitive engagement is responsive to instructional practices. I managed all of the recruitment, data collection, and data analysis for this work. Additionally, I authored the work pending submission in the International Journal of STEM education.

2 – DEVELOPMENT OF THE STUDENT COURSE COGNITIVE ENGAGEMENT INSTRUMENT (SCCEI)

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Abstract

Background: Evidence shows that students who actively engage with learning materials demonstrate greater learning gains than those who are passively engaged. Indeed, cognitive engagement is often cited as a critical component of an educational experience. However, understanding how and in what ways cognitive engagement occurs remains a challenge for engineering educators. In particular, there exists a need to measure and evaluate engagement in ways that provide information for instructors to deploy concrete, actionable steps to foster students' cognitive engagement.

Purpose/Hypothesis: The present study reports the development and validation evidence of a quantitative instrument to measure students' in-class cognitive engagement. The instrument was informed by Wylie and Chi's ICAP model of active learning as well as contextual concerns within specific engineering courses.

Design/Method: The process followed the classical measurement model of scale development. We provide a detailed overview of the item development and scale validation processes, focusing on the creation of individual subscales to measure different modes of cognition within learning contexts.

Results: Validation testing of the Student Course Cognitive Engagement Instrument (SCCEI)

provided evidence of validity, indicating reliable claims about student cognitive engagement in the classroom can be measured by the instrument. Further, results suggest

the need for additional engagement scales that distinguish between particular activities within a mode of engagement as defined by ICAP.

Conclusions: The present study contributes to the growing body of literature on cognitive engagement of engineering students. Results address the development of measurement tools with evidence of validity for use in STEM education.

2.1 Introduction

Engineering education research emphasizes the importance of engagement for student learning and academic success (Christenson, Reschly, & Wylie, 2012; Fredricks et al., 2004; Jones, Paretti, Hein, & Knott, 2010). Researchers prompt educators to innovate and generate engaging courses for the betterment of their students (H. L. Chen, Lattuca, & Hamilton, 2008; Chi & Wylie, 2014). Yet, educators are often left to make meaning of what student engagement might look like in their course without the support of the researchers who study engagement. To do so requires educators to interpret theoretical definitions of engagement and apply them to their unique course contexts. One strategy to promote innovation related to engagement in the classroom is to provide educators with tools to measure their success in facilitating student engagement. Tools to measure engagement place the responsibility of theory interpretation on the tool developers, thereby limiting the need for educators to do this themselves. This mitigates concern that educators who inappropriately assimilate theory-based practices into their courses may conclude they are simply ineffective (Henderson & Dancy, 2011).

One foundational component of measurement tools is clearly defining the phenomenon to be measured (DeVellis, 2017). However, a notable challenge is that there are many different, and equally valid, ways of defining and discussing student engagement in extant engagement literature. Craik and Lockhart (1972) discussed engagement in terms of depth of cognitive processing (e.g. *shallow* versus *deep)*; recently, theorists have examined engagement in terms of its multifaceted nature (e.g. *behavioral, emotional, and* *cognitive engagement)* (Appleton, Christenson, Kim, & Reschly, 2006; Fredricks et al., 2004). While these different ways of conceptualizing engagement have been informative in different contexts, determining the most authentic way to assess indicators of engagement that have the most direct and observable bearing on teaching and instruction in the classroom remains a challenge for engineering educators. For example, despite the fact that research has repeatedly indicated the existence of a strong positive relationship between student learning and cognitive engagement, it has been difficult to measure cognitive engagement in the classroom satisfactorily (Chi & Wylie, 2014). This is perhaps the case because a definition for the concept of cognitive engagement has been particularly elusive.

Recently, Chi and colleagues proposed the Interactive, Constructive, Active, and Passive (ICAP) framework, a model for conceptualizing different dimensions of cognitive engagement (Chi & Wylie, 2014). The framework establishes modes of cognitive engagement that can be observed as overt behaviors in students. The present study sought to develop an instrument to that leveraged the ICAP framework to indicate the mode of cognitive engagement students exhibited in classroom learning contexts such as notetaking and processing material. This survey is intended to be applicable to educators who want to better assess student cognitive engagement in their engineering classes, especially as they reflect on the impact of instructional innovations intended to enhance student engagement in their classroom. We also hope that the STEM education research community would find the instrument a viable tool to assess depths and quality of cognitive engagement in a range of classroom contexts. The present work provides a detailed overview of how the instrument was developed to measure student cognitive engagement.

2.2 Relevant Literature

This section briefly discusses how engagement has been defined, emphasizing significant literature contributing to the development of student cognitive engagement theories. We also discuss the ICAP framework, and its usefulness in capturing different dimensions of cognitive engagement. This section provides an overview of theoretical perspectives of engagement in extant literature that informed how we operationalized cognitive engagement, while a general overview of survey development literature is discussed in the methods section.

2.2.1 Engagement

Researchers have sought to define engagement in a broadly encompassing manner. Within the scholarship of teaching and learning, engagement is generally construed as specific behaviors that students exhibit within a learning environment that indicate the quality of their involvement or investment in the learning process (Pace, 1998). Some researchers have posited that engagement can be thought of as a meta-construct—one that can be broken down into the components of *behavior, emotion,* and *cognition* (Fredricks et al., 2004). Behavioral engagement entails involvement in learning and academic tasks, as well as participation in school-related activities. Emotional engagement encompasses students' affective response, or commitments, to activities in their learning environment.

Cognitive engagement, the focus of the present work, refers to the level of psychological investment in the learning process exhibited by the learner (Fredricks et al., 2004). Exploring the impacts of engagement, broadly defined, on student outcomes such as persistence, migration, self-efficacy, and student performance has been useful to the engineering education research community (S. Freeman et al., 2014; Kashefi, Ismail, & Yusof, 2012; Ohland et al., 2008; Sun & Rueda, 2012). However, some have argued that student engagement, as broadly defined in many studies, only captures observable behavioral activities that are not necessarily indicative of students' cognitive investment in the learning process. This, perhaps, is due to the fact that students' behavioral activities are the only aspect of the engagement meta-construct that can be directly observed and thereby assessed (Fredricks et al., 2004). Cognitive and emotional engagement are thus considered latent constructs; they cannot be directly measured, and require more intentional approaches that focus on the measurement of related variables to be captured (McCoach, Gable, & Madura, 2013).

2.2.2 Cognitive Engagement

Cognitive engagement is conceptualized in the learning and instruction literature as the psychological investment students make towards learning – which ranges from memorization to the use of self-regulatory strategies to facilitate deep understanding (Fredricks et al., 2004). Irrespective of pedagogical strategies, research shows that meaningful learning is predicated on quality cognitive engagement (Guthrie et al., 2004; K. A. Smith et al., 2005a). In fact, cognitive engagement is at the hallmark of the *Seven*

Principles of Good Practice in Undergraduate Education (Chickering & Gamson, 1987). Among other things, Chickering and Gamson's seven principles, which include active learning and contact between students and faculty, emphasize the importance of cognitive engagement to learning. Deep cognitive engagement has been linked directly to achievement (Greene, 2015). To increase cognitive engagement, students must move from *shallow* cognitive processing to *meaningful* cognitive processing (Craik & Lockhart, 1972). Deep cognitive processing allows for the kind of mental connection and knowledge elaboration that fosters higher level cognitive learning outcomes, while shallow processing perpetuates rote learning most engendered by lack of robust engagement with the learning materials (Christopher et al., 2005).

2.2.3 Measurement of Cognitive Engagement

Measuring this important construct is not a new venture, as several education researchers have developed a variety of approaches to assessing students' cognitive engagement. Meece, Blumenfeld and Hoyle (1988b) conceptualized cognitive engagement in terms of student goals and their impact on learning, and thus proposed individual cognitive engagement as a function of learning goals. Inspired by Meece et al., Greene and Miller (1996) developed a measure of *meaningful* and *shallow* cognitive engagement based on a student achievement framework dubbed the Motivation and Strategy Use Survey. They reported empirical data to support the predictive validity evidence of a measure of cognitive engagement based on a goal-achievement theoretical framework. Their study confirmed a relationship between perceived ability and goals student set for their learning

(Greene & Miller, 1996), reaffirming the importance of student cognitive engagement. Validation evidence of this instrument was collected from an educational psychology class and items were general and not engineering-course specific. Appleton et al. proposed a measure of cognitive and psychological engagement that is focused on "students' perceived competence, personal goal setting, and interpersonal relationships" (Appleton et al., 2006, p. 431). Their 30-item Student Engagement Instrument (SEI), was developed based on a context-student engagement-outcomes taxonomy derived from a review of engagement-related literature at the time. SEI was designed to assess the cognitive engagement of middle school and high school students. Similar to the SEI, the Motivated Strategies for Learning Questionnaire (P. R. A. O. Pintrich & A, 2015) also provided insight into student cognitive engagement, as defined in terms of motivation. While showing evidence of validity for generalized measure of a student's engagement, both instruments have limited usefulness in specialized contexts such as an engineering course. The SEI does not relate to a specific learning context (e.g. a singular classroom), and the MSLQ does not clearly report on modes of cognition (e.g. at what point is engagement *meaningful*?).

Scoping instruments to measure cognitive engagement as it relates to a course is important if such measurement tools are intended to be used in assessing instructional effectiveness or to evaluate pedagogical practice—particularly given that there have been calls within our research community to modify engineering classes to encourage active learning (i.e. Chi, 2009; Prince, 2004). As stated by Greene in *Measuring Cognitive Engagement With Self-Report Scales: Reflections From Over 20 Years of Research*, there are limited tools to measure cognitive engagement in uniquely challenging context of the sciences (2015). Chi and Wylie's Interactive-Constructive-Active-Passive (ICAP) framework for linking cognitive engagement with learning outcomes provides a theoretical model for operationalizing and measuring cognitive engagement in STEM course-based or classroom learning contexts.

2.2.4 Interactive-Constructive-Active-Passive (ICAP) Framework

Chi foregrounded her ICAP framework in a comparative review of research that focused on exploring and classifying active learning activities in the classroom (Chi, 2009). The goal of the work was to "provide a framework differentiating [modes of cognitive engagement], in terms of [students'] overt activities and their corresponding cognitive processes" (Chi, 2009, p. 75). According to Chi, the framework was not "meant to be definitive, but only as a starting point to begin thinking about the roles of overt learning activities and their relationship to internal processes" (Chi, 2009, p. 75). Subsequently, Chi and Wylie further developed their theory of cognitive engagement to include four modes: 1) Interactive, 2) Constructive, 3) Active, 4) Passive (Chi & Wylie, 2014). The framework, known as ICAP, links observable behavioral actions of students in different learning situations to distinct modes of cognitive engagement. This way, they moved away from the historical ambiguity associated with broad operational definitions of cognitive engagement.

The ICAP framework operationalizes engagement in terms of activities that are applicable to, and observable in, a number of learning environments. They posit that students show deeper psychological investment in learning, and are more cognitively engaged as they move from *[P]assive* to *[A]ctive* to *[C]onstructive* to *[I]nteractive*. Invariably, each mode of cognitive involvement requires different levels of knowledge-change processes, or means of acquiring and knowing through learning, that result in increasing levels of meaningful learning from passivity to interactivity (Chi & Wylie, 2014). To illustrate this, Chi and Wylie drew distinctions between modes of engagement by indicating distinctive actions and verbs that characterize each level.

According to the ICAP framework, when Passively Engaged, students are only oriented towards instruction. For example, students may passively *listen* to a lecture, *read* books, or *watch* a video. Students become Actively Engaged when they *repeat*, *rehearse*, or *copy* notes. To be considered Constructively Engaged, a student must take the original material and manipulate it in a meaningful way. Meaning that, constructively engaged students *reflect*, *integrate*, and self-*explain* concepts. Interactive Engagement represents the highest level of cognitive engagement; students may engage in discussions in which they explain their thoughts and positions to one another. Students may *defend*, *ask*, and *debate* as they interactively engage in the learning context (Chi & Wylie, 2014).

One objective of the ICAP framework is to provide instructors with a tool that enables them to assess the more of cognitive processing of students. This is accomplished by observing students' learning behaviors as they engage with learning tasks in the classroom (Chi & Wylie, 2014). This task of observing and inferring cognition based on students' overt behaviors can prove daunting to instructors based on factors such as their student population size, time and effort required during class time, and understanding of the assumptions of the framework. Furthermore, the usefulness of seeking to observe cognition has been questioned by Appleton, who has suggested that making inferences regarding students' cognitive engagement via observation is not as valid as obtaining students' perspectives on their learning experiences (2006).

While the ICAP framework allows for inferences on students' mode of cognitive engagement during a classroom learning activity, a survey-based measurement schema to provide educators aggregated feedback of students' perspective on their own cognitive engagement has yet to be developed. Because the ICAP framework currently relies on the interpretations of an observer, it is limited in its scalability to serve as an effective tool for assessing and evaluating students' cognitive engagement. The ICAP framework also focuses on a learning activity as opposed to the experience of an individual learner. These scalability and specificity challenges create a need to develop measures that both solicit individual student perceptions and are grounded in the ICAP framework.

2.2.5 Evaluating the Robustness of the ICAP Framework

In response to the ICAP framework, some have designed studies to test the comparative efficacy of instructional methods that encourage each level of the four cognitive engagement highlighted by the ICAP framework. Some of the early work to test the ICAP hypothesis was conducted by Menekse and colleagues (Menekse, Stump, Krause, & Chi, 2011, 2013). In their studies, they compared the learning gains of students' contexts that either promoted Interactive, Constructive, Active or Passive learning activities. They found that students had higher and deeper conceptual understanding of materials science and engineering concepts when taught using learning activities that fostered Interactive Engagement. Additionally, the test scores demonstrated that students had significant incremental learning gains from Passive to Active to Constructive to Interactive activities—which affirms the central ICAP hypothesis.

Wang and colleagues collected and coded data from a Massive Open Online Course (MOOC) discussion forums using coding schemes based on the ICAP framework (Wang, Yang, Wen, Koedinger, & Rosé, 2015). They aimed to better understand how students engage in online learning environments that often lack teacher and peer social presence (Akcaoglu & Lee, 2016). They observed that students' Active and Constructive discussion behaviors significantly predicted students' learning gains, consistent with the ICAP hypotheses (Wang et al., 2015). Additionally, Marzouk, Rakovic, and Winne (2016) used the ICAP framework as a means to generate feedback for students to improve metacognitive skills.

The associations between overt behaviors and cognitive engagement underscores the predictive validity of the framework and strengthens the case for using it as a conceptual framework for designing a cognitive engagement instrument. Drawing on the ICAP framework, DeMonbrun and colleagues mapped instructional practices to the four modes of cognitive engagement. Then, students were prompted on their *response* to the instructional practice (i.e. Value, Positivity, Participation, Distraction, Evaluation) (DeMonbrun et al., 2017). While DeMonbrun used the ICAP framework to indicate the *mode* of the classroom students were in, they did not map the engagement of students to ICAP, or specifically study cognitive engagement. Yet, their work serves to validate that ICAP is a reliable indicator for modes of cognitive engagement in measurement scales.

Because of the importance of cognitive engagement in the development of meaningful learning environments for students, we argue that an optimal instrument would leverage the modes of cognitive engagement proposed by ICAP to provide an empirically reliable tool for assessing engagement in classroom learning contexts. How students interact with one another, take notes, and process material, which are behaviors associated with elements of the ICAP framework, are classroom learning contexts relevant to engineering courses and influenceable by educators and thereby provide a foundational starting point for assessing cognitive engagement.

2.3 Methods and Results

In the following sections, we summarize the development of our instrument to measure student cognitive engagement based on the ICAP framework. This instrument is a part of ongoing program of research aimed at holistically understanding how STEM students engage with their courses both inside and outside the classroom. While our previous work has offered specific details on modifications made to various versions of our instrument (Authors, 2018), here we explicate the iterative processes of survey development that led to the current version with evidence of validity and reliability.

Our approach follows recommendations by DeVellis in *Scale Development: Theory and Applications* (DeVellis, 2017) in large part because the work focuses on the development of measurement tools in educational contexts. DeVellis outlines 8 main steps in the development of a scale. We describe in sequence how we executed each of these steps in developing the Student Course Cognitive Engagement Instrument (SCCEI). The overlapping and iterative nature of scale development is particularly evident in Steps 2, 3 and 4 (*generating an item pool, determining a format for measure,* and *expert review,* respectively) — we generated an item pool, determined item formats, and conducted expert reviews in a concurrent series of activities. Therefore, we present Steps 2, 3, and 4 in a single section to allow the reader follow the logic behind the selected items and measurement format. The 18 items tested for the SCCEI validity are presented at the conclusion of Step 4. This paper seeks to illustrate how we followed recommended practices in instrument development in an effort to provide a transparent description of the process.

2.3.1 Step 1: Determine Clearly What it is You Want to Measure

The first step in scale development is to think "clearly about the construct being measured" (DeVellis, 2017, p. 105). Obvious though it may sound, it is often the case that this is particularly important in determining the operational definition of the *construct* to measure and the theoretical framework to draw from (Benson & Clark, 1982). Step 1 is important in defining how the intended new instrument differs from any other existing instrument. Identifying the appropriate theoretical framework is germane to item specification and development.

As noted earlier, engagement has been broadly defined and discussed at various levels of specificity in the literature. Researchers emphasized the importance of determining the level of specificity when conceptualizing engagement in an effort to develop a tool to measure the construct (Sinatra et al., 2015). We seek to develop an instrument that assesses cognitive engagement that leveraged the strengths of the ICAP framework (Chi & Wylie, 2014). The ICAP framework is premised on empirical data that associates certain observable behavioral characteristics with cognitive engagement and learning gains. The ICAP framework does not directly address cognition. Rather, behavioral responses are used as proxies for students' cognitive engagement. Utilizing the ICAP framework as our foundational definition for cognitive engagement was strategic given that the framework has been positively received and well-cited within the engineering education research literatures (e.g., Menekse et al., 2013; Wang et al., 2015).

We based our *construct* and item specificity on how the ICAP framework describes behavioral responses that depict the four levels of cognitive engagement. Because the ICAP framework can be applied to a wide array of learning activities, we looked for learning activities ubiquitously present in engineering courses and influenceable by educators. Constructs to measure were the modes of engagement when interacting with peers, taking notes, and processing material in a course. While these constructs do not holistically represent learning in a classroom, or the ICAP framework, they provide an intentional starting point from which to understand modes of cognitive engagement in engineering classes.

After extensive literature search, a decision was made to allow students to reflect on their own cognition, not only for benefits gained from self-reflection (D. Nicol & MacFarlane-Dick, 2006), but because their perspective on their own engagement is valuable. Appleton et al. argue that self-report is more useful than observation and rating scales when analyzing emotional and cognitive engagement specifically (2006). They argue that observation and teacher-rating scales are unreliable measures of emotional and cognitive engagement due to its highly inferential nature. While self-report may not be reflective of an absolute reality, we are not seeking to prove that students are a perfect judge of their own behaviors (or cognition for that matter). Rather, students' own beliefs about their engagement shape their reality and, in turn, the reality of those seeking to educate them. Therefore, we employed self-report in this study to enrich our understanding of student engagement.

2.3.2 Steps 2, 3 & 4: Generate an Item Pool, Determine the Format for Measurement, and Expert Review

In Step 2 of DeVellis's model, the developer "generate[s] a large pool of items that are candidates for eventual inclusion in the scale" (p. 109). It is important to generate items that reflect the survey's purpose in sufficient quantity and redundancy. In Step 3, we determine the format for measurement, addressing the significance of the type of scaling, number of response categories, and the time frames associated with item. Steps 2 and 3 should occur simultaneously, ensuring that items are matched with an appropriate format for measurement. The purpose of Step 4 is threefold: (1) have experts rate how relevant the items are to the construct being measured, (2) evaluate for clarity and conciseness, and (3) point out phenomena not addressed in the survey (p. 118).

Here, we present the initial items we developed and their coinciding format for measurement, followed by an overview of the review and modifications made to both, and finally a presentation of the items and format for measure to study validity in subsequent steps.

Items and measurement schema were developed by our research team of experts in different disciplines including engineering education, psychometrics, educational research, social networking, and faculty change. We conducted virtual meetings monthly for a year as part of an ongoing development (Steps 2 and 3) and review (Step 4) process. We reached out to Ruth Wylie, a co-author of the published classic work on the ICAP framework, to provide expert review of our items. An additional, substantial piece of the Step 4 expert review was interviewing faculty and students. While extensive findings of the feedback generated by both faculty and students can be found elsewhere (Authors, 2017; Authors, 2018), here we present the findings most directly related to modifications made to our instrument.

When determining how to specify items for each construct, we considered how ICAP's action verbs were related to interacting with peers, taking notes, and processing material.

Consequently, we ensured each item reflects at its root action verbs associated with each of the four levels of cognitive engagement, thus aligning with ICAP.

First, our research team paired the verbs used by Chi and Wylie (2014) with a large range of potential actions or cognitive states (e.g. we paired the generative verbs *compare* and *contrast* with *lecture concepts and course content* to construct items that capture the presence of Constructive Engagement). Secondly, we generated multiple items to capture each construct being measured. We selected adjectives to minimize overlap between discrete items. Third, in accordance with Benson and Clark (1982), we created a redundant set of items about twice as large as would be needed to capture all the dimensions of the construct we intend to measure. This recommendation is intended to ensure sufficient number of items are retained, as some (poor items) may be lost to the validation process.

Lastly, we narrowed our initial pool of items while ensuring the generalizability of those items and their ability to measure each level of cognitive engagement that ICAP prescribes. We ended up with 38 items (see Table 2.1) to measure four levels of cognitive engagement. Figure 2.1 below offers a visual depiction of how the ICAP theory was translated into a redundant set of items.

Table 2.1: The 38 items developed in Step 2, with the modes of ICAP they intended to measure. Items were grouped into categories based on the presence of verbs related to the specific ICAP mode of engagement.

ICAP Category	***Question***
Interactive	I defend my approach to others when discussing course content.
	I discuss my position with others regarding the course content.
	I ask questions to understand other students' perspectives when discussing course content.
	I answer questions describing my perspective when discussing course content
	I explain concepts to others when discussing course content.
	I justify my perspective to others when discussing course content
	I evaluate alternatives with others when discussing course content.
	I do not discuss course concepts with other students.
	I work with other students to understand ideas or concepts regarding course content.
Constructive	I take notes in my own words.
	I add my own notes to the notes provided by the lecturer.
	I draw pictures/diagrams/sketches to clarify course content.
	My course notes include additional content to what the teacher provided.
	I add my own content to the course notes during lecture.
	I consider how multiple ideas or concepts relate.
	I consider how lecture content relates to content from other courses.
	I consider how lecture content relates to course assignments.
	I compare and contrast lecture concepts to concepts from other courses.
	I do not consider how course content relates to other courses.
Active	I take verbatim notes.
	I copy solution steps verbatim.
	I only copy the notes the instructor writes down.
	I do not add my own notes to the course notes.
	I apply current concepts being taught to previous course content.
	I combine current concepts with previous course content
	I apply current solution steps with previous course content.
	I combine current solution steps with previous course content.
	I do not apply course content to previous content.
Passive	I listen to lectures without doing anything else.
	I listen to what the teacher is saying and do not do anything else
	I do not think about course content during lecture.
	I focus my attention on things other than course content during lecture.
	I do not write notes during lecture
	I do not pay attention to course content during lecture.
	I think about current concepts covered in this course.
	I think about previous concepts covered in the course.
	I think about solution steps during the lecture.
	I think about previous solution steps during the lecture.

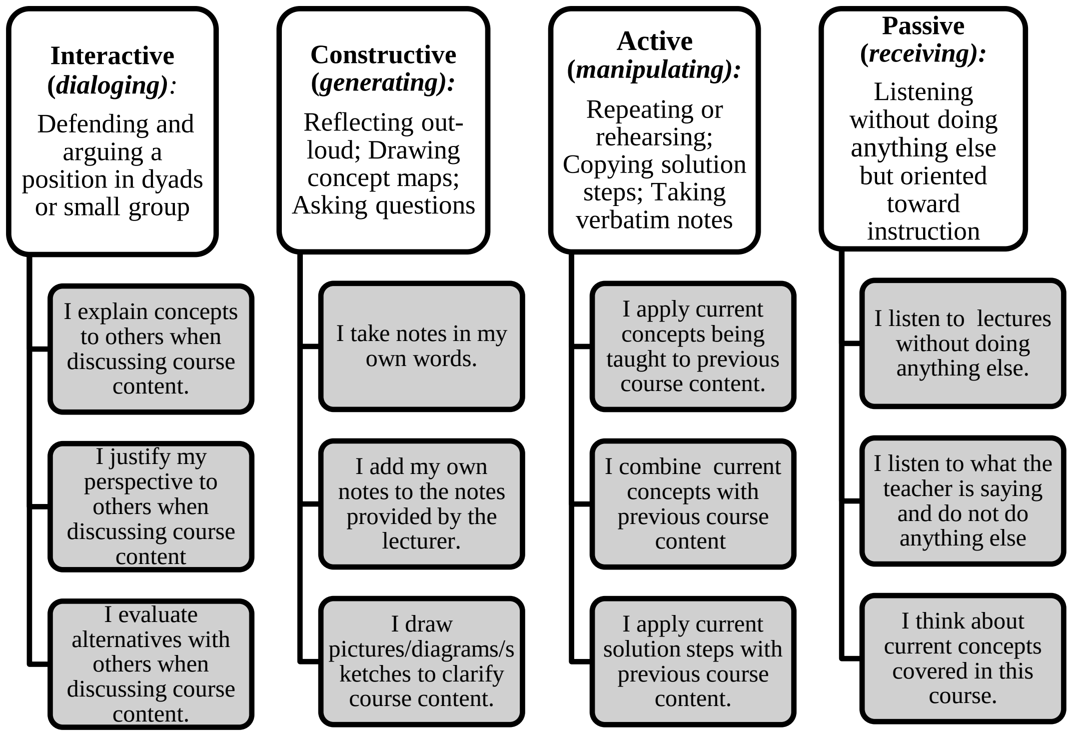

Figure 2.1: Language originally a part of the ICAP framework, and sample questions that resulted in early development stages. Text in the top white boxes is directly from Wylie and Chi's 2014 work. The questions are a sample in which redundant verb usage and activities can be seen.

DeVellis recommends proactively choosing a timeframe that reflects the objective of the survey. Timeframe highlights the temporal feature of the construct being assessed. Some scales may have a universal time perspective (e.g. stable traits such as locus of control), while others require transient time perspective (e.g. a depression or some activity scale). In determining appropriate response scale for the survey, we considered possible timeframes that our items could address: a singular incidence/activity, an individual class period, or the aggregate experience of the course. We decided that this particular Likert scale would address the aggregate experience of the in-class activity of a student for initial testing.

We simultaneously sought to determine an appropriate scale format for the items generated during Step 2. Because we were interested in assessing how well respondents believed the items described their learning behaviors, we chose Likert-scale type using the appropriate language "...descriptive of my…" as our response type (Table 2.2 shows the Likert scale option format that we adopted). This wording was based on a previously developed Likert scale used in educational research related to classroom practices (Walter, Henderson, Beach, & Williams, 2016). In order to determine a convenient level of response options, DeVellis suggests that one considers that respondents are able to *discriminate meaningfully* between response options (DeVellis, 2017, p. 123). For example, it is more conceptually convenient and meaningful to use a 3- or 5-scale Likert type, than to use an 11 or 100-scale type. The fewer the options, the fewer the labels needed (e.g. Strongly disagree ... strongly agree) to describe intermediate options. In fact, some empirical studies on survey design has suggested the 5 or 7-Likert type scales as more reliable than scales with more options (Preston & Colman, 2000; Weijters, Cabooter, & Schillewaert, 2010).

Table 2.2: The 5-point Likert scale associated with the 38 items developed in Step 2. With each response option, students were reminded to consider only in-class activity.

Prompt: *The following items refer to activities you engage in during class without being directed to do so by your teacher*				
Not at all descriptive of my in-class activity	Minimally descriptive of my in-class activity	Somewhat descriptive of my in-class activity	Mostly descriptive of my in-class activity	Very descriptive of my in-class activity

This instrument was built in Qualtrics (Qualtrics, 2005), an online platform for survey distribution and analytic tools. For initial testing, there were 480 total student responses from 24 different courses. Each of the instructors from the 24 courses was solicited for feedback in a series of interviews. In these interviews, they were asked to share their beliefs on the functionality of the instrument in their classroom environments and what they hoped to gain from the use of such an instrument. Of the 480 students who participated in the study, 13 students volunteered to be interviewed to discuss and justify their responses to survey items.

We learned from these interviews that students often used both in-class and out-of-class justification for their responses to items, all of which were explicitly intended to relate to their in-class activity. We therefore determined in future iterations of the survey both in-class and out-of-class engagement should be measured simultaneously to explicate the location of the engagement. While we did not seek to validate the out-of-class engagement scale in this study, it provided students with an opportunity differentiate between where engagement activities take place. Evidence that students did distinguish between the two scales is presented in our other work (Authors 2019).

Students aggregating their in-class and out-of-class engagement when responding to items resulted in us modifying the format to measure to explicate the location of engagement. We chose modify the timescale of the single Likert scale to multiple scales representing different timescales: frequency and duration of activities in-class, and frequency of activities out-of-class. Responses to the in-class frequency scale were the focus of validation study, while the duration and out-of-class scales are to be utilized for future scale development. We envisaged that using three, 5-point Likert scales concurrently for each survey item will overburden respondents and hinder response rate (Preston & Colman, 2000; Weijters et al., 2010). Three, 3-point Likert scales were used instead (see in Table 2.3) to capture participants' response on multiple timescales.

Table 2.3: The three, 3-point Likert scale used. Students were prompted with the three scales simultaneously, with headings indicating the location of activity. Only the in-lecture frequency scale was used for validation studies.

Prompt: *I justify my perspective to others when discussing course content.*								
In lecture (*frequency*)			**In lecture** *(duration)*			**Outside the classroom**		
Few to no lecture periods	Some lecture periods	Most lecture periods	Little to none of the lecture period	Some of the lecture period	Most of the lecture period	Hardly ever	Some days	Most days

Subsequently, we conducted factor analysis to extract an optimum number of factors that underlies the scale and to document validity evidences for the scale. We examined evidence for construct validity by conducting exploratory factor analysis (EFA) of students (N = 480) responses to items on the survey. Tentatively, six factors were extracted using principle axis factoring and rotated using oblique procedure. Kaiser-Meyer-Olkin (KMO) was 932, indicating that the measure of sampling adequacy was sufficient for the EFA. Bartlett's test of Sphericity of $\chi^2(703) = 9196.892$ $p < .001$, suggesting that there were patterned relationships among the survey items. The decision to retain seven items was based on factors with eigenvalues greater than 1. In an effort to assure content validity, we noted the ways the ICAP theory could or could not be applied to these factors in the following ways.

Items generated appeared to measure a mode of engagement that falls beyond the ICAP framework—disengagement. Chi and Wylie's Passive Engagement indicates orientation towards instruction, and some students will indeed fall below this threshold. This means some students will not be oriented towards instruction (Passively Engaged) but will be disengaged with the material altogether. Although we designed some items to be reverse scored, the negatively worded items coalesced around a common factor related to disengagement. We note that some suggest against the practice of including reverse coded/negatively worded items (Roszkowski & Soven, 2010). Therefore, these items related to disengagement were removed. The study of students who fail to engage entirely—those who are disengaged—is beyond the scope of the modes of cognition measured by SCCEI.

Originally, we developed items to measure modes of cognition associated with both notetaking and processing. Preliminary EFA analysis suggested that items factored in alignment with their learning activity (i.e. processing), not simply their mode of cognitive engagement. We noted from preliminary interviews that students seemed to fail to distinguish between various verbs associated with higher-order processing of material, making Constructive Processing difficult to measure. Beyond this, researcher expertise suggested that notetaking in engineering courses typically falls above Passive Engagement (i.e. copying notes is more ubiquitous than emphasizing preexisting notes) and therefore was not measured by the SCCEI.

With refined content validity, we concluded that our items preliminarily measured five distinct phenomena of cognitive engagement: Interactivity with Peers, Constructive Notetaking, Active Notetaking, Active Processing, and Passive Processing. Items were intended to represent an aspect (or indicator) of the mode of cognitive engagement in a classroom with respect to a specific learning experience; the SCCEI may indicate levels to which student Constructively or Actively take notes, Actively or Passively process information, and Interact with their peers. Items did not holistically encompass a mode of cognitive engagement, rather they indicated its presence. Furthermore, the SCCEI does not measure ICAP holistically, rather it relies on ICAP to better understand cognition within classroom notetaking, processing of material, and interactivity with peers.

We leveraged the preliminary factor analysis to determine the highest correlating items related to our five newly hypothesized phenomena, and iteratively sought evidence for construct and content validity from interview datasets and expert reviews. Items were systematically removed until there were 3 to 4 remaining items for each of the five factors. In the end, a set of 18 items remained for validity testing (see Table 2.4). At the conclusion of Steps 2, 3 and 4, we had conducted a thorough review of both our items and format for measure to provide a foundation for construct and content validity in future steps.

Table 2.4: The 18-item version of our survey which uses a comparison of Likert scales to isolate in-class engagement.

ICAP Category	***Question***
Interactivity with Peers	I defend my approach to others when discussing course content. I discuss my position with others regarding the course content. I explain concepts to others when discussing course content. I justify my perspective to others when discussing course content.
Constructive Notetaking	I add my own notes to the notes provided by the teacher. My course notes include additional content to what the teacher provided. I add my own content to the course notes.
Active Notetaking	I take verbatim notes (meaning word for word directly from the board/PowerPoint slide/doc camera etc.). I copy solution steps verbatim (meaning word for word directly from the board/PowerPoint slide/doc camera etc.). I only copy the notes the teacher writes down.
Active Processing	I connect current concepts with previous course content. I apply current solution steps with previous course content. I think about previous concepts covered in the course. I consider how multiple ideas or concepts relate.
Passive Processing	I pay attention to my teacher or whomever is speaking. I follow along with my teacher or whomever is speaking when they discuss examples. I listen when my teacher or whomever is speaking. I follow along with the activities that take place during the course.

2.3.3 Step 5: Consider Inclusion of Validation Items

The validation items of Step 5 are intended to limit the influence of factors not related to construct being measured. A common example is social desirability, being that certain responses to given items can be seen as more desirable. In our study, we did not include validation items due to our focus on indicating the presence of modes of cognitive engagement related to ICAP and providing educators feedback about their courses (i.e., because our work is exploratory, it is not clear what items might be used to validate our scales). Other scales such as the Motivated Strategies for Learning Questionnaire (Pintrich, Smith, Garcia, & Mckeachie, 1993) may provide useful validation items in future work.

2.3.4 Step 6: Administer Items to a Development Sample

In Step 6, the survey was administered to a large sample population. The population ought to be representative of the larger population for which the survey is intended; in the case of our instrument, we sought to develop a survey that could indicate cognitive engagement of students in engineering courses varying in structure, style, and content. To this end, we recruited 15 engineering courses at eight different institutions that took place at varying points in a four-year curriculum. Institutions ranged in size, emphasis in research, and location. Enrollment in the courses ranged between 33 and 235. As part of reliability testing, an intraclass correlation coefficient (ICC) was generated based on the mean scores of each item for the 15 courses sampled. The ICC estimate and its 95% confidence interval was calculated using SPSS statistical package based on single-rating, consistency (as opposed to absolute agreement), and a 2-way random-effects model. Our ICC value of .615 (95% CI, .456 to .788) indicates that SCCEI items explain approximately 62% of the variation in item scores between courses sampled, and is therefore considered to be moderately reliable (Koo & Li, 2016).

The total population surveyed was 1,412 students. After removing responses less than 50% complete, 1,004 responses were utilized for analysis, resulting in an overall response rate of 71%. This large sample was intended to be split in order to conduct both an exploratory and confirmatory factor analysis. For a summary of participant demographics, see Table 2.5 below.

Table 2.5: Summary of study population demographics for all student responses. For *Race and Ethnicity*, multiple options could be selected. All demographic information collected was optional. Engineering student population data was collected from *Engineering by the Numbers* (Yoder, 2018).

1	Study Sample	Engr. Student Population
Institution Type		
Large, public Northwest R1 institution	47%	-
Moderately-sized, public Northwest R2 institution	13%	-
Small, private Southwest teaching institution	7%	-
Large, public Southwest R1 institution	7%	-
Large, public Western teaching institution	7%	-
Large, public Southeast R1 institution	7%	-
Small, private Northwest teaching institution	7%	-
Moderately-sized, private Midwest research institution	7%	-
Course Focus		
Civil and Construction Engineering	40%	8%
General Engineering	27%	5%
Chemical Engineering	7%	7%
Mechanical Engineering	7%	22%
Electrical Engineering	7%	17%
Aerospace Engineering	7%	4%
Computer Science	7%	13%
Academic Level		
Freshman	38%	-
Sophomore	9%	-
Junior	23%	-
Senior	30%	-
Gender		
Male	82%	78%
Female	18%	22%
Nonbinary	0.7%	N/A
Race and Ethnicity		
Caucasian	78%	67%
Asian	13%	16%
Hispanic/Latinx	4%	12%
Black/African American	4%	4%
Native American	0.4%	0.3%
Pacific Islander	0.2%	0.2%

2.3.5 Step 7: Evaluate the Items

DeVellis notes that “item evaluation is second perhaps only to item development in its importance” (DeVellis, 2017, p. 139). Evaluation entails examining the manner in which particular items correlate, predict variance, and form reliable scales to measure the desired constructs. To evaluate our items, we conducted factor extraction methods and internal reliability testing in line with recommendations by DeVellis (2017) and Thompson (2004). First, to perform the proper calculations, Likert-type responses were converted into numerical scores. Specifically, we implemented a 3-point scale in which 1 represented low frequency and 3 represented high frequency. Items to which students did not respond were considered null and omitted from subsequent analysis. Exploratory and confirmatory factor analyses were conducted for evidence of validity.

2.3.5.1 Exploratory Factor Analysis

We conducted an exploratory factor analysis following recommendations from Thompson (2004) as well as Costello and Osborne (2005) on approximately half of the dataset. The dataset was split into two such that the demographics (class size, term sampled, gender, race/ethnicity, etc.) of each set were similar. Although ICAP is a well-established theory, the structure of, and interaction between, the various modes of engagement is relatively underexplored. Therefore, because we are simultaneously developing a set of scales and operationalizing a theory of student engagement, an exploratory factor analysis (EFA) was appropriate. We conducted EFA using SPSS Version 24™ with missing values excluded pairwise (N ~ 495)—assuming all cases were unique. We utilized principle axis factoring with oblique rotation of items due to correlation between items. Additionally, we ran reliability tests, using Cronbach's alpha as a metric. Our Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy was .834, indicating a sample sufficient for factor analyses (Cerny & Kaiser, 1977). Bartlett's test of sphericity indicated that the correlation matrix is not an identity matrix and is therefore useful for a factor analysis [χ_2 (153) = 2794.1, $p < .001$]. Additionally, with 495 respondents, our ratio of items to respondents was over 20. The number of respondents situates our data within the "very good" sample size as defined by Comrey (1988) and well above the 5 to 10 recommended by Tinsley and Tinsley (1987). We utilized principle axis factoring to better understand the variance between factors (as opposed to principle component analysis, which seeks to better understand how individual items explain overall variance in score).

Several approaches to determining the appropriate number of factors to extract in the dataset has been proposed, the most common being eigenvalue and scree plot (Costello & Osborne, 2005). However, both methods have been criticized as being inadequate to obtaining an optimum number of factors. The Parallel Analysis (PA) is proposed as a more reliable alternative (Crawford et al., 2010). Parallel analysis represents the amount of variance that would be explained by each factor with completely randomized responses to items; number of responses and items are set equal to the number present in the dataset, and the eigenvalues for each factor are generated. Parallel analysis eigenvalues are compared to the eigenvalues present in the actual dataset—the scree plot. We conducted a parallel analysis based on principle axis factoring (PA-PAF) by running a PA syntax in SPSS® 25 that simulated 5000 parallel data sets from the raw data set using a permutation approach. The PA analysis supports the five-factor model; when factors extracted from the dataset explain more variance than is explained by randomized responses in the parallel analysis, they are considered meaningful. This support is illustrated in the eigenvalue table (Table 2.6) and the scree plot (Figure 2.2) below. We therefore felt confident in extracting five factors. Each factor indicates the presence of a mode of engagement as defined by ICAP in the context of interacting with peers, notetaking, or processing material (see Table 2.7 for factors extracted).

Table 2.6: Results from PA-PAF, which suggest a five-factor model.

Root	Raw Data	Means	95th Percentile
1	**4.251**	**0.401**	**0.473**
2	**1.508**	**0.330**	**0.385**
3	**1.289**	**0.274**	**0.321**
4	**1.066**	**0.227**	**0.268**
5	**0.378**	**0.184**	**0.223**
6	0.092	0.145	0.180
7	0.052	0.108	0.140
8	0.013	0.073	0.104
9	0.004	0.038	0.066
10	-0.075	0.006	0.033
11	-0.077	-0.027	0.001
12	-0.115	-0.058	-0.033
13	-0.132	-0.090	-0.064
14	-0.159	-0.121	-0.095
15	-0.174	-0.153	-0.128
16	-0.205	-0.187	-0.161
17	-0.230	-0.223	-0.194
18	-0.243	-0.268	-0.234

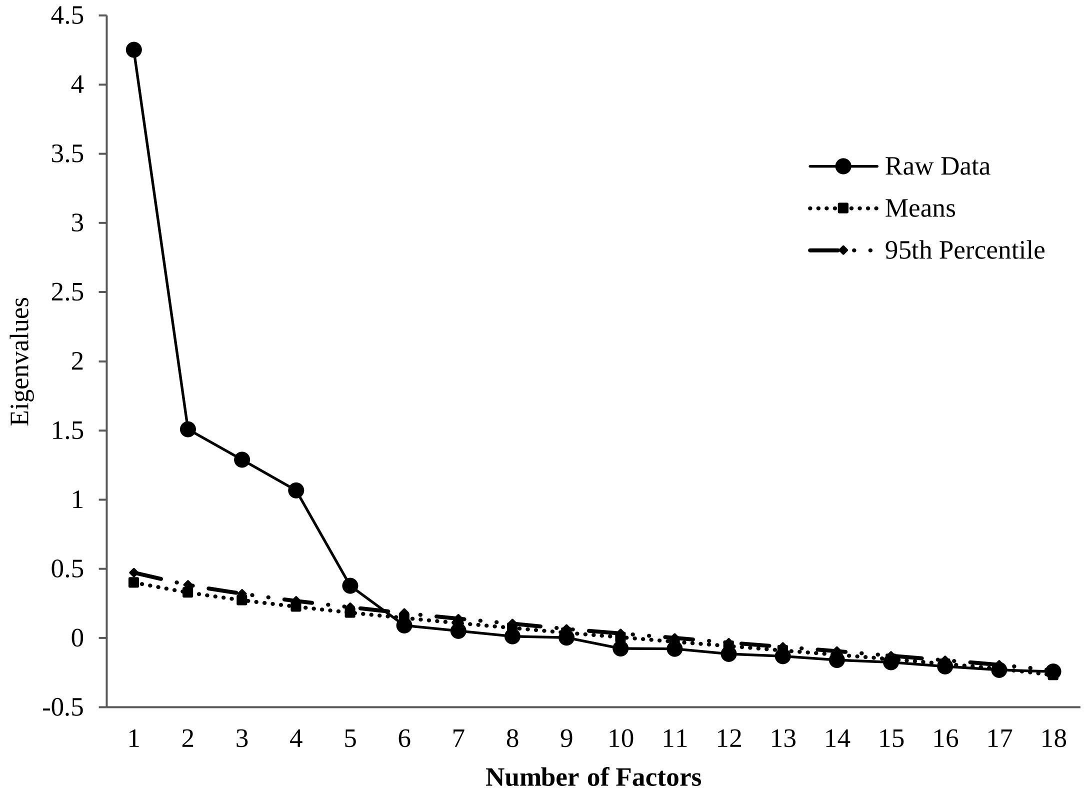

Figure 2.2: Scree plot and results of the parallel analysis. Each point indicates how much variance was extracted (represented by eigenvalues) for a given factor in the respective model.

Table 2.7: Results from the EFA related to frequency of in-class experiences.

Instrument Item	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Factor 1: Interactivity with Peers					
I defend my approach to others when discussing course content.	0.716				
I discuss my position with others regarding the course content.	0.662				
I justify my perspective to others when discussing course content.	0.656				
I explain concepts to others when discussing course content.	0.564				
Factor 2: Constructive Notetaking					
My course notes include additional content to what the teacher provided.		0.835			
I add my own notes to the notes provided by the teacher.		0.769			
I add my own content to the course notes.		0.651			
Factor 3: Active Processing					
I think about previous concepts covered in the course.			0.723		
I connect current concepts with previous course content.			0.632		
I apply current solution steps with previous course content.			0.495		
I consider how multiple ideas or concepts relate.			0.42		
Factor 4: Active Notetaking					
I take verbatim notes (meaning word for word directly from the board/PowerPoint slide/doc camera etc.)				0.755	
I copy solution steps verbatim (meaning word for word directly from the board/PowerPoint slide/doc camera etc.)				0.675	
I only copy the notes the teacher writes down.				0.567	
Factor 5: Passive Processing					
I listen when my teacher or whomever is speaking.					-0.915
I pay attention to my teacher or whomever is speaking.					-0.796
I follow along with my teacher or whomever is speaking when they discuss examples.					-0.619
I follow along with the activities that take place during the course.					-0.543
Eigenvalue	1.677	1.803	4.866	2.063	1.008
Percent Variance	9.315	10.017	27.035	11.461	5.601
Cronbach alpha Reliability	0.756	0.811	0.741	0.702	0.818

After determining five factors should be extracted, we looked at the loadings on each factor and the reliability of the items measuring each construct. The absolute value of all factor loadings were above the 0.3 minimum suggested by Hair et al. (Hair, Anderson, Tatham, & Black, 1995). Though the bounds on Cronbach's alpha for reliability are "personal and subjective", a lower bound of 0.60 is suggested (DeVellis, 2017, p. 145). Reliability for each factor is greater than this 0.60 bound, with some alphas exceeding 0.8. The large number of respondents and small number of items in our scale both influence alpha negatively (lower its value). Our intention was to build a useable instrument, and therefore we traded off a large pool of items for slightly lower reliability. Strong evidence is provided that these five modes of cognitive engagement are indeed distinct and can be defined, at least in part, by differences in behaviors and actions taken to complete in-class activities.

2.3.5.2 Confirmatory Factor Analysis

The remaining half of the dataset was used to confirm the findings of the EFA through a confirmatory factor analysis (CFA). Our CFA was conducted in alignment with Brown (2006), who suggests CFAs are useful in verifying both the factors and the relationship of items to factors in questionnaires. We conducted our CFA using AMOS Version 26™ with missing values replaced with means, as CFAs do not allow for missing data (N = 507). Our sample of 507 respondents far exceeds the minimum sample suggested by other researchers (Ding, Velicer, & Harlow, 1995; Gorsuch, 1983). We evaluated the model based on Comparative Fit Index (CFI), Tucker Lewis Index (TLI), Root Mean

Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR) model fit statistics. A CFI > .95, TLI > .95, RMSEA < .06, and SRMR < .08 is recommended for continuous data (Hu & Bentler, 1999).

The CFA yielded the following model fit indices CFI = 0.965, TLI = 0.957, and RMESA = 0.041, 90% CI [0.033,0.049], SRMR = 0.0436. Based on the recommendation noted earlier (Hu & Bentler,1999), the CFA model depicted in Figure 2.3 appropriately represents the sample data.

With evidence of good model fit, we analyzed the standardized factor loadings of items and covariances, average variance extracted, and construct reliability of each of the factors. Item reliabilities ranged from 0.531 to 0.884, which exceed the acceptable value of 0.50 (Hair et al., 1995). Covariance between factors ranged between 0.11 to 0.59, falling below the 0.85 threshold that indicates two factors may indeed be measuring a single construct (Kline, 2011). Visual representation of the CFA model along with standardized factor loadings and factor covariances can be seen in Figure 2.3. The construct reliabilities (CR) ranged from 0.681 to 0.861, and fell above the 0.60 threshold suggested by Bagozzi and Yi (1988). Values for average variance extracted (AVE) fell between 0.421 and 0.610; while it is commonly suggested that AVE values are above 0.5 (Hair et al., 2010), if CR values all remain above 0.6 some have suggested items within the factor should be retained (Fornell & Larcker, 1981). Table 2.8 provides a summary of these results. The cumulative effect of the CFA results added validity evidence to the model suggested by the EFA; we propose that the SCCEI measures five factors of cognitive engaging, indicating the presence of modes of cognition as defined by ICAP with respect to a given classroom experience.

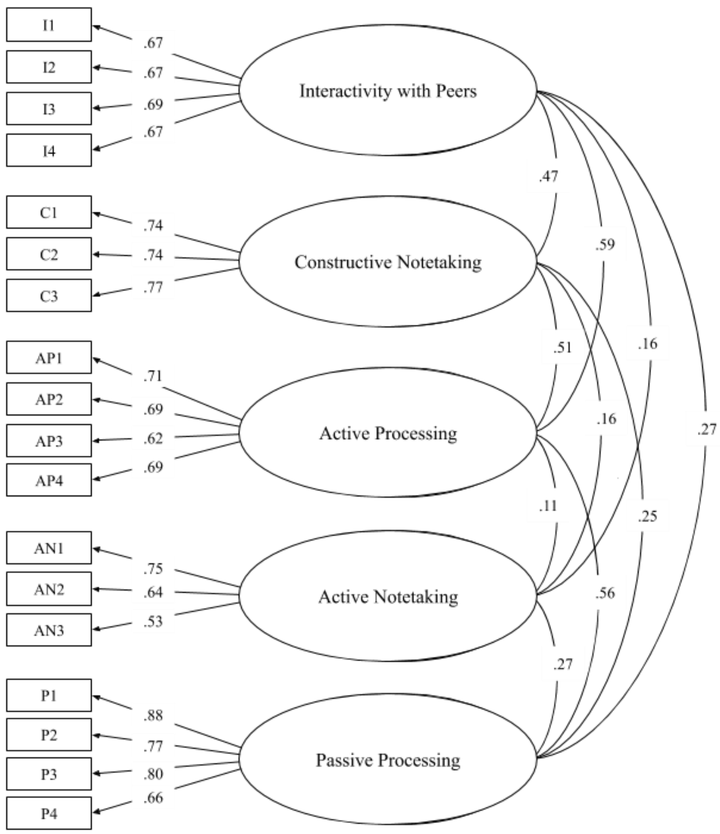

Figure 2.3: The CFA model related to frequency of in-class experiences. Arrows between factors (i.e Interactivity with Peers) and items (i.e. I1) represent standardized factor loadings. Connections between factors represent collinearity between factors.

Table 2.8: Results from the CFA related to frequency of in-class experiences.

Instrument Item	Standardized Factor Loading	Construct Reliability	Average Variance Explained
Factor 1: Interactivity with Peers		0.770	0.455
I defend my approach to others when discussing course content.	0.672		
I discuss my position with others regarding the course content.	0.666		
I justify my perspective to others when discussing course content.	0.693		
I explain concepts to others when discussing course content.	0.668		
Factor 2: Constructive Notetaking		0.794	0.562
My course notes include additional content to what the teacher provided.	0.738		
I add my own notes to the notes provided by the teacher.	0.738		
I add my own content to the course notes.	0.772		
Factor 3: Active Processing		0.772	0.459
I think about previous concepts covered in the course.	0.707		
I connect current concepts with previous course content.	0.689		
I apply current solution steps with previous course content.	0.617		
I consider how multiple ideas or concepts relate.	0.692		
Factor 4: Active Notetaking		0.681	0.421
I take verbatim notes (meaning word for word directly from the board/PowerPoint slide/doc camera etc.)	0.752		
I copy solution steps verbatim (meaning word for word directly from the board/PowerPoint slide/doc camera etc.)	0.644		
I only copy the notes the teacher writes down.	0.531		
Factor 5: Passive Processing		0.861	0.610
I listen when my teacher or whomever is speaking.	0.884		
I pay attention to my teacher or whomever is speaking.	0.767		
I follow along with my teacher or whomever is speaking when they discuss examples.	0.798		
I follow along with the activities that take place during the course.	0.657		

2.3.6 Step 8: Optimize Scale Length

The length of a scale should be modified in order to increase the reliability of the instrument in Step 8. To do so, developers must balance the benefit of a larger number of items increasing reliability with fewer number of items minimizing the burden on the participant (DeVellis, 2017). As we have established, a primary purpose of developing our survey was to provide educators with data on the engagement of students enrolled in their course. Through expert review, we determined that a shortened instrument would be crucial for its practical use. Educators mentioned the importance of an instrument that a majority of students would respond to, requiring that instrument to be of minimal effort to the student. To such an end, we focused our efforts on minimizing the number of items while still maintaining adequate reliability. The Cronbach's alpha of 0.60 and greater for each of the five factors indicated that our scale was both reliable and at a minimum length, and removing any additional items would serve to reduce the overall reliability of the instrument.

2.4 General Discussion

In this study, we reported the development of a new instrument designed to measure the cognitive engagement of engineering students. Chi and Wylie's review of cognitive engagement in the classroom provides a theoretical framework (ICAP) for the development of a new measure of cognitive engagement based on empirically supported relationships between students learning behaviors, their related cognitive activities, and learning outcomes. A secondary goal of this study was to illustrate the basic steps of scale development as recommended by DeVellis in ways that might serve as a resource for future developers.

Since its publication, the ICAP framework has been favorably received within the engineering education research community. In fact, DeMonbrun and colleagues have initiated a measure of cognitive engagement based on the framework (DeMonbrun et al., 2017). They posit that a student will identify a classroom as Interactive, Constructive, Active, or Passive and respond to that classroom environment cognitively, emotionally, and behaviorally (DeMonbrun et al., 2017). Here, we provide an instrument with validity evidence to determine how students report their own cognitive engagement in the classroom (e.g. the SCCEI allows for modes of engagement in a variety of classroom atmospheres).

Our primary objective was to develop and provide evidence of validity for a measure of cognitive engagement with ties to an empirically verifiable framework (which the ICAP provided), and that has broader applications to relevant situations. We set out to provide educators with a valid tool to measure the cognitive engagement of their students while notetaking, processing material, and interacting with peers. Through an extensive collection of validation evidence, this study presents an instrument that allows engineering educators to make valid claims about students' cognition in these instances. Through expert evaluation of items in each factor of the scale, we were able to ascertain that the scale demonstrated both content and face validity for its intended application. We were also able to strengthen claims of the construct validity of the instrument based on the exploratory and confirmatory analyses conducted. We realize however, that instrument validation is an iterative process that requires multiple studies conducted across diverse populations to strengthen the evidence of the validity of an instrument. As such, we intend to follow up on this study by collecting data to test our validity claims among other student populations, as well as to examine the predictive and concurrent validity of the instrument against established measures or indicators of cognitive engagement. While teacher rating, student observation, and learning outcomes may still remain crucial indicators of cognitive engagement, we envision that the SCCEI could provide researchers with a robust approach for measuring cognitive engagement with classroom experiences, especially if the intent is to evaluate the effectiveness of particular instructional interventions. Additionally, the frequency scale of the SCCEI allows for educators to prompt students to report on their cognitive engagement at different timescales (i.e. daily, weekly, or term basis).

2.4.1 Implications Regarding ICAP Framework

Chi and Wylie proposed a pragmatic theoretical lens for differentiating student cognitive engagement in a classroom. The intent of ICAP is to provide a hierarchical description of cognitive engagement that begins with passive engagement (characterized by individualistic learning activities) and progresses to include interactive engagement (characterized by interpersonal, collaborative learning activities). Several studies have examined the central premise of the framework that learning outcomes are positively correlated with increasing levels of cognitive engagement.

In the first phase of our item evaluation, we observed that some respondents seemed to differentiate between verbs related to their experiences of within a course; items related to students' notetaking and their processing of material factored separately, even when related to the same mode of cognition. This suggests that researchers may be able to obtain more valid self-report of how engaged students are by focusing items to emphasize particular course experiences, such as when a student is taking notes. In their recent work, Chi and colleagues note that students have difficulty differentiating between Active and Constructive activities (Chi et al., 2018). It therefore may be useful to continue to develop scales that assess the presence of a mode of cognitive engagement related to classroom learning activities (i.e. when students are asked to solve a problem).

2.4.2 Limitations

Our sample was comprised entirely of engineering students. Although we designed our instrument to be useful across STEM courses, validation evidence is needed for use of the SCCEI outside of engineering. Our sample reasonably represented the population demographics, but Caucasian males remained overrepresented compared to national averages in engineering (see Table 2.5 above). Further work is needed to understand the nuanced ways in which underrepresented groups cognitively engage, particularly as to how it may differ from normative groups. Valid claims can be made insofar as an instrument provides valid evidence; our broad sampling of courses across many institutions allows the SCCEI to make valid claims about engineering students in general, but limits its ability to provide valid claims about specific engineering student populations. Civil and general engineering were overrepresented in our sample, while mechanical and electrical were underrepresented. Additionally, some disciplines were not represented at all and may require future validation

SCCEI items are based on the theoretical framework of ICAP, yet these items are limited in their ability to holistically represent a mode of cognitive engagement. Importantly, Interactivity with Peers indicates that the student reports *potential* for Interactive Engagement, but only nuanced observation and/or discussion with the student would allow for insight as to the level with which they were Interactively Engaged with the material while Interacting with Peers. Despite limitations, the SCCEI provides educators with meaningful insight as to the presence of various modes of cognitive engagement in different classroom learning experiences.

2.4.3 Future Direction

Validation efforts involve iterative evaluation and improvement of an instrument in order to improve its psychometric soundness. Currently, we have only three or four items to assess each of the five factors. To further improve the reliability of the subscale comprising the instrument, we intend to create and test additional items for each construct on the scale. In this study, we have examined the structural validity of the subscales on our instrument. Subsequently, we intend to conduct other studies to further strengthen the validity evidence of our instrument. We look to establish its construct and predictive validity by examining measures and proxies of cognitive engagement across a broader sample of students. Efforts will also be made, in the future, to determine the ability of the instrument to effectively discriminate cognitively engaged students from those who are not.

Because we intend to expand the items on the instruments to improve the reliability of the sub-sales, future work would consider focusing on a single subscale (i.e. Interactivity with Peers) and developing items to related constructs that could be administered apart from the larger scale for specific research needs and minimize the need to administer the entire cognitive engagement when that is not desired. We posit that more studies are needed to better understand the interplay between engagement inside and outside of the classroom on other variables that mediate or moderate student learning and performance in engineering—especially in specialized learning contexts, (e.g. flipped classrooms). More work is needed to develop scales to indicate the presence of ICAP modes of engagement beyond classroom walls.

Our intent was to develop a scale to measure a construct (cognitive engagement) that is subsumed within a meta-construct (student engagement) drawing upon a theoretical framework that has a strong empirical support. We envision that our study will inspire others to create scales based on empirically grounded theory to measure other constructs germane to engineering education research that are subsumed in broader meta-constructs.

2.5 Conclusion

The present study seeks to report our effort to validate a new instrument of cognitive engagement with a literature-based theoretical framework. Our scale development efforts were informed by DeVellis' research. As we explored DeVellis' recommendations, we demonstrated that identifying the relevant literature plays a major part in scale planning development. Consequently, we aligned, and reasonably integrated Chi and Wylie's ICAP framework of cognitive engagement (Chi & Wylie, 2014) to situate the purpose and scope of our instrument. This theoretical alignment was important to the authenticity and the validity of our scale. We demonstrated the importance of engaging experts and target stakeholders in increasing the content validity of the scale being developed, and perhaps more in creating an instrument that is relevant and has broader application. To create a good scale, one must be open to revising items on the scale, and may have to make the decision to remove poorly performing items. Further, items may not bound together on the same construct even though they were designed to do so. In fact, it is possible that different factor patterns may emerge, which then would require some theoretical framework to calibrate or interpret.

Finally, we intended to develop a four-factor instrument. However, the items comprising the proposed four-factor scale developed emerged into five factors that are theoretically relevant to the overarching framework on which the instrument was conceptualized. Our instrument provides new perspectives on the ICAP framework and extends its application for scalability to broader contexts. We are hopeful that this study will inspire other innovative research and development in the area of student cognitive engagement, particularly in engineering education.

3 – STUDENT PERSPECTIVES ON COGNITIVE ENGAGEMENT: PRELIMINARY ANALYSIS FROM THE COURSE SOCIAL AND COGNITIVE ENGAGEMENT SURVEYS

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Abstract

The following is a research paper centered around the discovery of the meaning of engagement to students and researchers. Increasing student in-class engagement remains a goal of the engineering education community, yet faculty continue to lack tools that allow them to measure their students' engagement. Development of tools surrounding engagement connects faculty to the best practices emergent from the research. Critical aspects of survey development include not only psychometric validity, but also shared contextual meaning among researchers, educators, and students. That is to say, instruments can have validity and reliability, but might not necessarily provide useful feedback to the faculty using them. The ways in which students' self-report is one way both faculty and researchers can make meaning of survey responses. As part of a larger research study, we used an innovative model to develop a survey tool to measure student's in-class cognitive engagement under Chi's **I**nteractive/**C**onstructive/**A**ctive/**P**assive (**ICAP**) framework. Students were included in the development process as a means of gaining understanding of their interpretation of survey items. We interviewed student survey participants, asking them to both explain what they believed the survey to be asking them and what actions shaped their responses. The purpose of this paper is to understand potential discrepancies between researcher intention and student interpretation of quantitative survey items. To that aim, we ask the following question: *How do students interpret survey items related to in-class cognitive engagement?*

Preliminary findings suggest students' interpretation of items points to a discrepancy between researcher and student meaning of engagement. Though the survey was intended to target in-class engagement, students often conflated their in- and out-of-class engagement behaviors. Moreover, students did not distinguish between language we intended to reflect different levels of cognitive activity. As we continue to develop surveys surrounding engagement, this study gives useful insight into how we can interpret student responses and provide meaningful feedback to faculty. This is accomplished by understanding the ways in which researchers, faculty, and students talk about engagement differently, and how that might lead us towards shared meaning.

3.1 Introduction

Engineering education research has historically paid much heed to student engagement (H. L. Chen et al., 2008; Heller, Beil, Dam, & Haerum, 2010; K. A. Smith, Sheppard, Johnson, & Johnson, 2005b). Despite continued reinforcement as a classroom best practice (S. Freeman et al., 2014; Nokes-Malach, Richey, & Gadgil, 2015), there are a lack of tools to measure student engagement. One potential reason for a lack of tools is a lack of consensus among researchers regarding the meaning of engagement. Fredricks, Blumfeld, and Paris synthesized much of the existing research on engagement in 2004, developing a three-part model of understanding student engagement (Fredricks et al., 2004). Students are said to engage behaviorally, cognitively, and emotionally; by understanding all three modes of engagement, a comprehensive picture can be generated of how students are engaged (Fredricks et al., 2004). While an educator may be able to observe the behavior and even social engagement of their students, observation of the cognitive engagement of students proves problematic. To address this issue, Chi and Wylie developed the ICAP framework (Chi & Wylie, 2014). The ICAP framework intends to link the often-elusive cognitive engagement to overt, observable behaviors. Foundational to this study is the use of a survey tool based upon the ICAP framework. This survey, the In-Class Cognitive Engagement (ICCE) survey has emerged from the development of a larger project targeting student engagement cognitively and socially (A. J. Ironside et al., 2017). Development of the ICCE survey remains ongoing. Here, we seek to discuss student perceptions of this instrument. This research is positioned as meaningful towards the larger project aim of measuring student engagement, but also contributory to the body of knowledge surrounding student involvement in survey development.

3.2 Literature Review

As previously mentioned, engagement is an important factor in active student learning. While aspects of engagement like behavioral engagement lend themselves well to observable study, cognitive engagement has proved less obvious to observers and thereby is less frequently researched (Appleton et al., 2006). Research that does exist shows cognitive engagement's positive relationship to desirable student characteristics such as goal orientation, motivation, and collaboration (Christopher et al., 2005; Meece, Blumenfeld, & Hoyle, 1988a; Nokes-Malach et al., 2015). To link cognitive engagement to a more easily observed and researched trait, Chi and Wylie developed the ICAP framework (Chi & Wylie, 2014). This framework, consisting of four modes of engagement (Interactive>Constructive>Active>Passive), with each mode of engagement being recognized by a type of action taken by a student. For example, a Passively engaged student will simply observe a lecture and remain oriented towards instruction. To move into Active engagement, the student begins to take notes from what is being presented by the instructor. The student moves to Constructive engagement when they generate their own knowledge and manipulate the presented material. Finally, should the student choose to share knowledge with their neighbor, they move into Interactive engagement (Chi & Wylie, 2014). The framework offers several advantages. By indicating cognitive engagement by behaviors, observations can lead to an understanding of cognitive states of students. Additionally, when prompted, students may be able to more accurately describe their action instead of just discussing how they were thinking. These factors position the ICAP framework as a natural match for the development of an instrument to measure student cognitive engagement.

Our research team has currently been developing such a tool, the ICCE survey, based on ICAP and validated by faculty (A. J. Ironside et al., 2017). Yet, it remains important to connect with the users of the survey, the students, during development. In this way, the assumptions of the ICAP framework can be validated in survey form. This study is situated within the history of work that employs qualitative think-aloud interview techniques as an essential component of survey validity. Such research has shown the importance of feedback as quality assurance for instructors and classroom change (Centra, 1973; Leckey & Neill, 2001). The use of student feedback makes for the better development of an instrument that is meaningful in providing feedback to important stakeholders such as faculty.

3.3 Methods

In order to explore further the meaning students attribute to items developed by our research team, we conducted qualitative interviews with engineering undergraduate students. We presented students with the current draft of the ICCE survey containing questions directly linked to overt behaviors and subsequently asked them to explain their interpretation of the items listed. Both *a priori* and open coding techniques were implemented to first characterize engagement mode, and then provide additional descriptive power within each pre-established category. The following sections provide an overview of the research participants, data collection approaches, the instrument used to guide interviews with students, and the iterative analytic process.

3.3.1 Survey Development

As noted, the survey used in this study is derived from a larger project aimed at measuring students cognitive and social engagement both in and out of class. The present work focuses on students' in-class, cognitive engagement through use of the ICCE survey. For both brevity and clarity, only questions directly related to observable behaviors were used in the modified version of the ICCE survey presented to the students in this study. This allowed for the researchers to delve deeper into how students perceived survey questions while relating them to a concrete form of engagement. The questions provided to students both in survey form and during the interview are seen in Table 3.1 below.

Table 3.1: Survey questions and their correspondence to ICAP modes of engagement

I	*I work with other students to understand ideas or concepts regarding course content.*
	I do not discuss course concepts with other students.
C	*I take notes in my own words.*
	I add my own notes to the notes provide by the teacher.
	My course notes include additional content to what the teacher provided.
	I add my own content to the course notes during lecture.
A	*I take verbatim notes (meaning word for word directly from the board/PowerPoint slide/doc camera etc.)*
	I copy solution steps verbatim (meaning word for word directly from the board/PowerPoint slide/doc camera etc.)
	I only copy the notes the teacher writes down.
	I do not add my own notes to the course notes.
P	*I listen to lectures without doing anything else.*
	I do not think about course content during lecture
	I focus my attention on things other than course content during lecture.
	I do not write notes during lecture.
	I do not pay attention to course content during lecture.

3.3.2 Participants and Recruitment

Participants were recruited from a single class at the research site. The class was chosen as a single case study to evaluate student perceptions of the ICCE survey during the development phase. The class was a junior level thermodynamics course in the department of chemical engineering. The class was selected based upon an interactive classroom environment, large class size, and professor willingness and interest in participation in the research. At the end of the first week of the term, the research team introduced themselves to the class, explained the purpose of the study, and requested student participants who would be willing to complete the ICCE survey and a follow-up interview. The researchers informed the students of the activities associated with consenting to participate in the study. The researchers also told the students that the study would include a survey and an interview about their classroom behavior over the course of the term. The researchers did not give the students specific details of the different types of engagement that the survey and interview would examine. The research team posted a recruitment document to the class website, which also provided the details of the study and requested participants. In addition, students received $40 compensation for their participation. In total, 13 students were full participants in this study.

3.3.3 Interview Protocol

In order to maximize the effect of student interviews for this study, a protocol for semi-structured interviews for the students who completed the engagement survey was used. Jacobs and Furgerson developed a protocol for student interviews intended for students new to qualitative research (Jacob & Furgerson, 2012). Elements of this protocol were adopted in the interviews used this study. After the student participants had completed the ICCE survey, they sat down in a one-on-one interview with the researcher. To begin the interview, the researcher guided the interviewee through all the questions in the survey, one-by-one. The researcher read each question and asked for the student's interpretation of it. The researcher followed up to ensure the student was explaining why they answered the question the way they did. During these questions, the researcher took notes and wrote down clarification questions to ask the student at the end of the interview. Additional follow up questions by the researcher included questions about the difficulty of the survey. The researcher concluded the interview by reviewing the notes and asking students for any further clarification.

3.3.4 Analysis

The purpose of the analytic approach used here was to gain a deeper, more nuanced understanding of the meaning participants assigned to quantitative probes of classroom behaviors. The final aim was to more closely align survey items with researchers' intentions. To code participant responses, we conducted two waves of analysis. First, we conducted *a priori* coding according to our pre-determined cognitive engagement categories (i.e., ICAP). Following the categorization of participant quotes, the lead Author performed an iterative process of descriptive coding to identify the common aspects within each category of interpretation. The final result is four categories (one for each of the ICAP variables), with accompanying rich descriptions that express students' and researchers' shared understanding of the ICAP variables.

3.4 Results

The following results are based off student responses to interview questions regarding the survey they took in conjunction with their course. The purpose of the methods was to generate findings to answer the question: *how do students interpret survey items related to in-class cognitive engagement?* While students were asked to reflect on survey questions individually, results present their collective interpretation of items related to each particular mode of engagement from the ICAP framework. This provides insight in the ability of the ICCE survey to target a student's mode of cognitive engagement. The results point to both general and specific trends in student understanding of the ICCE survey, which serve to inform the survey's ongoing development and validation.

3.4.1 Interactive

When discussing interactive engagement, students seemingly conflated all their experiences with classmates in their course. Despite survey questions targeting student behavior involving interaction in the classroom, students would reference the groups they met with when tackling homework: "**We don't meet every single day, but we meet when we need to.**" This student was not referring to their in-class engagement, rather their out of class interactions. The groups students worked with to complete out of class work were frequently referenced in the interviews. Beyond this, students discussed how their interactions with students outside of class shaped their in-class activities. For example, some students claimed they made an effort to sit by and work with students they already knew.

Wording of the questions and scales did not generate consistent interpretation among students. Some students interpreted the statement *I work with other students to understand ideas or concepts regarding course content* as "**If I was confused about something, how likely would I be to clarify with somebody,**" changing the question from one of description to one of frequency. Other students saw the question asking how likely they were to follow instructions to work with another student in class. Despite instructions stating "*The following items refer to activities you engage in during class* *without being directed to do so by your teacher"* some students seemed to consider the structure of the class and its allowance for their interaction with others:

> **"It's mostly [the professor] just talking, and the occasional concept… well, not the occasional, the very frequent concept warehouse, and then the occasional 'discuss this with your neighbor.'"**

The two questions discussed as part of the interactive mode of engagement were inversely correlated, meaning a *very descriptive* response to one question corresponded to high interactive engagement, while *very descriptive* on the other question corresponded to low interactive engagement. These inverse correlations proved challenging to students. In the interview setting, one student admitted to failing to read the *do not* component of the question.

3.4.2 Constructive

Questions related to constructive engagement centered around notetaking. The concept of notetaking, and what it meant to add content was interpreted widely by students. When explaining the meaning of *taking notes in my own words*, one student said,

> **"If I'm taking notes based on what the teacher says rather than copying down work that they're doing, then I might paraphrase or word it so I'll understand it better when I read it back"**

In contrast, another student saw notes in their own words to mean copying down words spoken by their professor: **[The professor] would say it and not write it down and so I would just add something [to my notes].**" When speaking of *adding notes to those provided*, a student discussed means of recoding how to locate information:

> **"Say there's this integral, or this derivative, and I would point out this is this variable, and here's where we can go find this in the tables. I would sort of describe to myself how I would use the notes or equations that I'd been given."**

The three quotes above all point towards students' emphasis on the ability of their notes to provide them or direct them to supplemental information. In this way, students saw their own notes as a means of better understanding the material or emphasizing an important topic.

As was seen with interactive engagement, some students believed the additions they made to their notes outside of the classroom classified as *additional content*. This conflation between in-class and out-of-class experiences persisted despite explicit instruction to only consider in-class experiences. Students seemingly believed the question to be asking how descriptive adding notes was of their activity during notetaking portions of the class period. Students did not seem to consider their notetaking action in the context of the entire class period. Of larger concern, one student justified their response to *add my own content* as: "**I just wanted to change it up, to be honest. Because I read all [questions related to notetaking] as the same… basically the same question.**" This quote is evidence of the larger theme that students seemingly did not differentiate between questions related to constructive engagement, and therefore found the survey repetitive to a confusing degree.

3.4.3 Active

Questions related to active engagement centered around notetaking and example problems. When discussing notetaking *verbatim* or *only the notes the teacher writes down*, students considered either how much of the instructor's notes they copied down, or what portion of their notes were verbatim from what was written on the board. Interpretation varied on the meaning of *the teacher writes down*; some students saw this to include PowerPoint and other means of textually presenting information, while other students saw the question limited to the information physically written by the professor.

When discussing *example problems* and *solution steps*, students agreed that a solution step would involve math, equations, variables, figures and/or a derivation. Students' general perception was if they copied the solution steps verbatim every time a solution was written by the professor, then this item would be *very descriptive* of their in-class behavior. One student explained that *I take verbatim notes* would be *somewhat descriptive* of their in-class activity when, "**Half the notes are verbatim, not half the lecture period is verbatim notes**". This clarifies that students did not consider the lecture period holistically when responding, but the portion of class dedicated to taking notes.

In terms of effectiveness of the learning strategies, students seemed conflicted regarding copying or verbatim notetaking. When presented with example problems, some students saw copying down solution steps as an effective learning strategy. One student justified their actions as:

> **“Sometimes when we were dealing with highlighting equation to solve problems, if I was going to write that equation down, I would definitely write it down verbatim, that way I could reference it later”.**

Other students saw example problems requiring them to “**Go look in the book, and see okay, this is the section that came from, and here’s the assumptions you have to make that [the professor] might not have mentioned.”** Both responses indicated the student’s desire to reliably be able to access information to solve similar problems at a future juncture.

3.4.4 Passive

Listening and attentiveness were the foundational behaviors related to passive engagement. When discussing *listening to the lecture without doing anything else,* students presented contrasting viewpoints on the bounds of this question. One student suggested that listening was simply not always the appropriate action: “**I would try to be engaged as possible, but sometimes we would be doing other things, obviously, besides just lecture in that class.**” Listening, as defined by the student, related strictly to lecture. If thinking only of when the lecture occurred, it remains ambiguous if their engagement corresponded to a *very descriptive* response (engaged when lecture was occurring and listening was appropriate), or if the other non-lecture activities shaped their response towards *not at all descriptive* (other activities occur in the course and so listening without doing anything else was not appropriate). In contrast to the prior students, one student saw the same question to mean, “**I’m sitting there and not thinking about other things, I’m not on my phone, I’m not doing whatever**”. The "whatever" referenced by the student corresponds to non-course-related activities. This student's interpretation of the question is focused more on course-related versus non-course related content, as opposed to the first student thinking of different actions in response to course content.

Questions surrounding attentiveness saw a range of responses. When prompted with *I focus my attention on things other than course content during lecture*, one student said, "**Whether or not I was distracted during the lecture.**" The student's response view of passive engagement is mild in contrast to the view presented by a student prompted with *I do not pay attention to course content during lecture.* This student saw the question to mean "**checking out completely.**" The student is describing a complete lack of engagement rather than passive engagement. A lack of engagement, or a state of unengaged, was not measured explicitly by the scale and emerged as incorporated into passive engagement.

3.5 Discussion

The following discussions are based on the results presented above. Here, we aim to bring to light the ways in which students interpreted survey items to inform both the assumptions about engagement presented in the literature and the development of survey items to measure it.

3.5.1 ICAP Framework

Within the ICAP framework presented, four hierarchal modes of engagement are intended to represent increased student learning as they progress towards Interactive engagement. This research has shown that while the hierarchal engagement model may be true in many, or even most, cases, notable exceptions do exist. Students who discussed taking word-for-word notes to ensure that an equation was appropriately depicted would demonstrate the Active mode of engagement. For these students, engagement with a particular equation may require this basic activity to ensure ongoing learning. In this way, the ICAP framework is limited; while Interactive engagement may frequently be beneficial to learning, it is not always the case.

Seen in the Passive results were students who discussed being not at all engaged in the material. As defined by Wylie and Chi, Passive engagement is “directed towards instruction” (Chi & Wylie, 2014). Students did not interpret all Passive questions in this manner. Results point towards an additional mode of engagement not encompassed in the ICAP framework. Students in this additional category are unengaged, or not positioned in any way towards course content.

3.5.2 Out-of-Class Activities

In questions related to all four modes of engagement, students exhibited confusion between the activities taking place in class and those taking place outside of class. The conflation persisted, despite the inclusion of *of my in-class activity* to each response option (e.g. *very descriptive of my in-class activity).* Students did not appear to draw a distinction between *where* they engaged with course content, rather *how* they engaged with course content. Despite the fact that the course was traditional in nature, meaning students were not regularly expected to take notes outside the classroom, students still did not find the location of activities distinct.

3.5.3 Frequency

The scale provided to students ranged from *not at all descriptive of my in-class activity* to *very descriptive of my in-class activity*. This behavior-based scale targeted understanding the activity of a student as it related to the entire course. Despite this, students talked about their engagement in terms of frequency. Students answered questions based on how they engaged *when* participating in a particular activity (e.g. when taking notes, a student might indicate how often they took them verbatim or added their own content).

3.5.4 Misinterpretation, Fatigue, and Reverse-Coded Questions

Throughout the interviews, there were several instances in which students brought up a failure to read a question correctly, got tired of answering the same questions, or exhibited a stronger response to a question coded in reverse. These results raise concerns related to the length of the survey and the viability of questions coded in reverse. Statistical validation of the survey could be used to limit the number of questions required to understand the mode in which a student engages. Reverse-coded questions have long raised questions in regard to their meaning in scale development (Chang, 1995) and have posed difficulties in other studies measuring student cognitive engagement (Appleton et al., 2006). Therefore, they must be continually validated throughout survey development to better understand their meaning. The randomization of survey items has been historically used to address order bias and limit its influence over data (Perreault, 1975).

3.5.5 Conclusions and Future Work

The purpose of this work is to contribute to the body of knowledge surrounding the measurement of student engagement. Additionally, this work has been poised to have direct and tangible impacts on the ongoing development of the ICCE survey. This survey is in the process of incorporating changes bases upon the results of this work. In new versions, questions have been added to address unengaged students. In an effort to address the lack of distinction of activity by location, questions have been modified to compare responses to in-class and out-of-class engagement alongside each other. This serves to address future needs of classrooms in which activities outside the classroom mimic traditional in-class actives (e.g. flipped classrooms). The scale has been modified to one of frequency, the most common way in which students understood their engagement.

More work is needed to unpack the questions surrounding the hierarchy of the ICAP framework in engineering. Work evaluating the nature of engagement linked to higher levels of learning in engineering classrooms would provide value feedback to faculty seeking to modify their classrooms. Further work is needed in the realm of survey development to better understand the ways in which students can provide feedback with accuracy.

4 – WIP: MEASURING STUDENT COGNITIVE ENGAGEMENT USING THE ICAP FRAMEWORK IN AND OUTSIDE OF THE CLASSROOM

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Abstract

The following is a Work in Progress paper related to the deployment of an instrument to holistically measure the cognitive engagement of STEM students. Engagement continues to be shown as an important factor in the academic success of STEM students, and therefore of interest to both educators and the research community. Of the components said to make up engagement (behavioral, emotional, and cognitive), cognitive engagement persists as difficult to measure due to its lack of observable characteristics. The ICAP theory proposed by Chi and Wylie uses validated means to link levels of cognitive engagement with overt, observable behaviors in students. While this theory does much to advance teachers' perceptions of engagement in their own classroom, it is explicitly not a measurement schema. We set out to use the validated link between overt behaviors and cognitive states to develop a tool that allowed students to report on their own cognitive engagement. As the ICAP theory suggests, cognitive engagement is influenced by the environment in which student learning takes place. Despite educators developing curriculum (i.e. homework, projects, writing assignments, etc.) to influence student's out-of-class environment, cognitive engagement outside the classroom is rarely addressed in the literature on STEM students. One of the unique contributions of our instrument is the measurement of cognitive engagement in two distinct environments: inside the classroom and outside the classroom. We developed a measurement schema that prompted students to report on their in-class engagement and out-of-class engagement for each instrument item. Here we analyze data from over 500 early respondents to our instrument. We use paired t-tests to present preliminary findings,

indicating that students have unique responses to in-class and out-of-class items. Our results suggest the importance of a measurement schema that allows for students to report more holistically on their cognitive engagement experience as it relates to a single class. This work has the potential to allow educators to glean information that empowers them to make targeted changes on the curriculum they develop for students inside and outside the classroom.

4.1 Introduction and Relevant Literature

The current emphasis on active learning prompts educators to modify their courses in ways that increase the engagement of their students with the suggested benefit being increased learning gains, retention, and greater academic success (Prince, 2004). Yet, even within the research community it is acknowledged that engagement is multi-faceted and difficult to define (Appleton et al., 2006). Educators are therefore left to make their own judgements on what their classrooms will look and feel like if their students are engaged. Research has shown that it is cognitive engagement (over behavioral or emotional engagement) that is indicative of higher-order processing (Sinatra et al., 2015). It therefore becomes important that educators are able to assess the cognitive engagement of their students in straightforward and meaningful ways.

Chi and Wylie made strides towards the assessment of cognitive engagement in the classroom with their ICAP framework (2014). The framework ties overt, observable behaviors to four distinct modes of cognitive engagement: **I**nteractive, **C**onstructive, **A**ctive, **P**assive. ICAP allows educators to observe their classroom and infer a mode of cognitive engagement among their students: Interactive Engagement is associated with perspective-sharing conversations between students, Constructive Engagement with adding notes to those provided, Active Engagement with underlining and highlighting a text, and Passive engagement with sitting and listing to instruction, etc. (Chi & Wylie, 2014). The framework also allows for the development of learning activities that target a particular mode of engagement among students (Chi et al., 2018). In this way, it is an ideal framework for educators seeking to meet the calls of the community to implement active learning strategies in the classroom. There remains room for the ICAP framework to expand into an explicit measurement tool of cognitive engagement, as it was not developed as such. Additionally, the ICAP framework limits educator knowledge of student engagement to that which happens in the classroom and can be directly observed. There currently existed few ways for educators to assess how their students interact with course material once they are outside the classroom.

Educators often intend for important learning to take place out-of-class; flipped courses intend for content learning to take place at home, homework assignments imply a need for practice outside the classroom, and group assignments facilitate interactivity beyond classroom walls. Simmons et al. profiled the out-of-class engagement of civil engineering students using the Postsecondary Student Engagement (PosSE) Survey, finding that the majority of these students reported actively engaging with out-of-class activities (2018). Additional work with the PosSE called for research on *how* and *why* students engage in out-of-class activities.

In our previous work, we have discussed the ability of the ICAP framework to be transitioned into a reliable self-report instrument. We developed a set of items related to each mode of engagement and rigorously developed the Student Course Cognitive Engagement Instrument (SCCEI). In this extensive development process, we interviewed both faculty and students about their thoughts on cognitive engagement broadly and our items specifically. It was in these interviews that we began to note the interplay between engagement in the classroom and engagement outside of the designated lecture period. While our intent was always to develop instruments to measure holistic engagement—inside and outside the classroom—we recognized the potential value in measuring in-class engagement and out-of-class engagement in a single instrument. We therefore developed a single set of items to address both in-class and out-of-class engagement.

One aim of our work is to answer the question: *in what ways to can student's in-class cognitive engagement be distinct from out-of-class cognitive engagement in self-report instruments*? More broadly, with future work, we seek to report to educators on the in-class and out-of-class cognitive engagement of their students, with strategies to increase students' alignment with higher modes of cognition. In this work, we present our preliminary findings that indicate a significant difference between in-class and out-of-class engagement as measured by the SCCEI. Such results suggest that the ICAP framework can be meaningfully expanded to include out-of-class engagement. With future work, distinctly measuring in-class and out-of-class engagement has the potential to influence how educators make targeted changes to their courses to provide students with the benefits associated with active learning.

4.2 Methods

The work presented here is part of a larger, ongoing project to measure student cognitive engagement inside and outside the classroom. While our extensive item development and refinement process (Barlow et al., n.d.), (Lutz et al., 2018) and data from student and faculty interviews (A. J. Ironside et al., 2017; A. Ironside et al., 2018) has been outlined elsewhere, we have yet to analyze and present the intersection of in-class and out-of-class engagement. Data from student responses to the SCCEI are analyzed for significantly different responses to in-class and out-of-class items for each mode of engagement.

4.2.1 Student Course Cognitive Engagement Instrument

As noted, we determined out-of-class cognitive engagement to be an understudied area, and relevant to educators. We saw a need to facilitate a direct comparison between the two when our previous work found that students often conflated their in-class and out-of-class engagement (A. Ironside et al., 2018). We therefore developed items that could be applied to both inside and outside the classroom learning, and had students respond to the items with two separate 3-point Likert scales. Likert scales were related to frequency of cognitive behaviors or engagement (see Table 4.1 below)

Table 4.1: The three-point Likert scale students were prompted with for items related to in-class and out-of-class engagement. Student viewed both scales simultaneously, as shown below.

Prompt: I justify my perspective to others when discussing course content.

In lecture			**Outside the classroom**		
Few to no lecture periods	Some lecture periods	Most lecture periods	Hardly ever	Some days	Most days

Through several rounds of development, we established a set of 21 items reliably factored into six distinct modes of engagement: Interactive, Constructive, Active Thinking, Active Doing, Passive, and Disengaged. The ways in which the factors differed from the ICAP theory are as follows: Active Engagement factored into Thinking and Doing modes, with one mode representing students' reporting on their cognition directly (Thinking) and the other using the established proxy of behaviors (Doing); Disengaged is the construct that represents a lack of engagement, a construct which is noted in the ICAP framework (Chi & Wylie, 2014) but not included. For each of the six modes, students were prompted with three to four questions related with either their behavior or cognitive engagement. Items included *I defend my approach to others when discussing course content*, *I think about previous concepts covered in the course*, etc (see **Appendix A** for all survey items and factor groupings)

4.2.2 Data Collection

Approximately 530 undergraduate STEM students from four northwestern universities were recruited for validation of the SCCEI. In previous work, this data allowed us to perform the Exploratory Factor Analysis (EFA) required to validate the six constructs (or modes of engagement) being measured. With knowledge of items that factored together, we began student scoring. Scores were obtained by first converting Likert data to ordinal data, with 0 equivalent to *few to no lectures/hardly ever*, 0.5 equivalent to *some lectures/some days*, and 1 equivalent *to most lectures/most days*. This scoring system was intentionally selected—and mirrors the way other educational surveys have been scored, see (Walter et al., 2016)—one can think of the score as a percentage of alignment with an item (i.e. *few to no lectures* is representative of 50% alignment with an item). Scores for individual items related to each construct were then averaged, indicating an average percent alignment with each mode of cognitive engagement, for inside and outside the classroom, for all participants. Null values were assigned to participants who opted out of a question, and they had no impact on the average score.

4.2.3 Comparison of In-Class and Out-of-Class Scores

Our interest was in seeing if students meaningfully distinguished between their in-class and out-of-class engagement when presented with two scales simultaneously. Therefore, we ran six paired t-tests in SPSS, one for each established mode of cognitive engagement. Paired t-tests were appropriate, as each participant was measured in both samples being compared.

4.3 Results and Discussion

The results from our paired t-test (see Table 4.2) indicate in-class and out-of-class engagement can be measured distinctly along all modes but Interactive. This was accomplished with a simultaneously presented Likert scales, and is true at the 95% confidence level ($p < .05$). One plausible reason Interactive engagement was not found to be significant is students who engage Interactively are connected both inside and outside the classroom. Implications might include a need for instructors to synchronously facilitate Interactive engagement inside and outside the classroom to increase Interactive engagement in the course. Additionally, means for Disengagement were significantly *lower* inside the classroom than outside. Plausible explanations include that students who are Disengaged in the classroom may choose to cognitively engage outside the classroom (i.e homework). This points to questions regarding how to reach Disengaged students; possibly such students are and can be engaged deeper in contexts other than lecture. Such findings fit within the limited body of literature discussing out of class engagement (Rutledge, Pe, & Tech, 2015; Simmons, Van Mullekom, & Ohland, 2018; Simmons, Ye, et al., 2018)

Table 4.2: Rests from paired-t test. For each pair, individual student scores were averaged for all items relevant to the construct.

Construct (Pair)	**Location**	**Mean alignment with construct**	**Std. Dev**	**Difference in Mean**	**t**	**df**	**Sig .(2-tailed)**
Interactive	In-class	.560	.243	-.0119	-1.322	537	.187
	Out-of-class	.572	.239				
Constructive	In-class	.423	.390	.0228	2.574	532	.010*
	Out-of-class	.400	.296				
Active Thinking	In-class	.680	.238	.0472	6.175	534	.000*
	Out-of-class	.634	.242				
Active Doing	In-class	.446	.280	.0542	6.265	534	.000*
	Out-of-class	.392	.285				
Passive	In-class	.839	.225	.1102	10.838	525	.000*
	Out-of-class	.729	.270				
Disengaged	In-class	.269	.256	-.0709	-7.277	536	.000*
	Out-of-class	.340	.250				

4.3.1 Future Work

While we have shown the SCCEI measures modes of cognitive engagement inside and outside the class distinctly, work remains to clarify the meaning of these constructs to students and educators. We plan to continue this work both quantitatively and qualitatively. We have proposed interviewing students with respect to their in-class and out-of-class engagement for all of their courses as a means to identify consistencies and inconsistencies. Additionally, a quantitative study is underway in which a larger sample of courses is collected from a more diverse set of institutions to further validate the results.

There is room for further study in how students think about their cognitive engagement differently in different contexts. Particularly, there is an interest in how students Interactively engage with one another both inside and outside the classroom. Is there a correlation between educators forming groups in their classroom and Interactive engagement that takes place outside the classroom? Moreover, can Disengaged students be modified by educational practices in the classroom, or are such students more responsive to out-of-class activities? We see this work pointed towards empowering educators to make meaningful changes inside and outside the classroom.

5 – DISCOVERING UPPER-DIVISION STUDENTS' COGNITIVE ENGAGEMENT ACROSS ENGINEERING COURSES—AN INTERPRETIVE PHENOMENOLOGICAL ANALYSIS APPROACH

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Abstract

Background: STEM education research has consistently purported that student cognitive engagement is tied to learning outcomes and can be influenced by pedagogical strategies. Yet, there is little research describing the experience of students as they engage with their courses, and what shapes this engagement.

Purpose/Hypothesis: Our research seeks to understand how upperclassman civil engineering students are engaged across their engineering courses, and the factors most salient in how they have come to engage in such a manner.

Design/Method: Five engineering students participated in a semi-structured interview where they were prompted to discuss their engagement generally throughout college, and specifically in their engineering courses from the previous term. We utilized interpretive phenomenological analysis (IPA) to make meaning of each participant's engagement experience; themes were drawn from analysis of each participant's individual transcript, and further meaning made from themes across participants.

Results: Primary themes from the IPA analysis showed that participants 1) established behavioral engagement values that remained constant across courses 2) used future goals to deepen cognitive engagement within the discipline 3) adjusted cognitive engagement to mirror the engagement stance of instructors and 4) blended influences to determine effective and efficient engagement strategies.

Conclusions: Findings indicate that students are future-minded in their decisions surrounding engagement, yet are still malleable to engage in more or less meaningful ways based on their instructors. This work builds evidence for the importance of instructors utilizing evidence-based instructional practices, as well as assisting students in exploring and developing career goals.

5.1 Introduction

Recent calls to active learning in STEM education have encouraged instructors to make modifications to their courses to generate higher levels of engagement among their students (Prince, 2004). Fundamental to generating student engagement is understanding the construct itself. Engagement is often considered a meta-construct (Appleton et al., 2006), and is frequently conceptualized as being constructed of multiple components. One popular conceptualization by Fredricks et al. (2004) states that scholastic engagement is comprised of behavioral, emotional, and cognitive engagement components. They indicate that of these, cognitive engagement is the least observable to instructors and therefore must be indicated by behavioral proxy or survey instrument.

Research has continued to develop both proxies (Chi & Wylie, 2014) and instruments (Appleton et al., 2006; Greene, 2015; Zhao & Kuh, 2004) as a means of assessing student cognitive engagement. Instruments to better understand how students respond to instructional practices (DeMonbrun et al., 2017) and interact with course material (Authors, In Review) have also been developed. Such research emphasizes the importance of cognitive engagement to student learning, and the crucial role instructors play in influencing it. As instructors move towards more cognitively engaging classrooms, they may realize their classroom is indeed made up of individual students with complex histories, interests, and abilities that influence how he or she cognitively engages in that particular course. The inherently difficult-to-observe nature of cognitive engagement may leave instructors further confused on how their students are responding to their teaching practices. Current literature offers little insight as to what might be going beyond what is observed in students: the driving forces that shape students' cognitive engagement within engineering courses is currently under-researched. While it would be near impossible to unpack the stories of all engineering students, we suggest understanding what shapes the cognitive engagement of a few upper-division engineering students provides a starting point.

In this study, we recruited five upper-division civil engineering students to participate in semi-structured interviews regarding their cognitive engagement in engineering courses. Interpretive Phenomenological Analysis (IPA), an in-depth approach to analyzing qualitative data, allowed for the organization of themes surrounding participants' cognitive engagement experiences. Results show that participants' perceptions, values, and contextual course features all shaped their cognitive engagement within engineering courses. We anticipate this study will be useful in building foundational understanding of what shapes student cognitive engagement in engineering courses. This is not because our sample is representative of population, but because it allows for the nuanced, personal nature of cognitive engagement to be presented.

5.2 Background

The background is intended to frame the study's work around cognitive engagement of students across their engineering courses. To do so, we briefly discuss engagement broadly, with an emphasis on cognitive engagement and how it is conceptualized and measured. This is followed by a presentation of our conceptual framework where we argue that the reality students experience in their courses is a valid field of study, and our purpose statement where we present the relevance of our research question.

5.2.1 Student Engagement

Student engagement has long been viewed as a multi-dimensional construct, of interest in part due to its relationship with enhanced student learning (Reschly & Christenson, 2012). Beyond this, student engagement can be seen as the glue that links the important contexts of home, schooling, and community together in working towards positive learning outcomes (Reschly & Christenson, 2012). One prevalent conceptualization of student engagement breaks it down into dimensions of behavior, emotion, and cognition (Fredricks et al., 2004). These dimensions help explain how engagement is tied to particular learning outcomes: behavioral engagement has been associated with academic achievement, emotional engagement has been shown to keep at-risk students in school, and cognitive engaging has been correlated with synthesis and deep-level understanding (Fredricks et al., 2004).

Ties to positive learning outcomes have catalyzed the development of measurement schemas along all three engagement dimensions. Some dimensions of engagement are more readily observable, such as behavioral engagement displays of effort, persistence, and attention (Sinatra et al., 2015); or emotional engagement displays of interest, happiness, and anxiety (Fredricks et al., 2004). Self-report metrics such as the Motivated Strategies for Learning (P. R. R. Pintrich, Smith, Garcia, & McKeachie, 1991) and National Survey of Student Engagement (Kuh, 2001) assess engagement and related factors in broader terms. Yet, cognitive engagement has remained difficult to both define and measure (Sinatra et al., 2015). One persistent difficulty in doing so is the lack of clear boundaries between where cognitive engagement ends and behavioral or emotional engagement begins. In fact, one well-cited framework of student cognitive engagement relied on overt *behaviors* to infer underlying cognitive states (Chi & Wylie, 2014). The intent of this framework, known as the ICAP framework, was to assist educators in evaluating the success of implementing active learning strategies in their own classrooms (Chi & Wylie, 2014), yet it has proven difficult for educators to develop and implement curriculum targeted at particular modes of cognitive engagement (Chi et al., 2018).

Conceptualizations of engagement (i.e. ICAP) provide insight into how a body of students may be engaging with course material at a given point in time. Survey instruments to measure cognitive engagement (Authors, In Review) are more aggregate in nature, providing insight to students' experience with course material over a greater period of time (entire lecture period, week, term, etc.). It is only deep inquiry with individuals provides insight as to what shapes cognitive engagement at a personal level. No work was found in the literature that provided deep exploration of the personal factors that influence cognitive engagement in STEM students. Such work would provide foundational understanding as to the ways in which students are malleable and responsive to their contextual course features.

5.2.2 Conceptual Framework

Critical to exploring how cognitive engagement is shaped within a student is the conceptual framework with which the researcher approaches the task. Where worldviews such as post-positivism have their place in measuring theory, and pragmatism in practice-based problem solving, constructivism lends itself useful to theory generation and understanding multiple participants’ meaning (Creswell, 2014). Constructivism suggests knowledge is self-constructed, and influences assumptions on how such knowledge ought to be disseminated in the classroom (Hutchinson & Huberman, 1994). More specifically, social constructivists believe that individuals develop subjective meanings from the worlds in which they live, work, and interact with others (Creswell, 2014). Social constructivist researchers ought to formulate a pattern of meaning from inquiry targeted at understanding the conditions in which individuals make meaning (Creswell, 2014). Thus, research on how individual students make meaning and decisions surrounding their engagement from their experiences in a classroom is inherently social-constructivist in nature. Researchers need not seek out an objective reality of a classroom, or how a student should respond to a particular set of teaching practices; rather, such research should seek to uncover the student’s experience in a broad sense, and how particular course factors influence their engagement. Furthermore, such research ought to acknowledge the role of the researcher in making meaning of the students’ lived experience.

5.2.3 Rational

Educators are continually called towards creating active learning environments. We have seen that active learning does indeed *work* (Prince, 2004), but we have yet to address who active learning works *for*, and in what ways. For example, problem-based learning and collaborative learning both result in learning gains (Dard, Lison, Dalle, & Boutin, 2010; K. A. Smith et al., 2005a), yet, others have gone on to say the impacts of problem-based learning and collaboration differ along gender, ethnicity, and individuality within students (Stump, Hilpert, Husman, Chung, & Kim, 2011). Other research has shown it is much more complex an issue than to simply state that it is better to learn together (Nokes-Malach et al., 2015). Teachers are left to sift through pushes towards implementing active learning practices and questions on how students benefit. Linked to positive learning outcomes (Chi, 2009), cognitive engagement is one key to understanding how active learning is working for students. It therefore becomes important that, as researchers, we seek to develop theories that explain how cognitive engagement is shaped within individuals in different contexts.

We note the inherent difficulty in separating cognitive engagement from the meta-construct of engagement. In discussing dimensions of engagement, Fredricks et al. (2004) states:

> **Defining and examining the components of engagement individually separates students' behavior, emotion, and cognition. In reality these factors are dynamically interrelated within the individual; they are not isolated processes. Robust bodies of work address each of the components separately, but considering**

> **engagement as a multidimensional construct argues for examining antecedents and consequences of behavior, emotion, and cognition simultaneously and dynamically, to test for additive or interactive effects.**

We therefore see a need not to isolate cognitive engagement when studying student engagement; cognitive engagement ought to be studied in light of the *antecedents and consequences* of behavior and emotion. We seek to study cognitive engagement by first developing a holistic understanding of students' engagement experiences, then focusing in on cognitive engagement specifically.

Theory generation and practical knowledge gains can emerge from qualitative research, so long as there is transparency and rigor in the methodology. Our methodology is based in Interpretive Phenomenological Analysis (IPA), an approach for understanding experience of students in engineering courses (J. L. Huff et al., 2015; Kirn, Godwin, Cass, Ross, & Huff, 2017). IPA is useful when seeking to understand a lived experience, such as how a student experiences engagement in engineering courses. Here, we rely heavily on the philosophical commitments of IPA as outlined by Smith et al. (2009), and look to others who have applied the methodology in engineering education contexts for further guidance (J. Huff & Clements, 2018; Kirn & Benson, 2018). IPA allows us to make meaning of the particular, that is the experience of the individual's engagement, while connecting meaning to themes common to a set of participants. Such results are uniquely situated to bring insight to the individual's experience, while poising us to interpret what changes might bring benefit to the broader setting in which the individuals are situated. It is the hermeneutic circle of interpretation that allows for meaning to be shared from participant, researcher, and reader: when prompted with an interview question, a participant makes meaning of it as they respond. The researcher makes meaning of their response through a careful series of analysis. Finally, you, the reader, make meaning of our interpretations presented in written word. This analysis allows us to present themes to answer the research question: *What shapes cognitive engagement in engineering courses of upper-division civil engineering students*?

5.3 Methods

In collecting and analyzing data, we followed an IPA approach: a small sample of students was recruited to share their experiences related to cognitive engagement in their engineering courses. The following methods further detail how participants and data were recruited, interviewed, and analyzed in alignment with IPA methodology. We seek to be transparent in our methods to allow the reader to make informed meaning of the results.

5.3.1 Recruitment and Sampling

Participants were initially recruited via a related study, in which a large number of courses were asked to deploy an instrument to measure cognitive engagement within a course (Authors, In Review). Students were asked if they would be interested in participating in a follow-up study to discuss their cognitive engagement as it related to their engineering courses. Students were also told there would be a monetary incentive for their participation. Of the 170 student participants in the previous study, 33 indicated interest in participating in the follow-up. Only upper-division students who were enrolled in the Civil and Construction Engineering program at a single Pacific Northwestern university were contacted. We therefore had a *purposefully selected* sample (Creswell, 2014), intended to allow the research team to focus on the phenomena (i.e. cognitive engagement) by minimizing confounding factors (e.g. major, academic level, institutional culture). From this initial round of recruitment, five students scheduled an interview with our team. The sample size is within the range suggested by Smith et al. (2007), and of similar magnitude to that which was seen in other similar studies (e.g. J. Huff & Clements, 2018; Kirn & Benson, 2018). In Table 5.1, we show brief demographic information on each participant and the pseudonym they are referred to henceforth.

Table 5.1: Demographic of participants

Pseudonym	Grade Level	Major	Sex
Bruce	Senior	Civil Engineering	Male
Alisa	Senior	Civil Engineering	Female
Zach	Junior	Civil Engineering	Male
Cole	Senior	Civil Engineering	Male
Kara	Senior	Construction Engineering	Female

5.3.2 Data Collection

Participants were asked to interview approximately two weeks after the completion of the winter academic term. This was intended to allow participants to reflect on their engagement from the previous term while minimizing external stressors (e.g. end-of-term projects, start of new classes). Participants were invited to a research meeting space in a familiar building, where a semi-structured dialogue lasted approximately one hour. The interview schedule was followed loosely, with the participant guiding the interview towards important facets of their engagement that may or may not have been specified in the schedule. The focus of the study remained cognitive engagement: the interviewer lead students to broadly discuss all facets of their engagement, and probed more deeply as cognition was discussed. It was during data analysis that cognitive engagement was explicated from other forms of engagement.

The interview schedule began with the researcher offering a short explanation of the research, explaining to participants that answers to all questions were voluntary, the nature of their qualitative responses would not be directly communicated to their instructors, and all data would remain anonymous. Additionally, the researcher offered participants a brief definition of the meaning of cognitive engagement in the context of the study: "*cognitive engagement can be thought of as how hard you are thinking, your mental effort, or your focus on course material"*. Interview questions began with asking participants to describe how they entered into engineering, how they would typify their engagement in college, its evolution over time, and major factors in how they engaged (interview *Part 1*, as seen in Table 5.2). The intent was to allow participants to openly discuss salient factors in their engagement and identity within engineering, which would guide the remainder of the interview. Using this knowledge, the researcher then asked participants to discuss engagement as it related specifically to a course, specifically their engineering courses from the previous term (*Part 2*, as seen in Table 5.2). Participants were asked to reflect on the courses they engaged most deeply with and those they did not, and why they chose to engage in such a manner. Finally, participants were asked to give advice to both instructors and engineering students on strategies that would lead to successful engagement, specifying what steps instructors might take to lead to more meaningful student engagement (*Part 3*, as seen in Table 5.2). In responding, participants illuminated further a piece of their engagement stance—the ways in which responsibility for engagement is divided and shared among instructors and students.

Table 5.2: General interview schedule used during data collection. The schedule was followed loosely, with each part covered using questions similar to those listed below.

Part 1	How did you get into engineering? What was your purpose and/or goals?
	When you think about your engineering courses, how would you characterize your cognitive engagement? Why do you engage in this way?
	In what ways has your cognitive engagement evolved over time? What were some of the biggest factors in its evolution?
Part 2	How would you describe your overall cognitive engagement with this course? What were some key factors that engaged you in this manner?
	How useful do you perceive this course being to your career? How does that influence your engagement?
	In what ways did you perceive the instructor trying to engage you? How effective were they?
	What were the biggest factors limiting your engagement with this course?
Part 3	What are steps that instructors take that are the most cognitively engaging? The least engaging?
	What advice would you give another student about their engagement? What advice would you give a faculty member seeking to engage their students?

5.3.3 Data Analysis

Following data collection, each interview was externally transcribed and internally reviewed. Review of the transcript included re-listening to audio recordings while reading transcripts to gain familiarity with the participant's voice and its conveyance through written word.

Cases were analyzed sequentially, with the researcher immersing herself in the data of a single participant and undergoing analysis before moving on to the next case. Per the IPA methodology(J. A. Smith & Osborn, 2007), each transcript was first annotated with descriptive, linguistic, and conceptual comments. These annotations formed the basis for participant-based emergent themes.

Emergent themes were centered around participant cognitive engagement, with the meta-construct of engagement used as contextualization. As participants discussed their engagement in broad terms, we honed in on the themes that related to the shaping of their cognitive engagement. To do so, we relied on the definition of cognitive engagement suggested by Fredricks et al. (2004): *[cognitive engagement] incorporates thoughtfulness and willingness to exert the effort necessary to comprehend complex ideas and master difficult skills*. Themes were generated from the data to tell the story of how a given participant came to cognitively engage in a given manner within engineering courses.

As emergent themes developed in each case independently, the researcher began to connect these themes together first within the case, and finally across the sample. Crucial to this process was the *dynamic bracketing* suggested by Smith et al. (2009). Dynamic bracketing, the process of continually setting aside interpretations to remain grounded in the data, allowed each segment of data (i.e. each participant) to speak for themselves. While remaining grounded in the data, the researcher played an interpretive role in generating themes to tell a story across participants. This process developed a schema for answering the primary research question of *what shapes cognitive engagement in* *engineering courses of upper-division civil engineering students*? Four super-ordinate themes were developed and are discussed in the Results below.

5.3.4 Credibility and Trustworthiness

We acknowledge it is not simply adherence to a methodology that ensures credibility and trustworthiness, rather it is the clarity with which the reader can view the analytic process that allows them to accurately assess quality themselves. Therefore, we seek to clarify the ways in which credibility and trustworthiness were pursued, and acknowledge the positionality of the researchers in this process.

The ways in which phenomena are accurately represented, and how consistent the representation is with participants' experiences is defined as credibility (Whittemore, Chase, & Mandle, 2001). Per IPA methodology, we sought to immerse ourselves in a single participant's interview and dataset, bracketing off preconceptions and shallow interpretations. Yet, we acknowledge that each researcher brings their positionality to all interactions. Both authors are engineering education researchers trained in civil engineering, with the lead author a student to the second author. The lead author guided interpretations and analysis, while the second author offered ongoing feedback and review of the results. Authors were both trained in civil engineering, adding to the initial rapport with participants and adding to the credibility of the interpretations of their experiences (Berg & Lune, 2014; Guba & Lincoln, 1989). In previous work, authors had spent considerable time focusing on the experience of cognitive engagement in engineering students, and questioned what might play a significant role in shaping how a student engaged. Both authors had conducted extensive qualitative research prior, and were familiar with interviewing and extracting themes from qualitative interview data. Credibility was ensured through the researchers utilizing IPA as a tool to generate, refine, reconsider, and present themes to represent student experiences with engagement.

Trustworthiness is defined as the degree to which findings are represented honestly and evidence for such findings is sufficiently documented (Creswell, 2009). We report our findings, guiding the reader towards interpretations we see as meaningful through multiple participant quotes. We aim not to present the *true* meaning of the participants' words, rather we suggest that we provide a trustworthy interpretation that may be helpful as we consider the ways in which students engage in engineering courses.

5.4 Results

Our results show that an interconnected, and sometimes contrasting, set of behaviors, values, and cognitions can be used to answer the research question: *What shapes cognitive engagement in engineering courses of upper-division civil engineering students*? Here, ideals and enactments of participants are consolidated into four super-ordinate themes, with occurrences within participants used as supporting evidence of how the theme applies on an individual level (i.e. to the particular). We present a summary of themes in Table 5.3 to guide the reader through the results; ***Descriptions*** indicate the ways in which themes build upon one another, and ***Example Quotes*** offer a poignant example of the theme within a participant.

Table 5.3: Summary of themes addressing what shaped the cognitive engagement within participants.

Theme	***Description***	***Example Quotes***
Established behavioral engagement values that remained constant across courses	Participants used self-awareness and early college experiences to create a set of personalized behavioral engagement values that they applied in their courses, largely irrespective of external influences.	*I've never not turned in an assignment* *I pay for it, I'm gonna sit there whether I pay attention or not, so yeah. I don't skip unless I'm seriously sick or have a doctor's appointment, or something*
Future goals used to deepen cognitive engagement within the discipline	Behavioral engagement values were associated with a vision for participants' futures, from which they developed meaningful cognitive engagement strategies for deep learning.	*And then in the future, I know we're not gonna do some of the exact same stuff, like we're not gonna be doing steel design technicalities to the T, but I know that the concepts and theories are still really important for the future.*
Cognitive engagement adjustments to mirror the engagement stance of instructors	Both cognitive and behavioral engagement strategies were brought to the classroom by participants, where instructors played a primary influencing role in how students adjusted their cognitive engagement on a course-by-course basis.	*As a student, like, I'm in this one class right now and the professor is totally engaged and writes all the stuff, it's just very genuine that it's his work, and it's so easy to learn from. Last term I had some professors that were using other materials and they didn't know how to do the homework assignments, they kind of just reading off the slides and it's just really difficult to learn that way for me*
Blended influences to determine effective and efficient engagement strategies	Participants looked to develop effective and efficient engagement strategies that reasonably aligned with their behavioral values, future goals, and the stance projected their instructors.	*That's when I'm just going to have to fall back onto this is just part of the step, part of the process, these are the fundamentals from which I'm trying to lay a foundation for the future. But it's a good reminder that even when you're in those types of [technical] classes and you're kind of burrowing deep, it's that you're not in a vacuum, this all exists in the real world and these have consequences*

5.4.1 Theme 1: Established behavioral engagement values that remained constant across courses

The backdrop of participants' engagement patterns was their entry into the engineering discipline. Participants were not students who had grown up wanting to be civil engineers; rather, they represented a group of high-performing, successful high school students who found themselves in civil engineering due to a mix of family and social pressures. Upon entering college, these students leveraged their capital to switch majors to find the "right" fit (Alisa and Kara), join the honors college (Zach), find a dual-enrollment master's program (Bruce), participate in a sorority (Kara), and/or take a co-op internship (Cole). Though varying, these somewhat disparate experiences instilled similar self-awareness among participants that shaped their behavioral engagement values.

Participants discussed their behavioral engagement values such as attending class, completing homework assignments, and passing tests/courses in terms of absolutes. Bruce repeatedly mentioned that he had "*never not turned in an assignment,*" even if sometimes those assignments were completed with "*not maybe having the best academic integrity*." Bruce alluded to a common theme among participants: behavioral engagement values are constant, but cognitive engagement values are dependent on contextual course features. For Bruce, the behavioral value was turning in assignments, closely associated with his identity as a successful student. Yet, the mental effort or exertion he put into his assignment (whether or not he cheated) was dependent on contextual course features (e.g. a homework assignment seen as unnecessarily burdensome). Alisa similarly was absolute in her description of her behavioral engagement pattern of attending class: *"I pay for it, I'm gonna sit there whether I pay attention or not, so yeah. I don't skip unless I'm seriously sick or have a doctor's appointment, or something."* The language Alisa associated with cognitive engagement depicted little certainty: "*whether I pay attention or not, so yeah."* Throughout her interview, Alisa discussed the contextual course features that might result in her paying much attention and those that resulted in her just simply "*sit[ting] there,*" but remained unwavering in her behavioral engagement values.

Underscoring participants' behavioral engagement values was a drive for successful completion of a course. For Bruce, Cole, and Zach, there was an awareness of their past successes and a belief that their established behavioral values would continue to lead them to successful outcomes. Zach framed it as "*my brain is kind of suited to the system that we've created to educate students and it usually works out for me in the end.*" Zach was not only aware of the education system in which he was a part, he used this awareness to predictively indicate his future successes based on continued enactment of his behavioral engagement values. Kara and Alisa emphasized more heavily the role their past engagement failures played on their current behavioral values. Both participants discussed a dramatic shift in their engagement after failing courses early in college. Alisa believed she "*wasn't doing college right*" when she was failing classes. She later developed values that helped her succeed: "*'Okay this makes more sense, what I'm doing is helping me.' That was when I started to go to office hours, and actually engaging with the material. More than just writing down the answer.*" Alisa moved from an abstract version of how to do college "*right*," to a set of personalized behavioral engagement values that she carried with her through her courses (notably going to office hours when she needed help).

The drive for successful completion of a course committed students to their behavioral engagement values despite circumstances they viewed as unfavorable. For Kara, contextual course features were enough to cause her to mentally disengage from a course, but remained committed to passing:

> **I didn't actually withdraw from the class, but mentally I was putting it on the back burner because I wasn't doing great, but it wasn't engaging. It wasn't super exciting subject to me. So I didn't really… I just did what I had to do to get past the class.**

Kara's commitment was not simply to pass the class but to "*get past the class.*" In order to do so, a particular level of cognitive engagement was required of her. It was in this way that behavioral engagement values shaped the cognitive engagement values of participants: cognitive effort was put forth in order to remain in alignment with behavioral engagement values. Cognitive engagement *beyond* the level that ensured alignment with self-imposed behavioral engagement values remained contextually dependent on course features.

5.4.2 Theme 2: Future goals used to deepen cognitive engagement within the discipline

As seen above, participants attached their behavioral engagement to a short-term goal (e.g. quickly completing a homework assignment, passing a course); it was participants' long-term future goals that deepened their cognitive engagement within their chosen engineering discipline. For Cole, his future goals included becoming successful in his career to the point of owning his own company: "*I know, I want to probably own my own company, or take over someone else's company, I don't know*." Cole's desire to be in management was echoed in all participants, yet, like Cole, these participants often used uncommitted language when discussing their future goals. It was therefore not the assurance of a particular future that resulted in participants deepening their cognitive engagement, rather it was their perception of the skills needed to fill the projected future role. When Cole enrolled in an engineering planning course that related to finance and business, his cognitive engagement notably deepened. He put forth cognitive effort to develop personalized strategies (in this case, watching videos) for deeper learning and mastery of the material:

> **I liked that one a lot. I feel like it also has to do with my interest, though, because I really like finance, and figuring out how all of that works, and how money works, so that was really interesting to me. And outside of the class, I watched more videos on how interest rates and all of that worked, so-**

Cole uses language such as "*figuring out how all of that works*," indicative of the meaningful cognitive engagement associated with material he found interesting and relevant to his future. Furthermore, Cole put effort into learning from videos as a result of his independent interest and investment, beyond the behavioral engagement established in response to his values. Participants' cognitive engagement similarly deepened across courses and subjects they deemed relevant to achieving their future goals.

Interconnectivity between cognitive engagement and future goals was further exhibited in the way participants often failed to generate meaningful cognitive engagement with courses they perceived held little relevant to their future. Kara became notably disengaged when her perceived future job did not require skills being taught in her course:

> **You're never going to have to design temporary shoring, whatever for a building. And it's, okay so that in the back of my head I'm in the class and I'm never going to have to actually calculate and punch these numbers. Yes, it's good to actually know if I walk into a construction site I'd be, 'Oh I know what that is'. That's more so where it's nice and I'm okay, I'm able to go in and talk the talk and be familiar with things. But then when it's the math, so I just have to like, I'm not going to be crunching numbers all day long, putting into equations like that. So that's kind of a trade-off for the conceptual stuff. I'm, okay good, I need to know this. Versus the actual math, it's ehh, someone else, it's not my job.**

Kara's inner battle was between a firm belief that certain things she learned in class were "*not [her] job*" and a hesitancy to dismiss a subject or course as holistically inapplicable *("Yes, it's good to actually know if I walk into a construction site*"). Thus, Kara aligned herself with her behavioral engagement values of attending a course to ensure exposure to material, but minimized her cognitive engagement based on a perceived lack of usefulness in achieving her future goals.

The future goals of participants were not attached to an unchanging reality, and were therefore negotiated as participants interacted with internships and course material. Participants indeed were more influenced by their beliefs about their future goals than the real-world experiences that related to them:

> **It's more helpful to know how what you're learning in class applies to the real world, or like what you'll actually be using in the real world, but I feel like they don't really pertain to each other, really at all. I mean, they kind of do, but not a lot. I was very surprised on how little I actually used, but I feel like it'll be a lot different when I work for the private company, because they're a lot more design side of things, and I feel like that's kind of like what we learned in class more. (Cole)**

Cole actively sought to connect his learning to his future, as he started off saying "*It's more helpful to know what you're learning in class applies to the real world,*" yet remembered experience taught him otherwise—the classroom was different than his experience of the workplace. In the midst of this dissonance, Cole concludes that there is likely more connection between his learning and future career coming just over the horizon in his job with a private company. Cole thus generated more meaningful cognitive engagement with the intent of applying acquired knowledge a future job.

Cognitive engagement within components of course material was similarly responsive to participants' beliefs about its usefulness to their future; the general strategy of participants was to engage meaningfully when examples were done in class, and pay little to no attention to the supporting theory or proofs (only as much as was perceived as useful to the future). This was, in part, due to participants believing their future job needs would mimic the needs of the present. Alisa exemplified both when she said:

> **So yeah, obviously homework's the first thing on my mind, so I'm like, "All right, if I pay attention now I'll be able to do the homework easier, and not wanna cry every time I look at a homework assignment. And then yeah, once again... So like taking the FE, I knew a lot of questions would be similar to the FE, and I know that the PE will probably be somewhat similar to what we're seeing. And then in the future, I know we're not gonna do some of**

> **the exact same stuff, like we're not gonna be doing steel design technicalities to the T, but I know that the concepts and theories are still really important for the future.**

Alisa presents the duplicity present in participants' view of their future; homework, the FE (Fundamentals of Engineering exam), the PE (Professional Engineering exam), and a job were all important futures to which course material must apply to be engaged with deeply. The ongoing negotiation between an uncertain future and a commitment to focusing on learning what was applicable to that unknown future, resulted in participants cognitively engaging to build connections between their coursework and future. It was apparent that these connections were self-generated or influenced by personal internship experience; instructors were not cited as a source of connecting participants to future goals.

5.4.3 Theme 3: Cognitive engagement adjustments to mirror the engagement stance of instructors

While values guided participants' behavioral engagement (Theme 1) and future goals shaped their cognitive engagement within the discipline (Theme 2), instructors/instruction played a significant role in shaping participants' cognitive engagement with a particular course. Kara was motivated to cognitively engage with courses that were interesting and applied to her, but the depth and persistence of her cognitive engagement was shaped largely by her instructors. Beyond this, she exhibited willingness to meaningfully cognitively engage with a course solely because of the instructor's engagement:

> **He did all these good just life stories that he talks about but also was another teacher like you could tell he wanted you to do well in the class. And so I was, okay, I do want to understand this and I do, it is, it's again, it's nothing super, I'd really use it. It's, oh it was a lot of math stuff. It's not really what I'm going to use in my lifetime. But because of him I was, okay, I feel I needed to. So I, I went to his office hours, probably every time we had a homework assignment due four or five, six homework assignments and stuff. I went all the time and would just sit in there and I'd work on it before if I got stuck and then I'd go to him and be, okay, what am I doing wrong? I keep, and then we just work through it step by step and I was, he's also probably one of my favorite teachers I've had in college. (Kara)**

Kara substantially adjusted her engagement based on the engagement of her instructor. Her mirroring of her instructor's engagement went beyond behavioral—she talked about "*wanting to understand*" and seeking to learn what she had done wrong while attending office hours, signs of meaningful cognitive engagement. For Kara, it was the importance of her instructors caring and wanting her to do well in the course that deepened her cognitive engagement with the course despite a lack of interest or relevance at the onset.

For all participants, there was a clear correlation between how much they cared and how much the instructor cared—participants mirrored the value of the course as determined by the instructor. This mirroring would go as far as to conflict with the future goals students professed; high quality of instruction, as seen with Kara, could result in creating a new interest with a subject, whereas poor instruction of a course led participants to disengage regardless of relevance to their future goals. Zach emphasized both, saying:

> **I think that perception of whether a professor cares, whether or not they necessarily do about any individual or not, makes a difference. So like, I really like structures and last term, my structures one, because I would say he has challenges showing that**

> **he cares, but it comes through that he does care about the students and making sure people succeed. And same for fluid mechanics last term, even though it was disorganized, she really cared about the students and really did want everybody to learn, whereas, like geotech where I was kind of in that middle ground, it was a bigger lecture, and it was just kind of like, he was just kind of there filling in his notes and questions. I know he does care, but there is kind of an aloof perception that maybe like, "Well if you don't care about this, why the hell should I care about this?" So whether or not he did or not, I think that would make a difference**

Zach points to a distinction in how instructors care and its result on his engagement—some it "*comes through*" whereas with others (e.g. his Geotech professor), the perception was that he was "*just kind of there filling in notes.*" Zach stated clearly a theme which echoed throughout participants: "*Well if you don't care about this, why the hell should I care about this?*" It was not that Zach believed instructors some did not care, instead he was primarily interested in the caring he could observe and mirror in his own engagement. Across participants, there was similar belief that instructor care should not exist in an abstract sense, but should be demonstrated in ways that could be perceived and mirrored. The ways in which instructors were perceived to care was nuanced and went beyond simply the behaviors. For Zach, his fluid mechanics instructor's behaviors were not engaging, rather it was her "*want[ing] everybody to learn.*" In this sense, participants were seen to mirror the cognitive state of *wanting to learn* more so than simply instructor behavior.

Time in college had developed in participants a deeply-held set of beliefs through which they perceived the level of care of their instructors. Bruce, immediately when discussing his engagement at the opening of the interview, brought up difficulty learning from instructors who used materials they did not develop. Bruce went on to repeatedly reference how difficult, frustrating, and uninspiring these professors were, and how his own engagement and learning reflected the investment of his instructors:

> **As a student, like, I'm in this one class right now and the professor is totally engaged and writes all the stuff, it's just very genuine that it's his work, and it's so easy to learn from. Last term I had some professors that were using other materials and they didn't know how to do the homework assignments, they kind of just reading off the slides and it's just really difficult to learn that way for me.**

Bruce starts off talking about "*as a student*," but curtails the thought and then begins to describe how his instructor was "*totally engaged*" and "*genuine*" in his work; it is as if Bruce uses the engagement of his instructors to justify his own engagement within the course. This extends to instruction Bruce does not find engaging—particularly instructors utilizing old material. If the instructor "*didn't know how to do the homework assignments*," Bruce concluded that neither should he. Other participants similarly had qualities of instruction they mirrored for positive cognitive engagement: Alisa cognitively engaged in classes that were challenging, Zach when use of a projected document camera allowed him to see more clearly as a colorblind student, Cole with hands-on learning, and Kara when instructors made connections to the "*real-world*."

While instructional practice preferences were somewhat unique to participants, a common set of practices emerged that resulted in the deepening of cognitive engagement. Clear and concise presentation of material minimized cognitive dissonance in participants, and resulted in deep thinking over material as they translated it into notes for their personal use. The organization, enthusiasm, and effort participants perceived in their instructors was mirrored in their cognitive engagement with course assignments. Zach went as far as to describe organization as the "*best thing*" instructors can do to engage their students: "*With the faculty, the best thing you can do is to have clear blocks and don't make them super long, like make a lecture that actually lasts 50 minutes, or lasts even 45 minutes and take questions at the end.*" Cole struggled to put to words exactly how instruction impacted his engagement, stemming from a strong interconnection between his own response to instructional practices and the practices themselves:

> **I feel like the teaching style, or just their personality, or energy, if they're very monotone, just like a robot, it's very hard to pay attention in class. But if they're excited about what they're teaching, and they're ... They like ... I don't know, I feel like you can just tell that they want you to learn, kind of thing. I don't know.**

Cole could "*just tell"* that instructors wanted him to learn as a result of his own belief that he needed to learn. The connection between Cole's cognition and that of his instructors was so strong that he in fact described *their* engagement when asked how an instructor influenced *his* engagement. Other participants similarly referenced an elusive understanding that their instructors wanted them to learn, and built their own desire to learn upon it. The shared set of instructional traits deemed engaging by participants indicated their responsiveness to best practices, and their willingness to abandon their own deep cognitive engagement in the absence of effective instruction.

Even though their cognitive engagement was dramatically influenced by their instructors, participants were hesitant to abandon their behavioral engagement values in response to instructional practices. Viewing instructors as human and cultivating their own values of engagement remained critical even in the mirroring of engagement participants exhibited. Cole showed how his behavioral engagement value of taking notes intertwines with the instructional practices in a course:

> **It really depends on how the teacher is actually teaching, though, because some classes, I can't really take notes, or I don't know what information is important to write down. If they have all the information's on the slide, like they just have a slide full of words, I don't really know what information is important, so that's why it helps me when they actually solve out problems, or they write ... They actually just write out on the board the important points or something like that.**

Cole's repeated use of "*actually*" indicated his comfort when his value of notetaking aligned with instructional practices of "*actually solv[ing] out problems*" or "*actually just writ[ing] out on the board*." Cole was at odds with instructors who did not clearly communicate information that was important on crowded slides. Cole was unable or unwilling to mirror the shallow cognitive engagement (i.e. presenting material with no manipulation) in his notetaking, leaving him with conflict between his engagement values and those of his instructor. Across participants, the greatest dissonance in their engagement occurred when their behavioral engagement values conflicted with the cognitive engagement projected by their instructors.

5.4.4 Theme 4: Blended influences to determine effective and efficient engagement strategies

As seen above, instructional practices could stand at odds with participants' own beliefs about engagement. Participants were seen to minimize the dissonance between these sometimes-conflicting influences on their engagement by moving towards effective and efficient strategies in their learning. We previously discussed how Alisa came to see office hours as a way for her to effectively learn material; while visiting office hours was a behavioral engagement value of Alisa's, it was also indicative of a deeper movement towards effective and efficient cognitive engagement in her education. Alisa no longer struggled with assignments on her own or took on the financial burden and extended time in college of failing classes.

The strategies for effective and efficient learning varied among participants: Kara took courses with a friend, Bruce turned to YouTube when struggling on assignments, and Cole typically worked alone as opposed to collaborating with peers. Cole stated that he worked alone because it was "*easier*" and "*more time efficient*." It was observed that when Cole did struggle, he would employ a broader range of effective and efficient learning strategies. His sequence was as follows: attempt work on his own, seek additional guidance from YouTube, ask his friends for help, and finally go to office hours with the instructor. Cole employed these strategies primarily because they were efficient and effective, not because they were most closely associated with his values, future goals, or impressed by the instructor. Bruce noted a conflict between his behavioral engagement values when he described telling himself at the start of every term he would read the textbook before lecture; the behavior never occurred because he "*seem[ed] to get by without having to*." These simplified engagement strategies allowed students to continue moving through their coursework without becoming cognitively overwhelmed or overburdened by their or their instructors' ideals.

Frustration emerged in participants when courses continued to demand their behavioral engagement, but required minimal cognitive engagement: "*But if a teacher is just reading word for word off of a slide, that's where it's like 'do I really need to be here? I could teach myself this right now'*" (Kara). Kara described a classroom that was no longer the most effective or efficient means for her to learn the material. Participants were vividly aware of their ability to engage with material beyond what was presented to them in the classroom; YouTube, Khan Academy, texting with peers, and notes made available online by the instructor were all cited by multiple participants as notably meaningful ways they independently cognitively engaged in their learning. These "beyond the instructor" learning mediums were utilized most heavily when instructional practices reflected levels of cognitive engagement below their own values or interest due to future goals.

Kara showed signs of her varying engagement strategies to effectively learn the material in various contexts:

> **And if it's a topic, it's okay, I can kind of figure this out on my own. That's probably one I will not show up. But if it's one, like have an 8am right now with 15% of the grade is participation. So it's okay, I got to show up and all of that. And then also again, if I really like my teachers that's going to get me to go more, or if we're doing group projects, that's going to get me to go more because I don't want to be the slacker in my group. And so I'm okay, I'm here. Let's do what we gotta do.**

Kara adapted her behavioral engagement strategies (e.g. not wanting to show up for early-morning lectures) to those of her instructor (e.g. the weight assigned to participation) when it was effective and efficient for her to do so. As stated above, Kara no longer wanted to fail courses and therefore was looking for the most efficient way to pass (provided the instructor was not inspiring deeper cognitive engagement). Kara knew when her behaviors could be modified and still result in her passing; her behavioral engagement was adjusted accordingly: "*When I can figure it out on my own. That's probably one I will not show up*"

Though all participants were persistent in the development of cognitive engagement for their personal benefit, contrasting ideals often led them to engage in the most efficient and effective manner possible. Zach projected minimizing dissonance when taking a technical course that would likely not interest him or align with his future goals:

> **That's when I'm just going to have to fall back onto this is just part of the step, part of the process, these are the fundamentals from which I'm trying to lay a foundation for the future. But it's a good reminder that even when you're in those types of [technical] classes and you're kind of burrowing deep, it's that you're not in a vacuum, this all exists in the real world and these have consequences both in the very day to day level, in the fact that you get to just sit here in a classroom and be comfortable, relatively speaking doing that, and also in a grand scale of the meta in civil engineering, infrastructure, all that stuff that I'm interested in (Zach)**

While Zach was often more reflective of the broader consequences of his engagement than other participants, he presented a theme that was common among them: sometimes it is was getting through and taking the next step forward that resulted in effective achievement of participants' values, goals, and course experiences.

5.5 Discussion

Inherent to IPA research is attention to the particular; the results of this work are intended to be representative of the lived experiences of participants in this study. We see a critical need for research attentive to the particular to inform the community's broader understanding of the student experience. Here, we outline the ways in which we see this work aligning with, and contributing to, the growing body of knowledge on student engagement, research-based instructional practices, and research on phenomena relevant to engineering education.

5.5.1 Alignment with Previous Research

Our results suggest that four themes can be used to frame the cognitive engagement of our upper-division, civil engineering student participants. Under *Theme 1*, participants were seen to establish behavioral engagement values that were consistent across their learning contexts. Other research has proposed that students' learning is shaped by their context and culture (National Academies of Sciences Engineering and Medicine., 2018a), aligning with our findings related to the personal stances and values we observed to influence engagement. We used the behavioral engagement values observed in *Theme 1* as foundational to understanding cognitive engagement in later themes, which is supported in research on strategy use and self-regulation as important aspects of understanding cognitive engagement in science (Greene, 2015). *Theme 2* suggests that future goals impacted the cognitive engagement pattern of participants, which aligns with the previously established relationship between future goal orientation and cognitive engagement in courses (Appleton et al., 2006; Greene & Miller, 1996). *Theme 3* indicates that instructors indeed play a meaningful role in engaging their students, as participants were seen to mirror the engagement of their instructors. Such results suggest that Conclusion 7-4 of *How We Learn* is applicable in the engineering education context: purposeful teaching is critical to students developing deep understanding (National Academies of Sciences Engineering and Medicine., 2018b). Furthermore, this echoes the findings of Heller et al., who note that students report it is something about their instructor's presence that makes their courses engaging (2010), and Chi et al., who found that instructors could generate learning gains by developing learning activities targeting deeper cognitive engagement (2018). Finally, *Theme 4* suggests that it was a blended influence of personal values, future goals, and instructional practices that led participants to make effective and efficient engagement decisions. Hickey and Granade proposed that reconciliation between individuals and their knowledge communities occurs as students internalize values and undergo sociocultural influence (2004). We found such reconciliation to be similarly true in our sample—it was through this reconciliation of sociocultural influences that participants came to effective and efficient engagement strategies in their later college courses. We reiterate the conclusions of Chen et al., who state that engagement is a *joint responsibility which relies on the attitudes and behaviors of both students and faculty*, but emphasize the importance of considering the critical role of faculty in the engagement experience (2010).

5.5.2 Implications of Sample and Methodology

While our work aligns with and supports previous research, there are implications unique and innovative to this work. Here, we leveraged the usefulness of the IPA methodology in understanding the lived experience of a group of upper-division, civil and construction engineering students—specifically what shaped their cognitive engagement within engineering courses. IPA allowed us to come to themes representative of the participants, then connect them to previous work. Connecting findings to previous work suggests that our sample is representative of a larger group's experiences (i.e. engineering students), while also provides insight into experiences unique to the sample (e.g. Zach's deep self-reflections, Kara's working through failing courses, etc.). As suggested by Huff (2015), the IPA methodology may be adopted by a wide variety of engineering education researchers seeking to study experience related to a wide array of phenomena of interest to engineering educators. We see ongoing need for participant experience focused research even within our own area of study (student cognitive engagement), as the experience of many remains underexplored; that which shapes the engagement of underrepresented, underperforming, first-generation, and nontraditional students is critical to addressing the continuing question of *who* active learning works for and *in what ways*.

5.5.3 Implications for Practice

We see a linchpin of our results to be that faculty indeed influence student's engagement in meaningful ways. Earlier we noted other studies provide evidence of such a relationship; the results of this study unpack the nuanced ways in which participants tended to mirror the cognitive engagement they perceived in their instructors. Importantly, participants had both the ability and means to acquire knowledge gains on their own—indeed, they often cited internet resources as information enough to allow them to align with their values and reach their future goals. It was therefore the *quality*, *effectiveness*, and *efficiency* of instruction that prompted participants to meaningfully engage and thereby learn from their instructors. Practically, results suggest that instructors need to clearly communicate to students that they themselves see the course material as worth cognitively wrestling with for understanding. Conversely, results suggest that poor instruction may result in substantial detriment to the cognitive engagement of students in the classroom; while highly motivated students (such as the participants in this study) may seek out other meaningful forms of engaging with learning material (e.g. the internet), it remains to be seen if unmotivated students choose to meaningfully cognitively engage at all.

Beyond the instructor, it was participants' future goals that largely shaped their meaningful cognitive engagement with particular course material; when participants saw a connection between what they were learning in class and an achievement of a future goal, their cognitive engagement increased. Though participants exhibited lack of certainty in regards to their future, they based important engagement decisions on a narrow view of their future career. Instructors may seek to present students with evidence for their probable career changes, and indicate how course material is useful for achieving goals that may seem less obvious (e.g. structural engineers may seek to be conscious of pipe flow constraints during design). Furthermore, instructors may seek to address the ways in which patterns of meaningful cognitive engagement may lead students to futures beyond what they currently envision for themselves.

5.5.4 Limitations and Future Work

The attention to the particular in this study is inherently limited. We seek to understand the experience of an admittedly narrow group of students as foundational work to understand the broader experience of students' cognitive engagement. Our findings are useful insofar as the interpreter (i.e. the reader) is thoughtful about the context in which they are making their own meaning. Data suggests that participants were not financially limited (i.e. they could fail a course and continue their studies), had access to social networks, and were supported by mentors/parents. Our participants therefore had access to the resources necessary reflectively considerer their engagement, its benefit to them, and adjust when previous attempts had failed. Participants were also largely successful, high-achieving, and self-identified as good students. We see a need for future work to begin to develop an understanding of varying student experiences within engineering. Participants in this study showed improvement and overcame obstacles over time; less is known about the students who do not improve. Furthermore, participants in this study had internship experience that led them to an understanding of their future goal and what might be required to achieve them. More work is needed to understand how students who do not have internship experience develop their future goals, and how instructors might elicit meaningful cognitive engagement with course material related to their indeterminate future.

While studying high-achieving students may initially seem counterintuitive, we suggest that it is indeed a useful metric for instructors seeking to better understand their classrooms. Results suggest that instructors might gauge their practices as they see the reflection of cognitive engagement in their high-achieving students. We also hope to inspire educators to thoughtfully consider their own engagement and its impact on their students, because even the most motivated students are influenced by their instructors' engagement. While it is often inferred that active learning will simply lead to deep student cognitive engagement, we have begun to see that engagement is influenced by a variety of factors. As instructors design their courses, we see a need to think in broader terms of how students are learning—not to seek out one-size-fits-all models of engagement. Further study is needed to explore the phenomenon of student cognitive engagement in diverse groups, with particular attention to low-achieving students who are at risk of leaving the discipline. Questions remain about students who have not developed behavioral engagement values that lead them towards meaningful cognitive engagement: what motivates these students, and at what capacity do they choose to meaningfully cognitively engage?

6 – CORRELATIONS BETWEEN MODES OF STUDENT COGNITIVE ENGAGEMENT AND INSTRUCTIONAL PRACTICES IN UNDERGRADUATE STEM COURSES

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Abstract

Background: Within STEM education, research on instructional practices has focused on ways to increase student engagement and thereby reap the associated benefits of increased learning, persistence, and academic success. These meaningful-learning goals have been tied most specifically to cognitive engagement, a construct that is often difficult for instructors to assess on their own. While it has been shown that certain instructional practices are tied to higher cognitive engagement in students, tools to measure instructional practices and student engagement have remained largely isolated in their development and use.

Results: This research uses previously developed instruments to simultaneously assess modes of cognitive engagement in students (Student Course Cognitive Engagement Instrument [SCCEI]) and instructional practices (Postsecondary Instructional Practices Survey [PIPS]) within a course. A sample of 19 STEM courses were recruited to participate in this study, with instructors and students each self-reporting data. Results from instructor and students in each course were scored, and ANOVAs and partial correlation analysis were conducted on the sample. ANOVAs indicated the significance of instructor tenure status and classroom structure on student engagement. From the correlation analysis, a significant relationship was found between four student-reported modes of cognitive engagement and instructor-reported teaching practices.

Conclusions: With an understanding of student engagement response to tenure and classroom structure, instructors may consider their teaching environment when

implementing instructional practices. Moreover, Interactivity with Peers, the deepest mode of cognitive engagement suggested by previous research, was correlated with instructional practices in our study, suggesting that instructors may be able to shape their students' learning by encouraging collaboration in the classroom. We also found that assessment played a role in students' cognitive engagement; this indicates that instructors may wish to thoughtfully consider their methods of assessment to facilitate modes of cognitive engagement associated with deeper learning of course material. By understanding factor correlations, the PIPS and SCCEI can be used in tandem to understand impacts of instructional practices on student cognitive engagement within a course. We conclude that there is a need for ongoing research to study the interplay of instructional practices and student cognitive engagement as instruments are developed to measure such phenomena.

6.1 Introduction

STEM education research aims to benefit students in science, technology, engineering, and math disciplines. Student engagement and its relationship with instructional practices is deeply influential in understanding how to better students' learning experiences. As we seek to offer an understanding of the interplay of instructional practices and student engagement, we first present the relevant literature related to each. We also address the ways in which the literature suggests a relationship between instructional practices and engagement, and the need for further empirical evidence of how the two are correlated.

6.1.1 Cognitive Engagement

STEM education communities are interested in better understanding student engagement, as it has been hallmarked as a key factor in increased student grades, retention, and knowledge gains (Freeman et al., 2014; Prince, 2004). Engagement is a multi-dimensional construct (Appleton, Christenson, Kim, & Reschly, 2006), that is often best understood to be comprised of several key components: behavioral, emotional, and cognitive (Fredricks, Blumenfeld, & Paris, 2004). Behavioral engagement can be thought of a student's active involvement in learning and course tasks (Sinatra, Heddy, & Lombardi, 2015). This active involvement is observable, and includes student's participatory behaviors and adherence to rules (Fredricks et al., 2004). Emotional engagement is defined by a student's affective or emotional responses to an academic subject or course (Fredricks et al., 2004). Positive and negative emotions have been shown to play an important role in choices surrounding emotional engagement. Like behavioral engagement, some of these positive or negative emotional engagement choices are external (Pekrun, 2006), and can be observed as happiness, sadness, interest or boredom (Fredricks et al., 2004). Cognitive engagement is more abstractly defined in part by students' psychological investment and motivation (Sinatra et al., 2015). While the construct of cognitive engagement is more difficult to clearly define and measure, it has been shown to have positive influence on student performance, persistence, and goal orientation (Appleton et al., 2006; Meece, Blumenfeld, & Hoyle, 1988)

A prominent framework for assessing cognitive engagement was pioneered by Chi in 2009, when she first began to establish different modes of cognitive engagement based on observable behaviors in students. Later, Chi and Wylie published the ICAP framework, which empowered educators to observe their students and interpret their cognitive engagement as one of four modes: **I**nteractive, **C**onstructive, **A**ctive, or **P**assive (2014). Our recent work focused on the development of an instrument that utilized the ICAP observational schema in a self-report instrument (Barlow et al., in review) This instrument, the Student Course Cognitive Engagement Instrument (SCCEI) was validated for engagement of STEM students related to a specific course. We prompted students to reflect on both their behaviors and cognition, finding that students responded consistently to five factors: Interactivity with Peers, Constructive Notetaking, Active Processing, Active Notetaking, and Passive Processing. The SCCEI is intended to provide STEM educators with a depiction of how students are cognitively responding to their instructional practices.

6.1.2 Instructional Practices

Researchers in STEM education have spent significant effort on uncovering what factors within a classroom influence a student's engagement (e.g. see Felder & Brent, 2005; Heller, Beil, Dam, & Haerum, 2007, 2010; Ohland et al., 2008; Stump, Hilpert, Husman, Chung, & Kim, 2011). It has been shown that instructional practices often play a central role; the structure of exams, lectures, and student interactions have all been shown to influence the engagement of students (Nicol & Macfarlane-Dick, 2006; Prince, 2004; Wang, Yang, Wen, Koedinger, & Rosé, 2015). Problem-based learning, cooperative learning, and flipped classrooms have likewise all been researched for their impact on student engagement (Dard, Lison, Dalle, & Boutin, 2010; Prince, 2004; Smith, Sheppard, Johnson, & Johnson, 2005). Yet, it remains important for instructors to consider the practices of their own classrooms, even those that do not fit clearly within the bounds of a particular strategy. To do so, educators can be asked to report on their own instructional practices surrounding factors notably important to engagement, including assessment, student interactions, and delivery of the content.

Methods of assessing instructional practices include student surveys, self-report surveys, interviews, class observations, and artifact analysis (American Association for the Advancement of Science [AAAS], 2012). Self-report has the unique advantage of collecting data from the perspective of the instructors, who have power to enact change in their own classroom. A review of 12 prominent instructor self-report instruments was conducted by Williams et al. in 2015. They found half (6) of the instruments were related to specific disciplines, while the others had been validated in a variety of STEM disciplines. Broader instruments either emphasized teaching specifically, or teaching and other elements of faculty work (Williams, Walter, Henderson, & Beach, 2015). The **P**ostsecondary **I**nstructional **P**ractices **S**urvey (PIPS) (Walter, Henderson, Beach, & Williams, 2016) is an instrument intended to span all disciplines that was found to focus most heavily on instructional practices (Williams et al., 2015).

PIPS is a validated, externally reviewed instrument composed of 24 instructional practice related items (Walter et al., 2016). Validation studies at a broad range of institutions and departments support a breakdown of items into either 2 or 5-factor models. Authors suggest that the 5-factor solution is most appropriate when more details on the instructional practices of a participant is valuable (Walter et al., 2016). These factors are: Student-Student Interactions, Content Delivery, Student-Content Engagement, Formative Assessment, and Summative Assessment. Within the original study, the PIPS was used to understand correlations between teaching practices and class size, instructor gender, and years of teaching experience (Walter et al., 2016). Though authors acknowledge that some of their constructs are intended to reflect how engaging the practices of the instructor are (see *Student-Content Engagement* of the 5-factor model), PIPS has yet to be used in conjunction with measures of student cognitive engagement.

6.1.3 Environmental Factors' Relationship to Instructional Practices and Student Engagement

When considering student cognitive engagement, it has been important to consider the context in which students are asked to engage. Past research suggests that students are impacted by their environment, including the tenure status of their instructors and the physical structure of the classroom (Lund et al., 2015). Here, we consider the relationship of both the physical structure of the classroom and instructor tenure status to the SCCEI modes of student engagement; consideration of such relationships provides further insight as to how student reports may responsive to these course features.

Both the instructor and the student have potential to be influenced by the classroom structure. Research has suggested that the implementation of student-centered instructional practices may be limited by classroom structure (Henderson & Dancy, 2007). Though classroom layout can be perceived as a barrier, it is not systematically tied to instructional practices that feature student-centered learning (Bathgate et al., 2019; Stains et al., 2018). Some have gone on to suggest instructors may be less likely to abandon newly-adopted active learning based instructional practices when the physical structure of their classroom is modified to specifically accommodate the teaching style (Knaub, Foote, Henderson, Dancy, & Beichner, 2016). When considering how students respond to classroom structure, Foote et al. indicated that studio classrooms are associated with higher levels of active learning (2014). Yet, others have suggested that student-student interactions can be facilitated even in classrooms with fixed, amphitheater-style seating (Lund et al., 2015). With some discrepancy in the literature, it becomes important to better understand how reported modes of student engagement are related to the classroom structure in which they learn.

When considering instructional change, it has been shown that the tenure status of an instructor shapes how they enact change in their classroom. One study found that the authority of instructors with tenure status may impede non-tenured instructors from implementing changes in their instructional practices (Quardokus Fisher, Sitomer, Bouwma-Gearhart, & Koretsky, 2019). Others have shown that beliefs about institutional support of teaching practices and balance between teaching and research differ along lines of instructor tenure (Landrum, Viskupic, Shadle, & Bullock, 2017). It likewise stands to reason that students will have a different course experience based on the tenure status of their instructor. In this work, we explored how classroom structure and tenure status explained variance in the SCCEI factor scores; this was done as a precursor to understanding the correlations between the two instruments.

6.1.4 Correlations between Cognitive Engagement and Instructional Practices

While the PIPS has yet to be used in conjunction with measures of student cognitive engagement, factors within the instrument suggest its relevance to engagement. *Student-Student Interactions* have been studied in the past through collaborative learning environments, finding that there are many circumstances when learning together is beneficial (Nokes-Malach, Richey, & Gadgil, 2015). This aligns with ICAP and the SCCEI, which posit that Interactive Engagement is the most sophisticated and beneficial for student learning (Chi & Wylie, 2014). *Student-Content Engagement* as measured by PIPS is what the ICAP framework was originally intended to measure—exploring how students make choices to cognitively engage with course content (Chi, 2009). Educators can design and redesign curriculum to increase student engagement, yet there is often far too little information available about what mode of engagement is achieved with a given assignment. Research continues to assess how *Content Delivery Practices* impact cognitive engagement, including the influence of flipped versus traditional lecture courses, project or problem based learning, and online course offerings. Finally, the *Formative* and *Summative Assessment* factors have notable relationships with cognitive engagement, including how students choose levels of sophistication to match those with which they are tested.

6.1.5 Overview of Research

We see each factor of the PIPS as poised to reveal aspects of student cognitive engagement. Missing from the literature is an empirical correlation between modes of cognitive engagement and instructional practices as measured by instruments with evidence of validity. There also exists an lack of empirical evidence that explains how various levels of tenure status or classroom structure explain the variance in the mode at which students cognitively engage. We therefore sought to answer the questions: (1) *How does instructor tenure status and classroom structure differentiate modes of student engagement?* and (2) *What are the correlations between SCCEI modes of cognitive engagement and PIPS factors of instructional practices?* Our aim was that educators may be empowered to make changes in instructional practices in their course with knowledge of how their practices correlate with student's cognitive engagement, as well as understand how contextual features of tenure and classroom structure may impact their change efforts. To answer Research Question (1), we conducted ANOVAs and generated data visualizations to represent the means of each of the SCCEI factors' correspondence with instructor tenure status and class structure. To address Research Question (2), we utilized partial correlation analysis to understand the relationship between instructional practices and modes of student engagement. We scored instructional practices using the PIPS and students' modes of engagement using the SCCEI; the partial correlation analysis allowed us to understand the correlations between the two instruments' factors within a course. Results indicate that there is statistical significance for students' mode of cognitive engagement with instructor tenure status and course structure.

6.2 Methods

The methods section below describes participant selection and data analysis. We also outline our sampling strategy, overview the function of the two instruments, and present the items of the PIPS and SCCEI.

6.2.1 Sampling

We aimed to recruit STEM courses from a variety of institutions that differed in their course level, classroom structure, and primary means of instructional practice. In all, over 100 courses were recruited for participation in this study from universities and community colleges across the United States. The sample began as a sample of convenience and was followed by snowball sampling (Berg & Lune, 2014). Instructors were recruited via email from the research team for participation in the study. Of the 100+ courses recruited, 37 indicated their interest in participating in the study. Once an instructor agreed to participate, all students in the course were recruited for participation in the study via course webpage. In this way, both the instructor and students in the class were considered participants in the study. Thirty-seven courses distributed the SSCEI to their students, and of those, 19 courses generated response rates greater than 10% and were included in the final study. There were 645 student responses to the SCCEI, with an overall response rate of 58%; average response rate of students was 51% with a standard deviation of 32%. The demographics of the courses in the study can be found in Table 6.1, and a summary of the student demographics can be found in Table 6.2.

Table 6.1: Summary of course demographics.

Course	*Discipline*	*Instructor Gender*	*Instructor Rank*	*No. of Students*	*Resp. Rate*
1	Civil and Construction Engr.	Male	Tenured	223	59%
2	Civil and Construction Engr.	Male	Tenured	116	100%
3	Civil and Construction Engr.	Male	Tenured	61	10%
4	Engr. Education	Female	Untenured, on tenure track	33	36%
5	Aerospace Engr.	Female	Untenured, on tenure track	62	77%
6	Civil Engr.	Female	Tenured	43	72%
7	Civil and Enviro. Engr.	Male	Tenured	39	28%
8	Civil and Construction Engr.	Female	Tenured	50	96%
9	Mech., Indst., & Mfg. Engr.	Male	Tenured	45	13%
10	Engr. and Manufacturing	Male	Tenured	33	18%
11	Civil Engr.	Male	Untenured, on tenure track	49	67%
12	Chemistry	Female	Untenured, not on track	96	99%
13	Biochemistry and Biophysics	Female	Untenured, not on track	24	33%
14	Civil and Construction Engr.	Male	Tenured	20	35%
15	Electrical Engr. & Comp. Sci.	Male	Tenured	30	20%
16	Chem., Bio., & Enviro. Engr.	Female	Tenured	56	59%
17	Mathematics	Male	Tenured	34	24%
18	Chem., Bio., & Enviro. Engr.	Female	Untenured, not on track	62	19%
19	Engr. Science	Male	Untenured, not on track	30	93%

Table 6.3: Summary of student population demographics.

	Study Population (%)
Student Academic Level	
Freshman	17%
Sophomore	13%
Junior	40%
Senior	29%
Student Gender	
Male	79%
Female	20%
Nonbinary	1%
*Student Race and Ethnicity**	
Caucasian	64%
Asian	16%
Hispanic/Latinx	11%
Black/African American	4%
Pacific Islander	3%
Native American	2%

*For *Race and Ethnicity*, multiple options could be selected. All demographic information collected was optional.

6.2.2 Notes on Instrument Use

Both the PIPS and the SCCEI underwent a development process to ensure that a set of items measured a single construct, or factor. Detailed information can be found on the evidence of validity for the PIPS and SCCEI instruments elsewhere (Barlow et al., in review; Walter et al., 2016). The factors of both the PIPS and SCCEI were derived using oblique rotations, meaning that there is an assumed correlation between factors (e.g. Interactive Engagement is assumed to correlate somewhat with Constructive Notetaking, and Content Delivery Practices with Formative Assessment, etc.). The focus of our research was to explore correlations of factors across the two instruments; we therefore do not present correlation of factors within instruments. Analysis utilized to develop factors (exploratory and confirmatory factor analyses [EFA], [CFA]) assumed normal distribution and linearity in the data. While we test the relevance of such assumptions here, we rely on the more robust samples present in the original studies for assumptions of normality and linearity of factors.

6.2.3 Measure of Instructional Practices

The PIPS facilitated instructor self-report along five distinct factors: Student-Student Interaction, Content Delivery, Student-Content Engagement, Formative Assessment, Summative Assessment (Walter et al., 2016). Each factor of PIPS is comprised of multiple items to measure alignment with a given construct. The factor Student-Student Interaction contains items that measure how instructors facilitate students' interaction with one another in the classroom, including both the structure of the course and the required activities of students. Content Delivery items relate to how instructors translate information to students, particularly through how the course is structured. Student-Content Engagement measures how instructors provide students with actives in the course from which they can reflect or make meaning of the material. Formative and Summative Assessment factors each address how students are tested within a course; Formative Assessment indicates testing that offers feedback to both instructors and students to shape the trajectory of learning whereas Summative Assessment measures formal testing and grading within a course. The items and descriptions as they relate to each of the five PIPS factors can be seen in Table 6.3 below.

Instructors were given access to the PIPS via Qualtrics (2005), an online survey platform. Each instructor was directed to respond to items with regards to a single term of a single course (the same course where students completed the SCCEI). The PIPS was deployed to instructors when the term was approximately 75% completed. This allowed instructors to reflect on a term of a course without generating undue pressure at the completion of the term. A randomized order of items was used to minimize fatigue effect. The response scale was the original scale from the study—a 5-point Likert; a score of zero was given to *not at all descriptive of my teaching*, with values increasing by one up to a score of four for *very descriptive of my teaching*. Walter et al. explicitly indicate the ways in which the PIPS is to be scored: values relating to items for each factor are summed, then divided by the total value possible for that factor. Thus, for each factor, faculty members were given a score between 0 and 100 (i.e. a percent alignment with the factor). No items required reverse coding. Higher scores were indicative of a *more descriptive* fit of the factor, not necessarily more preferable for engagement.

Table 6.3: The five-factor model of the PIPS survey.

Factor	***Description***	***Question/Prompt***
Student-student interactions	*Practices that describe interactions among students in class*	I structure class so that students explore or discuss their understanding of new concepts before formal instruction. I structure class so that students regularly talk with one another about course concepts. I structure class so that students constructively criticize one another's ideas. I structure class so that students discuss the difficulties they have with this subject with other students. I require students to work together in small groups. I require students to make connections between related ideas or concepts when completing assignments.
Student-content engagement	*Actions in which students manipulate or generate learning materials or products beyond what was provided by the instructor (similar to active and constructive elements noted by Chi and Wylie, 2014)*	I design activities that connect course content to my students' lives and future work. I frequently ask students to respond to questions during class time I have students use a variety of means (models, drawings, graphs, symbols, simulations, etc.) to represent phenomena. I structure problems so that students consider multiple approaches to finding a solution. I provide time for students to reflect about the processes they use to solve problems
Content Delivery Practices	*Practices that describe or influence how the instructor transmits information to the students*	I guide students through major topics as they listen and take notes. My syllabus contains the specific topics that will be covered in every class session. I structure my course with the assumption that most of the students have little useful knowledge of the topics. My class sessions are structured to give students a good set of notes
Formative Assessment	*Actions to monitor student learning that provide feedback to the instructor to inform teaching and/or to students to inform their learning*	I provide students with immediate feedback on their work during class (e.g., student response systems, short quizzes) I use student assessment results to guide the direction of my instruction during the semester I use student questions and comments to determine the focus and direction of classroom discussion. I give students frequent assignments worth a small portion of their grade. I provide feedback on student assignments without assigning a formal grade.
Summative Assessment	*Actions for formal evaluation of student learning, including grading policies*	My test questions focus on important facts and definitions from the course. My test questions require students to apply course concepts to unfamiliar situations. My test questions contain well-defined problems with one correct solution. I adjust student scores (e.g. curve) when necessary to reflect a proper distribution of grades.

In addition to questions related to instructional practices, the validated PIPS also asked instructors to identify their tenure status (*tenured, untenured on track, untenured not on track*). Similar to the way the PIPS development sought to explore relationships between responses to their instrument an tenure status (Walter et al., 2016), we sought to explore the relationship between tenure status and SCCEI scores. Furthermore, an additional question was added to the instructor instrument to better understand the physical structure of the classroom in which instruction took place. Instructors were asked *what is the physical structure of the course's primary classroom?*, and were given the options of *individual desks, students facing instructor; rows of tables, students facing instructor; pods of desks/tables, students facing other students*. Previous work provided similar responses for reporting of classroom structure (Lund et al., 2015). The questions facilitated an initial study of the relationship between student cognitive engagement and physical classroom structure.

6.2.4 Measure of Student Modes of Cognitive Engagement

In addition to the measurement of instructional practices, we sought to measure students' cognitive engagement at the course-by-course level. To understand modes of cognitive engagement of students within a course, it is important to clearly define differentiable modes. The ICAP framework provides a foundational understanding of modes of cognitive engagement (Chi & Wylie, 2014), with slight modifications being included from student self-report findings (Barlow et al., in review). Interactive Engagement or Interactivity with Peers references a dialogue between two students in which they add further definition to a course construct via an equally-participatory conversation (Chi & Wylie, 2014). Interactively Engaged students will co-create knowledge, and report high alignment to *I discuss my position with others regarding the course content.* Constructively engaged students will generate knowledge beyond that which is presented to them in a course. The SCCEI measures Constructive Engagement as students take notes (Constructive Notetaking); these students will integrate information and have a high alignment with *I add my own notes to the notes provided by the teacher.* Active Engagement, according to Chi and Wylie, requires focused attention and a basic level of information manipulation (i.e. underlining or highlighting) (2014). Work from the SCCEI measures two components of Active Engagement: Active Notetaking, and Active Processing. Active Notetaking is related to overt activities during notetaking that are indicative of an underlying cognitive state, including statements of *I take verbatim notes (meaning word for word directly from the board/PowerPoint slide/doc camera etc.)* (Barlow et al., in review). Active Processing is directly related to students' reports on their own cognition, where *I think about previous concepts covered in the course* would be reported with high alignment. Active Processing highlights the *focused attention* component of Chi and Wylie's definition, while Active Notetaking emphasizes the *basic information manipulation*. Passive Engagement is an orientation towards and receiving from the course content (Chi & Wylie, 2014). Passively Engaged students will listen without doing anything else, and report *I listen when my teacher or whomever is speaking*.

Both the SCCEI and the original ICAP framework proposed by Chi & Wylie assume that students who are more deeply cognitively engaged will fall into Interactive Engagement, while students who are less cognitively engaged will be considered Passively Engaged. In this sense, the student measurement assigns a value assessment to modes of engagement: Interactive > Constructive > Active > Passive. The SCCEI differentiates modes of engagement along factors; items as they relate to each mode of engagement can be found in Table 6.4.

Students were given access to the survey via the course website and asked to participate by their instructors. Students were considered to be anonymous in their responses, yet some forwent anonymity to earn extra credit in their course (courses where extra credit was offered provided an equally weighted alternative extra credit assignment). The randomized survey was administered via Qualtrics (2005) when the term was approximately 75% complete.

We sought to determine how the reported instructional practices were related to the overall student cognitive engagement present in the course, as reported by students. Therefore courses, not students, were scored as a result of the SCCEI. Modes of engagement were measured by two, 3-point Likert scales. For each item, students were asked the frequency with which they behave/think in such a manner both inside and outside of the classroom. Students were scored only using the scale from previous instrument development studies—an in-class frequency scale. A score of zero corresponded with a low frequency (*few to no lecture periods)*, while a score of two was given to the highest level of frequency (*most lecture periods)*. For each course, five sums were generated, one for each of the cognitive engagement factors. These sums were then divided by the total possible score for each factor (the number of student responses times the total possible value in a given mode for each student). Similar to instructor survey scoring, courses also received scores ranging from 0 to 100 that pertained to their mode of engagement (i.e. their percent alignment with each factor). Data from instructor and survey data were then combined for further analysis.

Table 6.4: The SCCEI used to measure student cognitive engagement

ICAP Category	*Description*	*Items*
Interactivity with Peers	*Engagement activities that involve knowledge generation between two peers*	I defend my approach to others when discussing course content. I discuss my position with others regarding the course content. I explain concepts to others when discussing course content. I justify my perspective to others when discussing course content.
Constructive Notetaking	*Engagement activities where students generate knowledge in their notetaking*	I add my own notes to the notes provided by the teacher. My course notes include additional content to what the teacher provided. I add my own content to the course notes.
Active Notetaking	*Engagement activities of copying course material into personal notes*	I take verbatim notes (meaning word for word directly from the board/PowerPoint etc.) . I copy solution steps verbatim (meaning word for word directly from the board/PowerPoint etc.). I only copy the notes the teacher writes down.
Active Processing	*Cognitive manipulation of course material as it is presented where no new knowledge is generated*	I connect current concepts with previous course content. I apply current solution steps with previous course content. I think about previous concepts covered in the course. I consider how multiple ideas or concepts relate.
Passive Processing	*Cognitive orientation towards instruction taking place in the course*	I pay attention to my teacher or whomever is speaking. I follow along with my teacher or whomever is speaking when they discuss examples. I listen when my teacher or whomever is speaking. I follow along with the activities that take place during the course.

6.2.5 ANOVA Data Analysis

We sought to analyze the relationship between instructor tenure status and class structure with SCCEI scores; we did not consider the relationship of instructor tenure and class structure to PIPS scores due to the small sample of instructors present in this study. As each student generated a score for each of the five SCCEI factors, the study can be considered a crossover repeated measures experimental design (Ramsey & Schafer, 2002). Therefore, a two-way repeated measures analysis of variance (ANOVA) was chosen to individually evaluate the effect of faculty tenure status and physical classroom structure on student engagement scores across the five SCCEI factors. Origin Pro 9.4, a statistical analysis software, was used to conduct ANOVA and post-hoc tests. A Tukey HSD post-hoc analysis was performed and allowed us to compare the mean engagement score differences pairwise for the three tenure statuses and three classroom structures within each of the five SCCEI factors. Significance was determined using these results. Additionally, visual representations were generated to present the means of each comparison.

6.2.6 Correlation Data Analysis

We posited that factors measured by the PIPS and SCCEI would indeed bear a relationship. To test this relationship, statistical analyses were considered for their relevance to the dataset. Correlation analysis is useful to symmetrically explore factors that are independent (Lindley, 1990). The PIPS asks instructors to report on their instructional practices and the SCCEI asks students to report on their cognitive engagement within the classroom. While related, the factors of these two instruments are independent; students were asked to report how they elected to engage in a course, not on how the instruction impacted their engagement. Therefore, a correlation analysis was utilized to determine the relationship between the PIPS and SCCEI factors. A partial correlation was selected—partial correlation is useful when it is desirable to remove the effect of a selected variable when determining the association of the remaining factors (Cohen, Cohen, West, & Aiken, 2003). In this analysis, the effect of class was removed in order to determine correlations between the PIPS and SCCEI factors across the sample.

SPSS version 25 was used to conduct a parametric correlation analysis. Parametric correlation uses Pearson's *r* as an indicator of significance, requiring normality and linearity in the dataset. Linearity was visually inspected with scatterplots of each factor dataset. Shapiro-Wilk was used to test for normality, as it has shown to be useful for small sample sizes (n < 50) (Razali & Wah, 2011). Significance of the Shapiro-Wilk indicates non-normal distribution at the 95% confidence interval (W < .05) (Shapiro & Wilk, 1965).

6.3 Results and Discussion

Here, we present statistical evidence in the form of descriptive statistics, ANOVAs, and correlation analyses to answer the research questions: (1) *How does instructor tenure status and classroom structure differentiate modes of student engagement?* and (2) *What are the correlations between SCCEI modes of cognitive engagement and PIPS factors of instructional practices?*

6.3.1 Overview of Data

Presentation of the descriptive statistics serves a dual purpose: first, the reader is empowered with a foundational understanding of the dataset and how factors relate to one another; second, descriptive statistics provide support for the subsequent statistical testing on the dataset. Scores for each factor are presented as a percent alignment, with a zero-score indicating the factor does not at all describe the teaching practices (PIPS) or does not frequently occur in the class period (SCCEI). A score of 100 indicated perfect alignment with the factor. The *n* for all factors was 19, as each instructor generated a single score for each factor and each class of student respondents generated a single score for each factor. Descriptive statistics for each factor are presented in Table 6.6 below.

PIPS factors showed relatively large standard deviations across all factors, averaging 18%. This indicates that the sample was relatively diverse in nature, particularly with respect to Content Delivery, Student-Student Interactions, and Summative Assessment; instructors showed substantial variation in their alignment to each factor. Formative Assessment and Student Content engagement were less diverse across the sample, suggesting that instructors in the study were more similarly aligned along these factors. Means remained relatively similar across factors, with Student Content Engagement being notably higher than other factors. The Shapiro-Wilk value was not significant for any of the PIPS factors, indicating normal distribution of the dataset.

Standard deviations for SCCEI factors showed a general increasing trend; Passive Processing was found to have the smallest standard deviation while Constructive Notetaking had the greatest. This aligns with the underpinnings of the ICAP theory which is hierarchical in nature: students who are Constructively engaged would be Actively and Passively engaged as well (Chi & Wylie, 2014). Decreasing standard deviations would suggest that some students remain at a particular engagement level as modes of engagement increase in sophistication. Means of the SCCEI likewise reinforce this phenomenon, with substantially higher alignment with most basic modes of cognitive engagement (i.e. Passive Processing) and lower means with more sophisticated modes (i.e. Interactivity with peers). The Shapiro-Wilk value was significant only for Passive Processing. This indicates that within this sample, Passive Processing was not normally distributed. Visual inspection indicates a negative skew of responses, where students indicated consistent high alignment with Passive Processing. While some have affirmed that normality is an important to understanding the power of Pearson's significance (Kowalski, 1972), others have suggested normality is a needless assumption (Nefzger & Drasgow, 1957), particularly when samples do not largely deviate from normal (Edgell & Noon, 1984). Because our sample did not largely deviate from normal distribution, we proceeded with parametric correlation analysis, using Pearson's *r* to indicate significance.

Table 6.6: Descriptive statistics

	Factor	*Mean*	*St. Deviation*	*Shapiro-Wilk Sig.*
PIPS Factors	**Student-Student Interactions**	60.3	21.3	0.263
	Student Content Engagement	75.9	13.3	0.82
	Content Delivery	59.2	26.9	0.066
	Formative Assessment	57.0	12.2	0.255
	Summative Assessment	53.0	22.6	0.272
SCCEI Factors	**Interactivity with Peers**	51.3	12.7	0.971
	Constructive Notetaking	51.9	15.2	0.405
	Active Notetaking	60.5	14.0	0.103
	Active Processing	66.6	9.9	0.998
	Passive Processing	89.6	8.0	0.023

6.3.2 ANOVA Results

The descriptive statistics presented above represented the five student cognitive engagement factors of the SCCEI and the five instructional practice factors of the PIPS across all courses. The instructors of the courses studied varied in their tenure status and in the physical environment in which they taught. The mean difference in student engagement scores resulting from either the interaction of classroom structure or tenure status and the five SCCEI modes of engagement was evaluated using two-way repeated measures ANOVA. Descriptive statistics for data used in the ANOVA are presented in Table 6.7. A Greenhouse-Geisser corrected repeated measures ANOVA determined that there was a statistically significant effect on student engagement scores for both the interaction of classroom structure and SCCEI factors [$F(6.50, 2068.47) = 6.60$, $p < 0.001$] and tenure status and SCCEI factors [$F(6.47, 2056.22) = 8.94$, $p < 0.001$]. Results from the Tukey post-hoc analysis are presented in Table 6.8; bar graphs are presented to help visualize trends on the impact of course structure and tenure status on SCCEI scores.

Table 6.7: Descriptive statistics of ANOVA datasets

Variable	Differentiator	N	SCCEI Factor	Mean	Std. Error
Tenure Status	Tenured	406	Interactivity with Peers	45.197	1.305
			Constructive Notetaking	52.217	
			Active Processing	63.742	
			Active Notetaking	60.612	
			Passive Processing	85.735	
	Untenured, on tenure track	92	Interactivity with Peers	63.813	22.741
			Constructive Notetaking	43.297	
			Active Processing	72.600	
			Active Notetaking	63.496	
			Passive Processing	88.225	
	Untenured, not on tenure track	141	Interactivity with Peers	58.333	2.214
			Constructive Notetaking	60.697	
			Active Processing	67.967	
			Active Notetaking	60.697	
			Passive Processing	93.233	
Class Structure	Individual desks	334	Interactivity with Peers	46.806	1.442
			Constructive Notetaking	48.927	
			Active Processing	62.700	
			Active Notetaking	62.076	
			Passive Processing	84.007	
	Rows of tables	209	Interactivity with Peers	51.635	1.823
			Constructive Notetaking	59.649	
			Active Processing	67.663	
			Active Notetaking	61.324	
			Passive Processing	92.803	
	Pods of desks	96	Interactivity with Peers	62.717	2.690
			Constructive Notetaking	51.389	
			Active Processing	73.524	
			Active Notetaking	56.858	
			Passive Processing	89.757	

Table 6.8: Tukey results indicating significance of pairwise comparisons

	SCCEI Factor	*Pairwise Comparison*		*Mean Diff*	*Std Error*	*t value*	*p-value*
Classroom Structure	Interactivity with Peers	Pods of desks	Rows of tables	11.08	3.25	4.82	**0.05****
		Pods of desks	Individual desks	15.91	3.05	7.37	**0.00****
		Rows of tables	Individual desks	4.83	2.32	2.94	0.75
	Constructive Notetaking	Pods of desks	Rows of tables	-8.26	3.25	3.59	0.41
		Pods of desks	Individual desks	2.46	3.05	1.14	1.00
		Rows of tables	Individual desks	10.72	2.32	6.52	**0.00****
	Active Processing	Pods of desks	Rows of tables	5.86	3.25	2.55	0.90
		Pods of desks	Individual desks	10.82	3.05	5.02	**0.03****
		Rows of tables	Individual desks	4.96	2.32	3.02	0.71
	Active Notetaking	Pods of desks	Rows of tables	-4.47	3.25	1.94	0.99
		Pods of desks	Individual desks	-5.22	3.05	2.42	0.93
		Rows of tables	Individual desks	-0.75	2.32	0.46	1.00
	Passive Processing	Pods of desks	Rows of tables	-3.05	3.25	1.33	1.00
		Pods of desks	Individual desks	5.75	3.05	2.66	0.86
		Rows of tables	Individual desks	8.80	2.32	5.35	**0.01****
Tenure Status	Interactivity with Peers	Untenured, not on track	Tenured	13.14	2.57	7.23	**0.00****
		Untenured, not on track	Untenured, on track	-5.48	3.52	2.20	0.97
		Tenured	Untenured, on track	-18.62	3.04	8.67	**0.00****
	Constructive Notetaking	Untenured, not on track	Tenured	8.48	2.57	4.67	0.07
		Untenured, not on track	Untenured, on track	17.40	3.52	6.98	**0.00****
		Tenured	Untenured, on track	8.92	3.04	4.16	0.18
	Active Processing	Untenured, not on track	Tenured	4.23	2.57	2.32	0.95
		Untenured, not on track	Untenured, on track	-4.63	3.52	1.86	0.99
		Tenured	Untenured, on track	-8.86	3.04	4.13	0.19
	Active Notetaking	Untenured, not on track	Tenured	0.09	2.57	0.05	1.00
		Untenured, not on track	Untenured, on track	-2.80	3.52	1.12	1.00
		Tenured	Untenured, on track	-2.88	3.04	1.34	1.00
	Passive Processing	Untenured, not on track	Tenured	7.50	2.57	4.13	0.19
		Untenured, not on track	Untenured, on track	5.01	3.52	2.01	0.99
		Tenured	Untenured, on track	-2.49	3.04	1.16	1.00

**Significant at the 95% confidence interval

Classroom structure was considered as a potential influence on student cognitive engagement factors; it serves to reason that students may feel more or less comfortable in implementing particular types of learning activities based on the physical structure of the seating (e.g. discussions with classmates may be more frequent when students are seated in pods of desks). Students reported more significantly more interactivity when seated in pods than when seated in either individual desks or rows of tables. This supports reports of barriers suggested by instructors, which indicate that seats bolted to the floor makes interactivity more difficult (Dancy & Henderson, 2008). Additionally, students reported significantly higher Constructive Notetaking when seated at rows of desks than when in individual desks. Though the reason for this difference remains unclear, one possibility is students have more physical room available to them when seated at tables than at smaller desks. When in pods of desks, students reported significantly higher levels of Active Processing than when in individual desks. As can be seen in Figure 1, rows of tables exhibited advantages in notetaking, while exhibiting higher engagement scores (not always significantly) in nearly every category when compared with individual desks. Pods of desks resulted in lower (though not always significantly lower) engagement in modes that required notetaking; for modes of engagement where interaction or processing was required, mean scores of students in pods where at or near the greatest. These results arguably point to a need to minimize individual desks in classrooms, and instead provide rows of tables to facilitate student engagement through notetaking and pods to facilitate student engagement through interactivity.

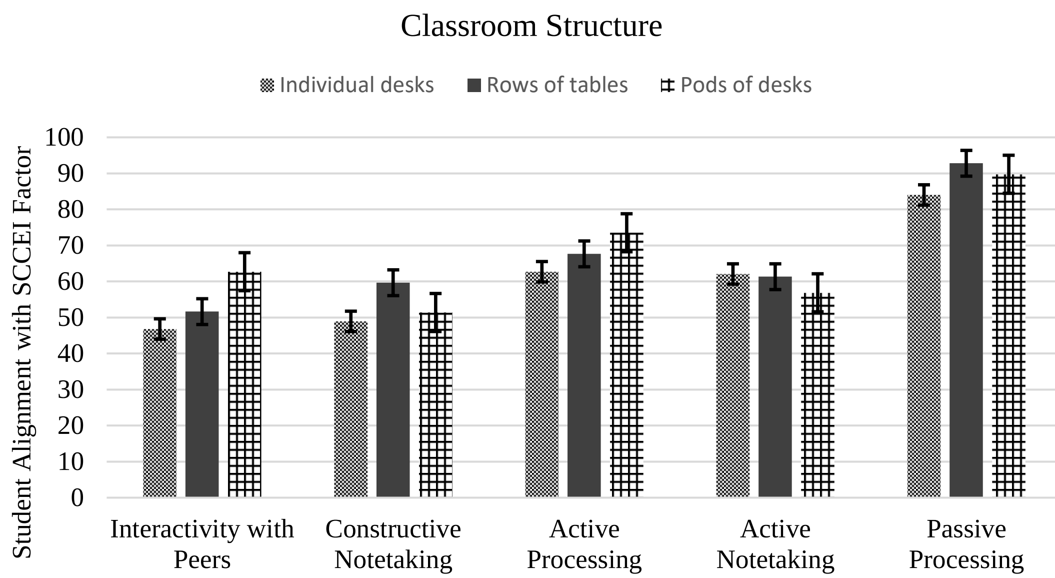

Figure 6.1: Variance in SCCEI factor means based on classroom structure.

Literature has suggested that tenure status influences how instructors implement learning strategies in their courses (Landrum et al., 2017); we considered that with these changes in instructional practices, students were likely to report differentiated modes of engagement. When students had instructors who were tenured, they reported significantly less Interactivity with Peers than students with untenured instructors (both on track and not on track). One plausible reason for this difference is tenured instructors may be integrated into departments where interactive classrooms are not the norm—this might create a barrier to implementing new learning strategies (Dancy & Henderson, 2008). One suggestion to increase implementation of best practices in post-tenured instructors is to include a professional peer review of teaching as part of the post-tenure review process (Henderson, Beach, & Finkelstein, 2011). Constructive Notetaking was reported as significantly lower by students when their instructors were untenured but on track, as compared with untenured, not on track instructors. Untenured but on track instructors may feel the burden of research pressures in a way that untenured, not on track instructors do not. It has been noted that tenure track professors are more likely to perceive less institutional support for teaching and greater value on research (Landrum et al., 2017). Our results indicate that students' cognitive engagement is impacted by these pressures. For a visualization of these results, see Figure 6.2.

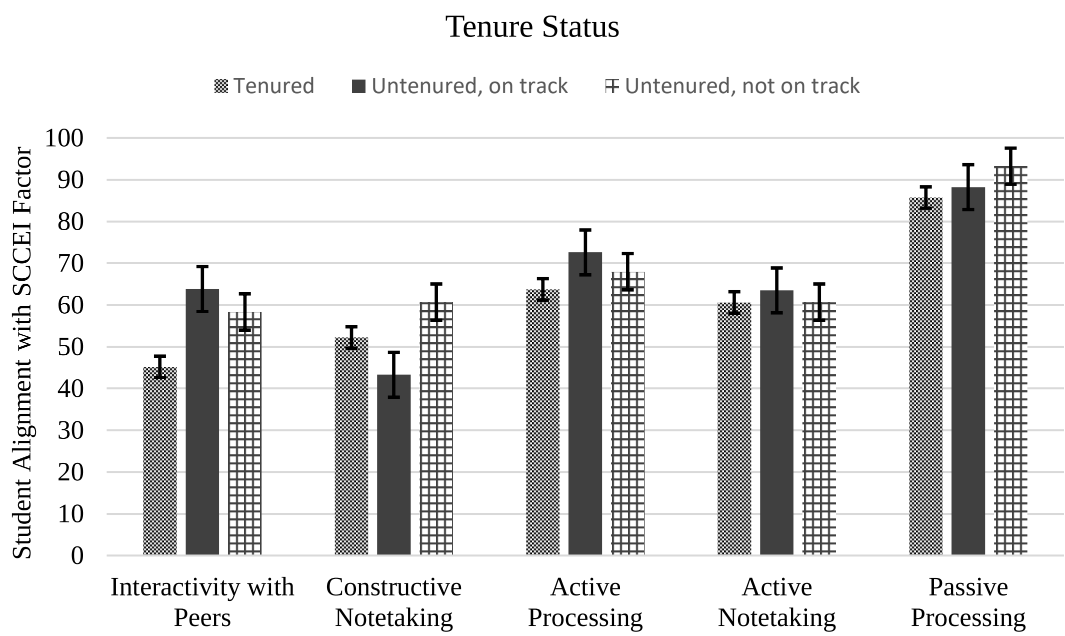

Figure 6.2: Variance in SCCEI factor means based on instructor tenure status

6.4 Correlations between Instruments

A correlation matrix resulting from a partial correlation analysis was conducted in SPSS version 25 using Pearson's *r* to indicate significance. The effect of class was removed by indicating class number as a control variable. The development of both the PIPS and SCCEI suggests some correlation between factors within either instrument; we therefore removed these correlations and significance from the matrix (e.g. correlation between PIPS factors Summative Assessment and Formative Assessment are not shown). In Table 9, we present the correlation matrix for factors between the PIPS and SCCEI. Correlations represent the strength of the relationship between factors, ranging from -1 to 1. Larger negative values indicate a strong inverse relationship between the factors—as one factor increases, the other factor decreases. High positive numbers indicate that factors are directly correlated. Significance indicates the percent likelihood that the correlation is a result of error. Confidence intervals can be derived from converting significance into percentages and subtracting from 100%. At the 95% confidence interval, three correlations were found to be significant. At the 90% confidence interval, an additional correlation was observed to be significant.

Table 6.9: Partial correlation matrix of SCCEI and PIPS.

		Content Delivery	*Student Content Engagement*	*Formative Assessment*	*Student-Student Interactions*	*Summative Assessment*
Interactivity with Peers	Correlation	-0.153	-0.242	0.062	0.446	-0.308
	Significance (2-tailed)	0.545	0.334	0.808	**0.064***	0.213
Constructive Notetaking	Correlation	0.140	-0.326	-0.301	0.020	0.306
	Significance (2-tailed)	0.579	0.187	0.224	0.937	0.216
Active Processing	Correlation	-0.017	-0.246	-0.295	0.276	-0.047
	Significance (2-tailed)	0.948	0.326	0.235	0.268	0.853
Active Notetaking	Correlation	0.768	-0.020	-0.103	-0.307	0.695
	Significance (2-tailed)	**0.000****	0.936	0.684	0.215	**0.001****
Passive Processing	Correlation	0.239	-0.273	-0.532	-0.290	0.134
	Significance (2-tailed)	0.339	0.273	**0.023****	0.243	0.595

**Significant at the 95% confidence interval
*Significant at 90% confidence interval

Active Notetaking was seen to have a strong correlation with Content Delivery. We see this as evidence of agreeance in how instructors report on their practices and how students respond to them. Content Delivery items include *I guide students through major topics as they listen and take notes* and *My class sessions are structured to give students a good set of notes*; Active Notetaking items include *I take verbatim notes (meaning word for word directly from the board/PowerPoint etc.)*. A positive correlation between the factors indicates that as instructors report stronger agreeance with items suggesting they provide students with structured notes, students likewise report increased frequency of copy notes from the board. Active Notetaking was also positively correlated with Summative Assessment at the 95% confidence interval. Summative assessment items include *My test questions contain well-defined problems with one correct solution.*

Results suggest that as instructors report increasingly high agreeance with providing assessment with singular correct answers, students report increasing frequency of taking verbatim notes on course content. This aligns with work that suggests students' learning strategies are influenced by the assessment demands of the course (Lucas & Ramsden, 1992).

A negative correlation at the 95% confidence interval was observed between Passive Processing and Formative Assessment. Passive Processing items include *I follow along with the activities that take place during the course*, with high alignment indicating student frequently listen to instruction. Formative Assessment items include *I use student assessment results to guide the direction of my instruction during the semester*, with high alignment indicating soliciting feedback in the form of assessment is descriptive of the course. A negative correlation between Passive Processing and Formative Assessment reveals that as instructors increase their feedback in the form of assessment, their students report less alignment with listening or following along in class. While at the onset this may appear counterintuitive, we see an alignment with these findings and the literature. Just as Chi & Wylie suggested in their original work with ICAP, Passive Engagement is simply orientation towards instruction (2014). By definition, active learning goes beyond listening and is extended to higher-order learning through activity (Freeman et al., 2014). This is echoed in work surrounding formative assessment—as students are presented with assessment that directs their learning, personal reflection and extension of knowledge is required (Kulasegaram & Rangachari, 2018). Here, we echo these findings and propose that as instructors are more aligned with Formative Assessment, their students will report lower frequencies of simply listening through Passive Processing in their courses.

At the 90% confidence interval, Interactivity with Peers and Student-Student Interactions was seen to be significant. Interactivity with Peers items included *I discuss my position with others regarding the course content*, and Student-Student Interactions items included *I structure class so that students constructively criticize one another's ideas.* This correlation is strong evidence for the direct influence of instructional practices on student cognitive engagement; as instructors reported that facilitating student interaction was descriptive of their courses, students reported meaningfully sharing their ideas with their peers. This supports work that indicates instructional activities can either support or inhibit collaboration in the classroom (Nokes-Malach et al., 2015). Furthermore, this suggests that both instruments are indeed measuring the same construct (interactivity in the classroom) with the respective factors. The correlation of a single construct measured by factors in two separate instruments points towards the usefulness in interpreting results based on the findings of multiple independent instruments.

6.5 Conclusions

STEM educators have been observed to be resistant to change, notably as they are prompted to implement research-based instructional practices (Henderson & Dancy, 2007). Active learning techniques to increase student cognitive engagement are well-researched instructional practices (Freeman et al., 2014; Prince, 2004; Smith et al., 2005)—practices the STEM education community sees great value in instructors implementing. Our research aligns itself with existing work in the STEM education community on the development of instruments to measure both instructional practices (PIPS) and student cognitive engagement (SCCEI).

Researchers have suggested instructors need contextual understanding of how to implement strategies, lest the deem them ineffective (Hutchinson & Huberman, 1994). Others have suggested resistance to change emerges as instructors believe their students oppose researched-based strategies in the classroom—particularly interactivity with their peers (Henderson & Dancy, 2011). We utilized both the PIPS and SCCEI in an effort to provide instructors with a more holistic understanding of their courses by correlating their own report on their practices to their students' experience of them. Our results showed that indeed as instructors reported greater alignment with facilitating Student-Student Interactions, students reported higher alignment with lecture periods where they interacted with their peers (Interactivity with Peers). This may be one early step in aiding instructors in understanding the contextualization of instructional practices, while breaking down the notion that students are unwilling to engage interactively.

Dancy and Henderson also suggested that in order to facilitate change in instructional practices, STEM researchers ought to connect their models with models in their discipline and the broader STEM education research community (Dancy & Henderson, 2008). By utilizing previously developed instruments from the STEM community, we participated in a foundational movement towards connecting multiple outcomes of multiple research projects. The use of tools that already have evidence of validity not only adds credibility to such tools, findings are expanded. Here, we noted the significance of both class structure and tenure status on modes of student cognitive engagement. Our findings reinforced those found in literature that discussed the influence of tenure and classroom structure on instructors' practices; such significance is supporting evidence of the interconnectivity of instructional practices and student cognitive engagement.

We found that Content Delivery was significantly correlated with Active Notetaking. This becomes important as the continual development of these instruments and others is considered. Though empirical validation is often extensive during the instrument development process—as it was for both the PIPS and SCCEI—clarity on the construct being measured can be overlooked. Using two instruments measuring related constructs in tandem allows for greater clarity on the construct measured by either instrument. Here, we gained a better understanding of what was actually being measured by Content Delivery and Active Notetaking due to their positive correlation—a compilation of instructors leading their students through content and them responding in turn by taking notes.

More broadly, the findings of this work suggest future instrument development ought to consider its alignment not just with instruments of measuring similar phenomena, but those measuring the related and influenced phenomena. While both the PIPS and SCCEI are independently useful to instructors, their use together tells more than either could apart. From the study, it was seen that students are responsive to their instructor's practices including assessment, content delivery, and peer work in class. Though student cognitive engagement and instructional practices are indeed individual constructs, their interconnectivity becomes important. As instructors, departments, and institutions seek to implement best practices in the classroom, a more holistic understanding of such constructs may be key. More work is needed to explore not only how cognitive engagement is related to instructional practice, but how other important constructs to STEM are related.

6.5.1 Limitations and Future Work

The small sample of this study inherently limits the reliability of the work. We do not make claims that the PIPS and SCCEI will always correlate in a consistent manner; instead, we present evidence for continued study to better understand how these instruments, and others, may be utilized together to better understand STEM courses. To further validate the findings of this study, we suggest implementing the PIPS and SCCEI in a broad range of STEM courses and correlating the results. Furthermore, we support work with these instruments and others that measure related constructs, and the expansion of such work on to other related constructs across STEM.

6.5.2 Declarations

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. The authors declare that they have no competing interests. Funding for this work was obtained from the National Science

Foundation (NSF) under award numbers 1544182 and 1544103. AB conducted the data collection, analysis, and write-up of the work. SB provided thorough review of the work, including substantial intellectual and editorial contribution. All authors read and approve the final manuscript. Authors would like to acknowledge Zachary Barlow for his consulting with regards to the statistical analyses performed in this study.

7 – CONCLUSIONS

Educators have power to change the type of assessment, the way students engage with content and each other, and the format information is presented. Some of these changes are more difficult than others to make, and educators can be known to ask *to what end*? The works of this dissertation generally point to a deeper understanding of how educators can better understand the engagement of their students and the role they play in influencing it. In this chapter, I present an overview of the significant findings from the preceding works. Additionally, I discuss the broader context of how these works fit together, and the larger conclusions that can be drawn from them. Beyond this, I offer insight as to how this work may be built upon for the betterment of the engineering education research community

7.1 General Discussion

In **Chapter 2**, I presented the development of the SCCEI. This instrument was intended as a tool for educators seeking to better understand the cognitive engagement of their students, and researchers seeking to move away from the general measure of *active learning* to more nuanced measures. Through the development process, we found that students could reliably report their cognitive engagement along five modes: Interactivity with Peers, Constructive Notetaking, Active Notetaking, Active Processing, and Passive Processing. This work was novel in its measurement of both behaviors and cognitive processing states. For behavioral factors (Interactivity with Peers, Constructive Notetaking, Active Notetaking), we relied on the ICAP framework (Chi & Wylie, 2014) to indicate the underlying mode of cognitive engagement. For cognitive processing factors (Active Processing, Passive Processing), we probed students directly on their cognitive engagement. The intended effect of the SCCEI is that educators may be able to accurately assess the cognitive engagement of their students, and thereby adjust their teaching to facilitate more meaningful engagement of their students. While instruments to measure cognitive engagement continue to be developed (see Appleton et al., 2006; Greene, 2015), the SCCEI is uniquely poised to meet the needs of educators by offering a measurement schema with differentiated modes of cognitive engagement. With knowledge of their classrooms, educators may develop curriculum to target a particular mode of engagement within their particular course context.

Chapters 3 and **4** primarily served the role of supporting the development of the SCCEI in **Chapter 2**. In **Chapter 3**, we solicited student feedback during the development process of our instrument. Though statistical evidence is typically used during development to ensure factors represent a single construct, we sought a broader evidence of validity; we intended for our instrument to not only be empirically reliable, but usable for the respondents. From student feedback, we learned the lack of differentiation students have when considering the context of their engagement—they regularly conflate in-class and out-of-class experiences. This finding was incorporated into the development of the SCCEI, where we provided participants with contrasting scales of in-class frequency of activities and out-of-class frequency of activities. By situating scales side-by-side, we postulated that students would differentiate between the context of their engagement experiences. This postulation was tested in **Chapter 4**, where paired t-tests were run on student responses to the SCCEI to evaluate the significance of responses to in-class and out-of-class scales. Results suggested that all modes of engagement were measured distinctly except Interactivity with Peers. The consistency of Interactivity with Peers across contexts points to the broader context of the work of my research team, which seeks to understand how the social network of peers fits within and outside of classroom contexts. The work of both **Chapter 3** and **4** support the extent of the development of the SCCEI, and provide better understanding as to its usefulness.

In the process of developing and testing the SCCEI, I began to question the ways in which students' cognitive engagement was consistent and inconsistent across their courses. My work with the SCCEI provided data on how students engaged in a single course; the literature lacked a robust analysis of how individual students made engagement decisions from course to course. I explored what shaped students' cognitive engagement across courses in **Chapter 5**. I interviewed a small, primarily uniform sample of upper-division civil engineering students and analyzed the data using Interpretive Phenomenological Analysis (IPA). Themes that emerged from the study suggested that students' values and future shaped their behavioral engagement decisions, which were then enacted upon by their instructor's engagement behavior. Students also integrated effectiveness and efficiency into their engagement decisions. This work provided fundamental evidence that even for high achieving students, cognitive engagement was influenced by their instructor's engagement decisions. Prior to this work, others had suggested the importance of students' corroboration of their instructors active learning strategies (Tharayil et al., 2018); there was a lack evidence suggesting that students might mirror the cognitive engagement stance they perceived their instructors to hold. This finding is significant in its impact on educators and researchers alike. When educators consider ways in which they can increase their students' engagement, they may consider their own stance, and how they might embody the cognitive engagement they hope to inspire in their students. For example, an instructor who uses the material developed by their predecessor may portray that the material does not require personalized understanding or deep consideration for mastery; they may observe their students mirroring this cognitive stance. The research community can now begin to consider the implications of both the individual and the instructor as they consider student cognitive engagement.

As I considered the way in which instructor practices were incorporated into measurement of student cognitive engagement, it became apparent that they were commonly neglected or ignored. Therefore, in **Chapter 6**, I intended to measure both student cognitive engagement and instructional practices with self-report instruments. The SCCEI was used for its differentiation of cognitive engagement into modes, and the Postsecondary Instructional Practices Instrument (PIPS) for its emphasis on five components of practices within STEM. Additionally, I explored how instructor tenure status and classroom structure impacted student engagement. Notable significant relationships were observed for Interactivity with Peers and tenure and classroom structure; educators may wish to be increasingly mindful of how their context might impact the effort required to facilitate their students' interactions. The relationship between the SCCEI and PIPS was explored using a partial correlation analysis, where correlation was determined between multiple factors. These findings become particularly relevant as recent work continues to suggest the difficulty educators have in developing curriculum targeting at increasing student engagement (Chi et al., 2018). By identifying the practices that are most strongly correlated with deeper modes of student cognitive engagement, educators may make changes to their curriculum that are likely to have the most impact on their students.

7.2 Intersection of Works

In the most basic sense, the cumulative effect of these works points to an awareness that understanding student cognitive engagement simply cannot be accomplished from a single vantagepoint. When developing the SCCEI, it appeared critical to include an endless array of questions to probe every possible circumstance a student might encounter—it is simply not possible. What the SCCEI does provide is insight. This insight allows conclusions to be drawn about how students are engaging (or not engaging) at a particular mode.

From there, it becomes important to understand what is causing students to engage in such a manner—*their instructor, their own experience, both*? Interviews with only a small, relatively uniform set of students show that the experience of students is vast; each student brings to the classroom their own perspective of effective teaching, their socioeconomic experiences, and their personal convictions on their role as a learner. The answer to the question of what shapes student cognitive engagement complex. Student engagement simply cannot be understood outside an awareness of both personal experience and instructional practices encountered in context. Both the instructor and the student have a role to play in their engagement, one likely influencing the other.

In a fundamental exploration of the influence instructional practice and student engagement have on one another, I found the two constructs do indeed bear a correlation. Certain instructional practices, such as how an instructor presents material or tests knowledge, impacts how the students might take notes. While such results do not suggest causality, they suggest that an instructor may make targeted changes to their practices to increase their students' engagement. With knowledge of students and instructors, more can be accomplished towards the active learning ends suggested in the literature.

7.3 Future Work

As has been shown with so many instruments before, the SCCEI can easily fade as the next new instrument is developed and validated. To avoid such a fate, the SCCEI ought to tie itself to broader context and expand its usefulness. Work with the SCCEI and PIPS in tandem was only a starting point. More work is needed in both qualitative and quantitative realms to explore the interplay of instructional practices, student cognitive engagement, and other related constructs. Beyond this, research should continue to qualitatively explore the engagement experience of students across contexts. More work is needed to explore how the engagement experience of minorities and underrepresented groups can be accurately portrayed. As these findings emerge, it is important that they build upon the findings of these works and others to build a robust understanding of the breadth of cognitive engagement experiences in engineering students.

REFERENCES

Akcaoglu, M., & Lee, E. (2016). Increasing social presence in online learning through small group discussions. *International Review of Research in Open and Distance Learning*, *17*(3), 1–17. https://doi.org/10.19173/irrodl.v17i3.2293

American Association for the Advancement of Science (AAAS). (2012). *Describing and measuring undergraduate STEM teaching practices. A report from a national meeting on the measurement of undergraduate science, technology, engineering and mathematics (STEM) teaching*. *AAAS.*

Appleton, J. J., Christenson, S. L., Kim, D., & Reschly, A. L. (2006). Measuring cognitive and psychological engagement: Validation of the Student Engagement Instrument. *Journal of School Psychology*, *44*, 427–445. https://doi.org/10.1016/j.jsp.2006.04.002

Bagozzi, R. P., & Yi, Y. (1988). On the evaluation of structural equation models. *Journal of the Academy of Marketing Science*, *16*(1), 74–94. https://doi.org/10.1007/BF02723327

Barlow, A. J., & Brown, S. A. (2019). Work in Progress : Measuring Student Cognitive Engagement Using the ICAP Framework In and Outside of the Classroom WIP : Measuring Student Cognitive Engagement Using the ICAP Framework In and Outside of the Classroom. *ASEE Annual Conference and Exposition Proceedings*.

Barlow, A. J., Lutz, B. D., Pitterson, N. P., Hunsu, N., Adesope, O., & Brown, S. A. (n.d.). Development of the Student Course Cognitive Engagement Instrument (SCCEI). *In Review*.

Benson, J., & Clark, F. (1982). A Guide for Instrument Development and Validation. *The American Journal of Occupational Therapy*, 789–800.

Berg, B. L., & Lune, H. (2014). *Qualitative research methods for the social sciences*. *Qualitative Research* (Vol. 8th). https://doi.org/10.2307/1317652

Borrego, M., Froyd, J. E., & Hall, T. S. (2010). Diffusion of Engineering Education Innovations: A Survey of Awareness and Adoption Rates in U.S. Engineering Departments. *Journal of Engineering Education*, *99*(3), 185–207. https://doi.org/10.1002/j.2168-9830.2010.tb01056.x

Brown, T. A. (2006). *Confirmatory Factor Analysis for Applied Research*. New York: The Guilford Press.

Centra, J. A. (1973). Effectiveness of student feedback in modifying college instruction. *Journal of Educational Psychology*, *65*(3), 395–401. https://doi.org/10.1037/h0035636

Cerny, B. A., & Kaiser, H. F. (1977). A study of a measure of sampling adequacy for factor-analytic correlation matrices. *Multivariate Behavioral Research*. https://doi.org/10.1207/s15327906mbr1201_3

Chang, L. (1995). Connotatively Consistent and Reversed Connotatively Inconsistent Items are Not Fully Equivalent: Generalizability Study. *Educational and Psychological Measurement*, *55*(6), 991–997. https://doi.org/10.1177/0013164495055006007

Chen, H. L., Lattuca, L. R., & Hamilton, E. R. (2008). Conceptualizing Engagement: Contributions of Faculty to Student Engagement in Engineering. *Journal of Engineering Education*, *97*(3), 339–353. https://doi.org/10.1002/j.2168-9830.2008.tb00983.x

Chen, J. C., Whittinghill, D. C., & Kadlowec, J. A. (2010). Classes that click: Fast rich feedback to enhance student learning and satisfaction. *Journal of Engineering Education*, *99*(2), 159–168. https://doi.org/10.1002/j.2168-9830.2010.tb01052.x

Chi, M. T. H. (2009). Active-Constructive-Interactive: A Conceptual Framework for Differentiating Learning Activities. *Topics in Cognitive Science*, *1*(1), 73–105. https://doi.org/10.1111/j.1756-8765.2008.01005.x

Chi, M. T. H., Adams, J., Bogusch, E. B., Bruchok, C., Kang, S., Lancaster, M., … Yaghmourian, D. L. (2018). Translating the ICAP Theory of Cognitive Engagement Into Practice. *Cognitive Science*, *42*, 1777–1832. https://doi.org/10.1111/cogs.12626

Chi, M. T. H., & Wylie, R. (2014). The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes. *Educational Psychologist*, *49*(4), 219–243. https://doi.org/10.1080/00461520.2014.965823

Chickering, A. W., & Gamson, Z. F. (1987). Seven principles for good practice in undergraduate education. *AAHE Bulletin*, *1*, 3–7. https://doi.org/10.1016/0307-4412(89)90094-0

Christenson, S. L., Reschly, A. L., & Wylie, C. (2012). *Handbook of Research on Student Engagement*. Springer.

Christopher, B., Walker, O., Greene, B. A., & Mansell, R. A. (2005). Identification with academics, intrinsic/extrinsic motivation, and self-efficacy as predictors of cognitive engagement. *Learning and Individual Differences*, *16*. https://doi.org/10.1016/j.lindif.2005.06.004

Comrey, A. L. (1988). Factor-Analytic Methods of Scale Development in Personality and Clinical Psychology. *Journal of Consulting and Clinical Psychology*. https://doi.org/10.1037/0022-006X.56.5.754

Costello, A. B., & Osborne, J. W. (2005). Best Practices in Exploratory Factor Analysis: Four Recommendtions for Getting the Most From Your Analysis. *Practical Assessment, Research & Evaluation*.

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*(6), 671–684. https://doi.org/10.1016/S0022-5371(72)80001-X

Crawford, A. V., Green, S. B., Levy, R., Lo, W. J., Scott, L., Svetina, D., & Thompson,

M. S. (2010). Evaluation of parallel analysis methods for determining the number of factors. *Educational and Psychological Measurement*. https://doi.org/10.1177/0013164410379332

Creswell, J. W. (2009). *Research Design: Qualitative, Quantitative and Mixed Approaches (3rd Edition)*. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. https://doi.org/10.2307/1523157

Creswell, J. W. (2014). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (4th ed.). SAGE Publications.

Dancy, M. H., & Henderson, C. (2008). Barriers and Promises in STEM Reform. *National Academies of Science Promising Practices Workshop*.

Dard, D. B., Lison, C., Dalle, D., & Boutin, N. L. (2010). Predictors of Student's Engagement and Persistence in an Innovative PBL Curriculum: Applications for Engineering Education. *International Journal of Engineering Education*, *26*(3), 1–12.

DeMonbrun, M., Finelli, C. J., Prince, M., Borrego, M., Shekhar, P., Henderson, C., & Waters, C. (2017). Creating an Instrument to Measure Student Response to Instructional Practices. *Journal of Engineering Education*, *106*(2), 273–298.

DeVellis, R. F. (2017). *Scale Development: Theory and Applications* (Fourth Edi). Los Angeles: Sage Publications.

Ding, L., Velicer, W. F., & Harlow, L. L. (1995). Effects of Estimation Methods, Number of Indicators per Factor, and Improper Solutions on Structural Equation Modeling Fit Indices. *Structural Equation Modeling: A Multidisciplinary Journal*. https://doi.org/10.1080/10705519509540000

Edgell, S. E., & Noon, S. M. (1984). Effect of violation of normality on the t test of the correlation coefficient. *Psychological Bulletin*, *95*(3), 576–583. https://doi.org/10.1037/0033-2909.95.3.576

Felder, R. M., & Brent, R. (2005). Understanding Student Differences. *Journal of Engineering Education*, (January), 57.

Foote, K. T., Neumeyer, X., Henderson, C., Dancy, M. H., & Beichner, R. J. (2014). Diffusion of research-based instructional strategies: the case of SCALE-UP. *International Journal of STEM Education*, *1*(1), 1–18. https://doi.org/10.1186/s40594-014-0010-8

Fornell, C., & Larcker, D. F. (1981). Evaluating Structural Equation Models with Unobservable Variables and Measurement Error. *Journal of Marketing Research*, *18*(1), 39. https://doi.org/10.2307/3151312

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School Engagement: Potential of the Concept, State of the Evidence. *Source: Review of Educational Research*, *74*(1), 59–109.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

Freeman, Scott, Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

Gorsuch, R. L. (1983). Factor Analysis. *Work Study*. https://doi.org/10.1108/EUM0000000002688

Greene, B. A. (2015). Measuring Cognitive Engagement With Self-Report Scales: Reflections From Over 20 Years of Research. *Educational Psychologist*, *50*(1), 14–30. https://doi.org/10.1080/00461520.2014.989230

Greene, B. A., & Miller, R. B. (1996). Influences on Achievement: Goals, Perceived Ability, and Cognitive Engagement. *CONTEMPORARY EDUCATIONAL PSYCHOLOGYAmes & Archer*, *21*, 181–192.

Guba, E., & Lincoln, Y. (1989). Guba, Lincoln (1989) Fourth Generation Evaluation Foreword.pdf. In *Fourth Generation Evaluation*.

Guthrie, J. T., Wigfield, A., Barbosa, P., Perencevich, K. C., Taboada, A., Davis, M.

H., … Tonks, S. (2004). Increasing reading comprehension and engagement through concept-oriented reading instruction. *Journal of Educational Psychology*, *96*(3), 403–423. https://doi.org/10.1037/0022-0663.96.3.403

Hair, J. F., Anderson, R. E., Tatham, R. L., & Black, W. C. (1995). *Multivariate data analysis: with readings*. *Statistics*. https://doi.org/10.2307/2983017

Hair, J. F., Black, W., Babin, B., & Anderson, R. (2010). *Multivariate data analysis* (7th ed.). Upper Saddle River: Prentice-Hall, Inc.

Heller, R. S., Beil, C., Dam, K., & Haerum, B. (2007). Student and Faculty Perceptions of Engagement in Engineering. *Journal of Engineering Education*, 253–262.

Heller, R. S., Beil, C., Dam, K., & Haerum, B. (2010). Student and Faculty Perceptions of Engagement in Engineering. *Journal of Engineering Education*, *99*(3), 253–261. https://doi.org/10.1002/j.2168-9830.2010.tb01060.x

Henderson, C., & Dancy, M. H. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Special Topics - Physics Education Research*, *3*(2), 020102. https://doi.org/10.1103/PhysRevSTPER.3.020102

Henderson, C., & Dancy, M. H. (2011). Increasing the Impact and Diffusion of STEM Education Innovations. *Characterizing the Impact and Diffusion of Engineering Education Innovations Forum*.

Hickey, D. T., & Granade, J. B. (2004). The influence of sociocultural theory on our theories of engagement and motivation. *Big Theories Revisited: Theories of Engagement and Motivation*, *4*(1997), 200–223.

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling*, *6*(1). https://doi.org/10.1080/10705519909540118

Huff, J., & Clements, H. (2018). The Hidden Person within the Frustrated Student: An Interpretative Phenomenological Analysis of a Student's Experience in a Programming Course. https://doi.org/10.18260/1-2--28971

Huff, J. L., Smith, J. A., Jesiek, B. K., Zoltowski, C. B., Graziano, W. G., & Oakes, W. C. (2015). From methods to methodology: Reflection on keeping the philosophical commitments of interpretative phenomenological analysis. *Proceedings - Frontiers in Education Conference, FIE*, (February). https://doi.org/10.1109/FIE.2014.7044253

Hutchinson, J. R., & Huberman, M. (1994). Knowledge and Dissemination and Use in Science and Mathematics Education: A Literature Review. *Journal of Science Education and Technology*, *3*(1).

Ironside, A. J., Pitterson, N. P., Brown, S. A. P. E., Fisher, K. Q., Gestson, S. L., Simmons P.E., D. R., & Olusola, A. (2017). Incorporating Faculty Sense Making in the Implementation and Modification of an Instrument to Measure Social and

Cognitive Engagement. In *American Society for Engineering Education Annual Conference & Exposition*.

Ironside, A., Lutz, B., & Brown, S. (2018). Student Perspectives on Cognitive Engagement: Preliminary Analysis from the Course Social and Cognitive Engagement Surveys. *ASEE Annual Conference and Exposition Proceedings*.

Jacob, S. A., & Furgerson, S. P. (2012). The qualitative report writing interview protocols and conducting interviews: Tips for students new to the field of qualitative research. *The Qualitative Report*, *17*(42), 1–10. https://doi.org/Retrieved from http://www.nova.edu/ssss/QR/QR17/jacob.pdf

Jones, B. D., Paretti, M. C., Hein, S. F., & Knott, T. W. (2010). An analysis of motivation constructs with first-year engineering students: Relationships among expectancies, values, achievement, and career plans. *Journal of Engineering Education*, *99*(4), 319–336. https://doi.org/10.1002/j.2168-9830.2010.tb01066.x

Kashefi, H., Ismail, Z., & Yusof, Y. M. (2012). Supporting Engineering Students' Thinking and Creative Problem Solving through Blended Learning. *Procedia - Social and Behavioral Sciences*, *56*(Ictlhe), 117–125. https://doi.org/10.1016/j.sbspro.2012.09.638

Kirn, A., & Benson, L. (2018). Engineering Students' Perceptions of Problem Solving and Their Future. *Journal of Engineering Education*, *107*(1), 87–112. https://doi.org/10.1002/jee.20190

Kirn, A., Godwin, A., Cass, C., Ross, M., & Huff, J. (2017). Mindful Methodology: A transparent dialogue on Adapting Interpretative Phenomenological Analysis for Engineering Education Research. *American Society for Engineering Education*. https://doi.org/10.18260/1-2--28669

Kline, R. B. (2011). *Methodology in the Social Sciences. Principles and practice of structural equation modeling*. (3rd, Ed.). NY, New York: Guilford Press.

Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine, 15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Kowalski, C. J. (1972). On the Effects of Non-Normality on the Distribution of the Sample Product-Moment Correlation Coefficient. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, *21*(1), 1–12.

Kuh, G. D. (2001). Assessing What Really Matters to Student Learning: Inside The National Survey of Student Engagement. *Change: The Magazine of Higher Learning*, *33*(3), 10–17. https://doi.org/10.1080/00091380109601795

Kulasegaram, K., & Rangachari, P. K. (2018). Beyond “formative”: Assessments to enrich student learning. *Advances in Physiology Education*, *42*(1), 5–14. https://doi.org/10.1152/advan.00122.2017

Leckey, J., & Neill, N. (2001). Quantifying Quality: The importance of student feedback.

Quality in Higher Education, *7*(1), 19–32. https://doi.org/10.1080/13538320120045058

Lucas, P., & Ramsden, P. (1992). Learning to Teach in Higher Education. *British Journal of Educational Studies*. https://doi.org/10.2307/3120902

Lutz, B. D., Ironside, A. J., Hunsu, N., Green, C. J., Brown, S. A., & Adesope, O. (2018). Measuring Engineering Students ' In-class Cognitive Engagement : Survey Development informed by Contemporary Educational Theories. *ASEE Annual Conference and Exposition Proceedings*.

Marzouk, Z., Rakovic, M., & Winne, P. (2016). Generating Learning Analytics to Improve Learners' Metacognitive Skills Using nStudy Trace Data and the ICAP Framework. In *LAL 2016 Workshop at LAK*.

McCoach, D. ., Gable, R. ., & Madura, J. . (2013). *Instrument Development in the Affective Domain: School and Corporate Applications* (3rd ed.). New York: Springer Science and Business Media. https://doi.org/10.1017/CBO9781107415324.004

Meece, J. L., Blumenfeld, P. C., & Hoyle, R. H. (1988a). Students' goal orientations and cognitive engagement in classroom activities. *Journal of Educational Psychology, 80*(4), 514–523. https://doi.org/10.1037/0022-0663.80.4.514

Meece, J. L., Blumenfeld, P. C., & Hoyle, R. H. (1988b). Students' Goal Orientations and

Cognitive Engagement in Classroom Activities. *Journal of Educational Psychology*, *80*(4), 514–523.

Menekse, M., Stump, G., Krause, S. J., & Chi, M. T. H. (2011). Implementation of differentiated active-constructive-interactive in an engineering classroom. *ASEE Annual Conference and Exposition*.

Menekse, M., Stump, G. S., Krause, S., & Chi, M. T. H. (2013). Differentiated overt learning activities for effective instruction in engineering classrooms. *Journal of Engineering Education*, *102*(3), 346–374. https://doi.org/10.1002/jee.20021

Morrison, J. S. (2006). Attributes of STEM Education. *Teaching Institute for Excellence in STEM*, 20.

National Academies of Sciences Engineering and Medicine. (2018a). Context and Culture. In *How People Learn II: Learners, Contexts, and Cultures* (pp. 21–34). Washington, D.C.: The National Academies Press. https://doi.org/https://doi.org/10.17226/24783

National Academies of Sciences Engineering and Medicine. (2018b). Implications for Learning in School. In *How People Learn II: Learners, Contexts, and Cultures*, (pp. 135–162). Washington, D.C.: The National Academies Press. https://doi.org/https://doi.org/10.17226/24783

Nefzger, M. D., & Drasgow, J. (1957). The needless assumption of normality in

Pearson's r. *American Psychologist*, *12*(10), 623–625. https://doi.org/10.1037/h0048216

Nicol, D. J., & Macfarlane-Dick, D. (2006). Formative assessment and self- regulated learning: a model and seven principles of good feedback practice. *Studies in Higher Education*, *31*(2), 199–218. https://doi.org/10.1002/j.2168-9830.2010.tb01056.x

Nicol, D., & MacFarlane-Dick, D. (2006). Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Studies in Higher Education*, *31*(2), 199–218. https://doi.org/10.1080/03075070600572090

Nokes-Malach, T. J., Richey, E., & Gadgil, S. (2015). When Is It Better to Learn Together? Insights from Research on Collaborative Learning. *Educ Psychol Rev*, *27*. https://doi.org/10.1007/s10648-015-9312-8

Ohland, M. W. (Purdue U., Sheppard, S. D. (Stanford U., Lichtenstein, G. (Stanford U., Eris, O. (Franklin W. O. C. of E., Chachra, D. (Franklin W. O. C. of E., & Layton, R. (Rose-H. I. of T. (2008). Persistence, Engagement, and Migration in Engineering Programs. *Journal of Engineering Education*, (December), 260–278. https://doi.org/10.1002/j.2168-9830.2008.tb00978.x

Pace, R. C. (1998). Recollections and Reflections. In J. C. Smart (Ed.), *Higher Education: Handbook of theory and research Vol. XIII* (pp. 1–34). NY: Agathon Press.

Pekrun, R. (2006). The Control-Value Theory of Achievement Emotions: Assumptions, Corollaries, and Implications for Educational Research and Practice. *Educational Psychology Review*, *18*. https://doi.org/10.1007/s10648-006-9029-9

Pekrun, R., & Linnenbrink-Garcia, L. (2012). Academic emotions and student engagement. In *S. L. Christensen, A. L. Reschley, & C. Wylie (Eds.), Handbook of research on student engagement* (pp. 259–282).

Perreault, W. D. (1975). CONTROLLING ORDER-EFFECT BIAS. *The Public Opinion Quarterly*, *39*(4).

Pintrich, P. R. . A. O., & A. (2015). Motivated Strategies for Learning Questionnaire (MSLQ). *Mediterranean Journal of Social Sciences*, *6*(1), 156–164. https://doi.org/10.5901/mjss.2015.v6n1p156

Pintrich, P. R. R., Smith, D., Garcia, T., & McKeachie, W. (1991). A manual for the use of the Motivated Strategies for Learning Questionnaire (MSLQ). *Ann Arbor. Michigan*, *January*. https://doi.org/ED338122

Pintrich, P. R., Smith, D. A. F., Garcia, T., & Mckeachie, W. J. (1993). Reliability and Predictive Validity of the Motivated Strategies for Learning Questionnaire (Mslq). *Educational and Psychological Measurement*, *53*(3), 801–813. https://doi.org/10.1177/0013164493053003024

Preston, C. C., & Colman, A. M. (2000). Optimal number of response categories in rating scales: Reliability, validity, discriminating power, and respondent preferences. *Acta Psychologica*, *104*(1), 1–15. https://doi.org/10.1016/S0001-6918(99)00050-5

Prince, M. (2004). Does Active Learning Work? A Review of the Research. *Journal of Engineering Education*, *93*(3), 223–231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x

Qualtrics. (2005). Qualtrics. Provo, Utah.

Razali, N. M., & Wah, Y. B. (2011). Power comparisons of Shapiro-Wilk , Kolmogorov-Smirnov, Lilliefors and Anderson-Darling tests. *Journal of Statistical Modeling and Analytics*, *2*(1), 21–33. https://doi.org/doi:10.1515/bile-2015-0008

Reschly, A. L., & Christenson, S. L. (2012). Jingle Jangle and Conceptual Haziness: Evolution and Future Directions of the Engagement Construct. In *Handbook of Research on Student Engagement* (pp. 3–20). Springer.

Roszkowski, M. J., & Soven, M. (2010). Shifting gears: Consequences of including two negatively worded items in the middle of a positively worded questionnaire. *Assessment and Evaluation in Higher Education*, *35*(1), 117–134. https://doi.org/10.1080/02602930802618344

Rutledge, D., Pe, S., & Tech, V. (2015). Developing the Postsecondary Student Engagement Survey (PosSES) to Measure Undergraduate Engineering Students ' Out of Class Involvement Developing the Postsecondary Student Engagement

Survey (PosSES) to Measure Undergraduate Engineering Students '.

Shapiro, A. S. S., & Wilk, M. B. (1965). An Analysis of Variance Test for Normality (Complete Samples). *Biometrika, Published by: Oxford University Press on Behalf of Biometrika Trust Stable*, *52*(3), 591–611.

Simmons, D. R., Van Mullekom, J., & Ohland, M. W. (2018). The Popularity and Intensity of Engineering Undergraduate Out-of-Class Activities. *Journal of Engineering Education*, *107*(4), 611–635. https://doi.org/10.1002/jee.20235

Simmons, D. R., Ye, Y., Ohland, M. W., & Garahan, K. (2018). Understanding Students' Incentives for and Barriers to Out-of-Class Participation: Profile of Civil Engineering Student Engagement. *Journal of Professional Issues in Engineering Education and Practice*, *144*(2), 04017015. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000353

Sinatra, G. M., Heddy, B. C., & Lombardi, D. (2015). The Challenges of Defining and Measuring Student Engagement in Science. *Educational Psychologist*, *50*(1), 1–13. https://doi.org/10.1080/00461520.2014.1002924

Smith, J. A., Flowers, P., & Larkin, M. (2009). *Interpretive Phenonenologial Analysis: Theory, Method and Research*. London: SAGE Publications.

Smith, J. A., & Osborn, M. (2007). Interpretative Phenomenological Analysis. In *Qualitative Psychology* (pp. 53–80). https://doi.org/10.1002/9781119975144.ch9

Smith, K. A., Sheppard, S. D., Johnson, D. W., & Johnson, R. T. (2005a). Pedagogies of Engagement: Classroom-Based Practices. *Journal of Engineering Education*, *94*(1), 87–101. https://doi.org/10.1002/j.2168-9830.2005.tb00831.x

Smith, K. A., Sheppard, S. D., Johnson, D. W., & Johnson, R. T. (2005b). Pedagogies of engagement: Classroom based practices. *Journal of Engineering Education*, (January), 87–101. https://doi.org/10.1002/j.2168-9830.2005.tb00831.x

Stump, G., Hilpert, J., Husman, J., Chung, W.-T., & Kim, W. (2011). Collaborative Learning in Engineering Students: Gender and Achievement. *Journal of Engineering Education*, *100*(3), 475–497.

Sun, J. C. Y., & Rueda, R. (2012). Situational interest, computer self-efficacy and self-regulation: Their impact on student engagement in distance education. *British Journal of Educational Technology*, *43*(2), 191–204. https://doi.org/10.1111/j.1467-8535.2010.01157.x

Tharayil, S., Borrego, M., Prince, M., Nguyen, K. A., Shekhar, P., Finelli, C. J., & Waters, C. (2018). Strategies to mitigate student resistance to active learning. *International Journal of STEM Education*, *5*(1). https://doi.org/10.1186/s40594-018-0102-y

Thompson, B. (2004). Exploratory and Confirmatory Factor Analysis: Understanding Concepts and Applications. *American Psychological Association*. https://doi.org/10.1177/0146621606290168

Tinsley, H. E., & Tinsley, D. J. (1987). Uses of factor analysis in counseling psychology research. *Journal of Counseling Psychology*. https://doi.org/10.1037//0022-0167.34.4.414

Walter, E. M., Henderson, C. R., Beach, A. L., & Williams, C. T. (2016). Introducing the Postsecondary Instructional Practices Survey (PIPS): A Concise, Interdisciplinary, and Easy-to-Score Survey. *CBE--Life Sciences Education*, *Winter 201*(15: ar53). https://doi.org/10.1187/cbe.15-09-0193

Wang, X., Yang, D., Wen, M., Koedinger, K., & Rosé, C. P. (2015). Investigating how student's cognitive behavior in MOOC discussion forums affect learning gains. In *International Conference on Educational Data Mining*.

Weijters, B., Cabooter, E., & Schillewaert, N. (2010). The effect of rating scale format on response styles: The number of response categories and response category labels. *International Journal of Research in Marketing*, *27*(3), 236–247. https://doi.org/10.1016/j.ijresmar.2010.02.004

Whittemore, R., Chase, S. K., & Mandle, C. L. (2001). Validity in Qualitative Research. *Qualitative Health Research*, *11*(4), 522–537. https://doi.org/10.1177/104973201129119299

Williams, C. T., Walter, E. M., Henderson, C., & Beach, A. L. (2015). Describing undergraduate STEM teaching practices: a comparison of instructor self-report instruments. *International Journal of STEM Education*, *2*(1), 18.

https://doi.org/10.1186/s40594-015-0031-y

Yoder, B. L. (2018). Engineering by the Numbers. *American Society for Engineering Education*, 11–47.

Zhao, C.-M., & Kuh, G. D. (2004). Adding Value: Learning Communities and Student Engagement. *Research in Higher Education*, *45*(2), 115–138. https://doi.org/10.1023/B:RIHE.0000015692.88534.de