PATTERNS OF ERRORS IN ENGINEERING STUDENTS' ENTREPRENEURIAL DECISION-MAKING

by

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ABSTRACT

Ongoing efforts seek to develop engineering students into entrepreneurially minded engineers. Often, work to achieve that goal relies on theories drawn from entrepreneurship research from business disciplines to develop interventions and ground research on engineering entrepreneurship education. However, despite repeated warnings by multiple scholars, there has been limited evaluation of whether such theories are appropriate to design interventions or understand the development of students' entrepreneurial expertise. Theories of entrepreneurship developed in the field of entrepreneurship typically make several assumptions or research design choices pertinent to their usefulness in education. Those assumptions include assuming those studied make no errors, building expert-comparative rather than expert-novice theories, and mythicizing and reifying certain types of entrepreneurs. One such theory, the *Theory of Effectuation*, is representative of these assumptions as well as being commonly used in entrepreneurship education as a model of correct decision-making. Prior studies have used the Theory of Effectuation to compare experts and students and track students' growth, but have presumed error free reasoning by both experts and students.

My dissertation focuses on empirically evaluating the appropriateness of one assumption from the Theory of Effectuation when applying the theory to engineering students' decision-making. The assumption I focus on is what errors engineering students make when working on typical early stage entrepreneurship decisions. The existence of such errors would call into question whether the Theory of Effectuation, which does not allow for such errors, can usefully describe engineering students' decision-making. Interpreting the resulting errors can also help educators inform educators about pre-existing knowledge and beliefs that students bring to entrepreneurship classrooms. This can enable the design of more effective research studies and interventions to improve the state of the field

To do so, I completed a verbal protocol study with engineering students at two universities. The verbal protocol used is based on one previously used to develop the Theory of Effectuation and asks participants to think aloud while making decisions typical of an early-stage entrepreneurial venture. I then coded the transcribed data from those protocols for conceptual errors related to business and management concepts. A thematic analysis of the results showed several consistent patterns of errors. Those included misinterpreting market research data as

representative of their company's financial performance, misunderstanding and using faulty analogies to analyze different outside investment options, and perceiving that they would personally receive all proceeds from a company's sale. In general, two overarching patterns emerged – overestimating the value of their venture and overestimating their control.

I end by interpreting the results through three existing areas of literature to provide new knowledge to engineering entrepreneurship educators. First, the patterns of errors appear similar to other misconceptions in that a potential alternative ontology that students rely on may exist in mythicization work, however more evidence is necessary to formally establish that the patterns of errors are in fact ontological miscategorizations. Second, the patterns of errors are strikingly similar to the myths about entrepreneurs that have been identified in media and research that reports on entrepreneurs. This suggests a specific source of students' preconceptions about entrepreneurship that educators should actively engage with. Third, the findings validate existing theoretical critiques of how entrepreneurship theory is used in engineering education. Specifically, theories developed in entrepreneurship literature appear to be a poor fit for engineering education research because of their embedded assumptions.

1. INTRODUCTION

Increasingly, the ability to think and act entrepreneurially is considered critical to the professional success of engineering students. As the opportunities that engineers encounter during their professional careers continue to evolve (Creed et al., 2002), a major emphasis is connecting their technical work to the creation of economic or societal value (Clough, 2004; Duval-Couetil et al., 2015; Kriewall & Mekemson, 2010). Introducing entrepreneurial topics into engineering curricula has emerged as the primary method to meet these evolving expectations (Duval-Couetil et al., 2012, 2015; Kriewall & Mekemson, 2010). The resulting work has spawned the subfield of engineering entrepreneurship education. The subfield includes not just resources for curricular change but also its own conferences, ASEE division, and funding programs (e.g., KEEN[1] and VentureWell[2]). The goals of the emphasis on entrepreneurship education extends well beyond encouraging more engineering students to start businesses.

The benefits expected from introducing entrepreneurship into engineering education are both broad and important. Entrepreneurship is often situated as part of the changing knowledge and process of engineering work (Sheppard et al., 2008). There, entrepreneurship is touted as an answer for the need to collaborate across disciplines, to act, and to link engineering work to the creation of value. A common need associated with this benefit is for engineers to be innovative, with innovation seen as an inherent part of entrepreneurship (Atkins et al., 2015; Goodman et al., 2016; Zappe et al., 2013a). In a bid to extend the benefits and goals of entrepreneurship education beyond business formation, many in the field have adopted the term *entrepreneurial mindset*. Adopting the term mindset goes hand in hand with a shift in programmatic outcomes to recognize that those who do not start a business still gain skills and ways of thinking that are valuable to many engineering careers.

One organization, the Kern Entrepreneurial Engineering Network (KEEN), defines entrepreneurial mindset as curiosity about the changing world, the ability to make connections to gain insight and manage risk, and the ability to create value for others (KEEN, 2016; Li et al., 2016). Others have focused on specific skills and attitudes characteristic of entrepreneurs that can

[1] The Kern Entrepreneurial Engineering Network (https://engineeringunleashed.com/) is an organization that funds and advocates for the introduction of entrepreneurial mindset and character education into engineering education.
[2] Formerly known as the National Collegiate Inventors and Innovators Alliance (NCIIA) https://venturewell.org/

help modern engineers succeed whether or not they create a business– including an increased ability to solve global challenges, enhanced leadership skills, the ability to plan and realize a business idea, better communication skills, and the ability to recognize opportunities (Duval-Couetil & Reed-Rhoads, 2012; Shartrand et al., 2010; Sheppard et al., 2015).

To achieve the claimed benefits, the development of entrepreneurial interventions for engineering classrooms continue to grow in both number and form. For example, to guide the development of their institution's engineering entrepreneurship minor, one school uses the book *The Innovator's DNA: Mastering the Five Skills of Disruptive Innovators*[3], a book that purports to describe the personal characteristics that distinguish innovative business executives (Neele, 2016). Others use varying descriptions of the 'entrepreneurial mindset' to build courses and interventions that include a diverse set of personal characteristics and business skills (Erdil et al., 2016). Still others seek to help students develop entrepreneurial competence by focusing on global challenges (Shartrand et al., 2010). While one might expect that creating a new business is a primary focus of entrepreneurship education, venture formation has become less of a focus over time in many entrepreneurship programs (Duval-Couetil et al., 2012; Pittaway & Cope, 2007). In fact, evidence suggests that engineering students do not see business formation as a significant part of entrepreneurship, but rather their interests lie in technology and innovation – which they heavily associate with entrepreneurship (Duval-Couetil et al., 2012; Fernandez et al., 2017). Duval-Couetil et. al. (2012)'s results show that faculty believe students need to be taught more about entrepreneurship, but the belief that entrepreneurship education is important seems to be where consensus in the field ends.

At the same time, a growing number of critiques have begun to directly comment on the variation in approaches and the weak level of theoretical grounding in entrepreneurship education, both in engineering and in general (e.g., Duval-Couetil, 2013; Huang-Saad et al., 2018; Kriewall & Mekemson, 2010; Mäkimurto-Koivumaa & Belt, 2016). To illustrate such concerns, several authors have analyzed how assessment techniques are adopted and used in engineering entrepreneurship education (Huang-Saad et al., 2018; Purzer et al., 2016). Purzer et al. (2016) cataloged 29 papers in engineering entrepreneurship education and identified 51 different assessment methods – including 21 surveys that represent broad and varied theoretical conceptions

[3] Dyer, J. H., Gregersen, H. B., & Christensen, C. M. (2011). The innovator's DNA: Mastering the five skills of disruptive innovators. In Harvard Business Review (Vol. 87, Issue 12). Harvard Business Press.

of entrepreneurial expertise. The surveys measured everything from skills, to personality characteristics and attitudes, to 'entrepreneurial orientation', to actual behaviors on a simulated task. Few of the papers perform evaluation or validation when they adopt tools from the management literature where entrepreneurship has traditionally found its home. One survey cataloged by Purzer et al. is the EAO instrument whose developers explicitly warned against using it to make comparisons between experts and students (Robinson, Huefner, et al., 1991). More recently, Huang-Saad et al., (2018) reviewed 232 studies and found limited examination of the impact of interventions. Instead, at least two-thirds focused on characterizing programs or methods of measuring entrepreneurship in engineering students. Similarly, and concerningly, only half of the studies that Huang-Saad et al. (2018) catalog either explicitly reference or ground their work in theories of entrepreneurship. Huang-Saad note that they were generous in identifying *theories* – using the term to refer to any grounding in prior work or groups of ideas that intend to identify what makes entrepreneurs successful or describe why someone starts a business.

For simplicity, I adopt Huang-Saad's generalized use of the term theory which is inclusive of any attempt to explain aspects of individual entrepreneurial action. In the literature review, I describe specific ways that those theories cause problems for entrepreneurship education because of their research goals and frameworks. Of the studies that Huang-Saad identify that do reference a theory, the most common theory that used is entrepreneurial intent. Entrepreneurial intent is a theory in management literature that seeks to explain the intention to start a business (Valliere, 2015). This is despite an ongoing decrease in the number of programs that focus on students starting a business as a key outcome – both in engineering and in business schools (Pittaway & Cope, 2007; Duval-Couetil & Reed-Rhoads, 2012). In addition to the methodological and theoretical critiques, Huang-Saad et al. note that there are differences in what they call "disciplinary norms". Examples of those disciplinary norms that are relevant to my dissertation include research goals, uses of theory, and assumptions made in research. In each of those areas Huan-Saad et al., identify differences between management and engineering education research.

Huang-Saad's concern's with disregard to differences in research goals and frameworks is critical to how my dissertation contributes to engineering education. One such difference is that entrepreneurship research from the management field seeks to explain the presumed sophistication of expert entrepreneurs and understand how their expertise differs from how other expert and organizations make decisions (Ogbor, 2000; Haynie et al., 2010). In the management literature,

description of expertise is frequently done by comparing one kind of business expert to another (Ogbor, 2000). In contrast, engineering education attends to the differences between experts and novices, and the progression of novices to experts. Crucially, the entrepreneurship research approach is useful to developing theories about expert entrepreneurs and contributing to economic growth, but less useful for understanding novices, their developing expertise, or their educational needs. Attending to the expert-novice difference is realistically necessary for engineering educators. Engineering students are likely inexperienced with many of the concepts and tools that entrepreneurship researchers can, and do, assume in all types of business experts (Mäkimurto-Koivumaa & Belt, 2016; Mäkimurto-Koivumaa & Puhakka, 2013). However, discussions of or attendance to the implications of the expert-comparative goals of entrepreneurship research are largely absent in engineering entrepreneurship education.

1.1 The limit of expert-centric approach to engineering entrepreneurship education

Engineering entrepreneurship education has inadequately engaged with the relevance of theories that primarily describe expert entrepreneurs and, if relevant, how such theories can be combined with learning theory to effect educational outcomes. Looking back over 100 years, entrepreneurship research has displayed a constant focus on describing how and why expert entrepreneurs make the decisions that they do (Knight, 1921; Ogbor, 2000; Schumpeter, 1927). That focus is seen as important because expert entrepreneurs are successful in cases that classical theories of business decision-making say they should not be. Towards that goal, research on entrepreneurship consistently prioritizes descriptions of how entrepreneurs make decisions, and how that decision-making differs. In such research, entrepreneurs are accepted as displaying a *different type of expertise*, one that is necessary to start a business and that does not make sense within existing frameworks for how business decisions should be made (Knight, 1921; Read et al., 2016; Sarasvathy, 2001). Non-entrepreneur participants in such studies are commonly experts of a different type such as investment bankers or experienced managers in existing businesses (Robinson, Stimpson, et al., 1991; Sarasvathy et al., 1998). These non-entrepreneurs typically have extensive experience with running businesses and, when asked, they can identify or implement techniques from their own knowledge about business management that are considered classical or traditional (Chandler et al., 2011; Robinson, Huefner, et al., 1991; Robinson, Stimpson, et al., 1991; Sarasvathy, 2008). Assumptions about expertise drive researchers to focus on differentiation

between the two groups of experts and ignore aspects of similarity in knowledge or shared areas of expertise (Robinson, Huefner, et al., 1991). The resulting theories of entrepreneurial expertise are informative on *how* entrepreneurs are different from their experienced non-entrepreneurial peers but often presume, rather than attempt to explain why, such differences are superior.

One theory of entrepreneurial expertise, based on expert-to-expert comparisons, is the Theory of Effectuation (ToE). In both engineering and business schools, ToE has come to be seen as an exciting new tool for teaching entrepreneurship (Nelson, 2012). The theory describes how the decision-making used by expert entrepreneurs' is different from that of investment bankers (i.e., experts in non-entrepreneurial business decision-making) (Sarasvathy et al., 1998). Sarasvathy proposes that expert entrepreneurs use a different type of logic than investment bankers. That logic is based on control as opposed to predication, and manifests through a set of heuristics unique to expert-entrepreneurs. The theory does not provide a learning/developmental pathway, or a comparison of experts and novices, but has been widely proposed as a theoretical basis for teaching and assessing entrepreneurship (Fernandez & Duval-Couetil, 2017a; b).

When first describing ToE, Sarasvathy was explicit about an assumption in her work – that competent execution of techniques is assumed and, as a result, the quality of execution of decision-making techniques is ignored (Sarasvathy, 2008). The nature of a study comparing two types of experts empowers such an approach (Sarasvathy et al., 1998). She grounds the assumption of expert competence in the pragmatic epistemic perspective she adopted during the study, and focuses her analysis on what is of value to her research goal - describing how experts' make decisions. The resulting description of ToE focuses on the choice of different techniques grounded in different internally consistent forms of logic by two types of experts to solve the same problems.

However, because Sarasvathy assumes both groups of experts are competent in their chosen tools, her resulting theory of entrepreneurial decision-making has specific limitations relevant to education. ToE does not speak to fundamental skills or knowledge employed by both groups of experts, to whether either group makes errors, nor does it theorize a developmental pathway from novice to either type of expertise. Such limits are by design (Sarasvathy et al., 1998). Therefore, ToE's process of creation limits its usefulness in developing entrepreneurship curricula. Unfortunately, the limitations of expert-expert comparisons are rarely attended to when engineering entrepreneurship education programs are developed (Mäkimurto-Koivumaa & Puhakka, 2013). One common manifestation of this problem is the use of measurement tools

developed for expert-comparative research, to study student populations and make comparisons of students and experts without addressing their generalizability or development assumptions (Robinson, Huefner, et al., 1991; Fernandez et al., 2015).

The aforementioned studies by Purzer (2016) and Huang-Saad (2018) illustrate the scale of such uncritical adoption of expert-comparative theory in engineering entrepreneurship education. In Purzer et al.'s work, surveys are the most common method of assessing entrepreneurial learning, with many being adopted directly from entrepreneurship research. Few pursue evidence supporting their use with students or perform any evaluation of whether the theoretical basis supports educational use (Huang-Saad et al., 2018; Purzer et al., 2016; Robinson, Huefner, et al., 1991). When studies are performed to assess the validity of constructs used to compare experts with engineering students, evidence suggests they do not hold up (Fernandez et al., 2015; Soohyun & Duval-Couetil, 2021).

Huang-Saad (2018) highlights the large number of theories of entrepreneurial expertise that are adopted in engineering education, and the low level of published empirical evidence that supports their use with students. Both Purzer and Huang-Saad identify behavioral and affective variables as being used more frequently than cognitive variables in studies of entrepreneurship in engineering education. While behavioral variables may make sense for comparing experts, such a comparison is much less useful for students because the expert-comparative studies presume equal knowledge and seek to explain different action with a given set of knowledge (e.g., Kaish & Gilad, 1991; Robinson, Stimpson, et al., 1991; Sarasvathy et al., 1998). It is worth noting, however, that drawing expert-novice comparisons from theories designed for expert-expert comparison are not specific to engineering educators work on entrepreneurship. Instead, the issue is addressed in several systematic literature reviews in entrepreneurship education generally, which come to similar conclusion of low confidence in the understanding of student entrepreneurs or the impact of entrepreneurship education (Pittaway & Cope, 2007; Rideout & Gray, 2013; Soohyun & Duval-Couetil, 2021). Fundamentally, the theories being used in entrepreneurship education research and interventions contain neither the goal nor the approaches necessary to identify novice behavior, student errors, or a development pathway between novice and expert decision-making (Fayolle, 2013).

My dissertation empirically explores whether students' decision-making is affected by the assumptions of competence found in expert-comparative theories of entrepreneurial expertise. The

study does not, and cannot, fix any problems that result from the use of expert-comparative approaches and theories to teach entrepreneurship. Nor does it seek to decide whether expert-comparative research and assumptions of competence are appropriate for entrepreneurship researchers to rely on. Instead, it provides empirical evidence that engineering students make errors in entrepreneurial decision-making and argues that those errors limit the appropriateness of using expert-comparative theories as tools to explain the development of engineering students as entrepreneurs. The work presented here questions the grounding of analyses of student behavior in such theories, precisely because the expert-comparative paradigm assumes no errors in executing decision-making techniques – a norm that is likely inappropriate for learners. This study is a first step to evaluating the applicability of theories that rely on expert-comparisons to engineering entrepreneurship education. It is also useful to educators in that it provides description and evidence of how novices deviate from expert business decision-making. Such descriptions are purposefully absent from existing theories of entrepreneurial expertise, and have been noted as critical for improving entrepreneurship education (Robinson, Stimpson, et al., 1991; Haynie et al., 2010; Fayolle, 2013)

1.2 Purpose of my dissertation

The purpose of my dissertation is to identify and describe the errors that engineering students, with varying but limited entrepreneurial experience, make when solving problems characteristic of early-stage entrepreneurial ventures. The presence of errors is an expected aspect of engineering students' entrepreneurial decision-making that is not part of expert-comparative theoretical frameworks to assess their work. Therefore, identifying students' errors can 1) highlight the limits of expert-referenced approaches with students, 2) bring to the fore the implications of those limits and 3) provide new knowledge about how engineering students understand entrepreneurship to aid educators in creating curricula. At this stage, such efforts need to be focused on identification, description, and (if appropriate) identifying shared organizing or structural characteristics – i.e., taxonomies. Before the errors can be used for comparative purposes (e.g., to compare experts and novices or students before and after a class) they must be identified and understood. Therefore, it is necessary to look for errors across the many diverse paths and levels of exposure to entrepreneurship and entrepreneurship education that typify the engineering student population.

To achieve the purpose of my dissertation, I conducted an exploratory think aloud protocol study informed by a single overarching research question:

What patterns of errors are observable in engineering students when they work to make decisions typical of early-stage entrepreneurship?

The study population comprises undergraduate engineering students with a broad range of experience and exposure to entrepreneurship to maximize the types of possible errors. I characterize my study as exploratory with no claims to this being a closed set of errors engineering students make related to entrepreneurial decision-making.

My dissertation is grounded in two areas of scholarship that have not previously been linked: The Theory of Effectuation (ToE) (Sarasvathy, 2008) from the business literature and work on misconceptions (Chi 2005) from the learning sciences. ToE is representative of the normative entrepreneurial scholarship described in the previous section, wherein differences between two types of experts are identified and analyzed for exploitation. It relies on the assumption that experts employ the logic they select accurately. No work has repeated the grounded approach of the original studies to establish the credibility of ToE as a way of analyzing a progression towards expertise.

Scholarship on *misconceptions* illuminates how naïve or misinformed conceptions about relevant concepts impede learning in a field. Misconceptions are notable because they are often much more difficult to correct than areas where students simply lack of knowledge. The reasoning for that difficultly is widely theorized and often attributed to the difficulty novices encounter when observing cause and effect in emergent systems (Chi, 2005; Streveler et al., 2008). In engineering education, identifying; measuring; and eliminating misconceptions has proven a useful area of scholarship in technical topics such as heat transfer and rolling dynamics (Adam et al., 2016; Prince et al., 2012). Those studies both used the identification of misconceptions as a stepping stone to develop a specific type of assessment instrument – concept inventories (Jorion et al., 2015). However, the underlying identification of misconceptions in many fields is a novel and ongoing project (Chi, 2005).

My study operationalizes those two areas of theory using a verbal protocol to contrast the decision-making of expert entrepreneurs from non-entrepreneurial business experts. The protocol is derived from that originally used to develop ToE (Sarasvathy, 2008). Using the protocol, data were collected from undergraduate engineering students. The engineering students represented in

my participant population possess a range of entrepreneurial experience. Some students report no exposure, family history, coursework, or personal experience, while some others report coursework family members, and even some individual experience with entrepreneurship. However, none of the students possess the types of experience and expertise that Sarasvathy (2008) used in identifying her study population. Studying errors among engineering students with a diverse set of backgrounds in entrepreneurship (e.g., from totally naïve, to some coursework, to meaningful personal experience) provides a broader cross-section of engineering students. That broader cross section assists in the goal of identifying and describing the largest possible number of categories of errors, which researchers and educators can use for future research including work that compares across students' backgrounds and education.

1.3 Novelty, implications, and limitations

The primary implication of my dissertation is understanding the types of errors engineering students make when reasoning through entrepreneurial decisions, *and* understanding how those errors affect studies of students that use existing theories of entrepreneurial expertise.

Evidence of recurring patterns of errors are an opportunity for educators to target interventions or future research to address the gaps that come from relying on expert-comparative theories. Fayolle (2013) noted that a problematic assumption is subsumed into all aspects of the entrepreneurial learning environment: The choice of decision-making techniques, rather than their competent use, represents entrepreneurial expertise. In providing recommendations for the field, Purzer et al. (2016, p. 31) noted that "researchers might explore methods to classify individuals as novices, emerging experts, and experts in engineering entrepreneurship" within existing theories of entrepreneurial expertise. In working towards that call, my work has two key implications for work in engineering entrepreneurship education.

First, my dissertation is a novel step towards the trajectory Purzer et al. called for. Building such a trajectory requires understanding not just the choices students make but the reasoning behind those choices and the quality of the students' execution. However, as Purzer and others have noted, studies typically focus on assessing the choice of technique as a proxy for growth, rather than assessing whether techniques are used well (Dew et al., 2009; Fayolle, 2013; Ogbor, 2000; Purzer et al., 2016). Said another way, my dissertation establishes how students make decisions that they believe are typical of their beliefs about early-stage entrepreneurial ventures,

rather than simply reporting whether those decisions are more similar to investment bankers or to entrepreneurs.

Specifically, I examine the nature of how students employ the techniques they select to solve entrepreneurial problems. Previously, such deep investigation of entrepreneurial decision-making has only occurred with experts (Sarasvathy et al., 1998). Follow-on research then uses expert decision-making as a quantifying scheme for studying students (Dew et al., 2009). To date, little to no research has performed deeper analysis of engineering students' entrepreneurial decision-making. My analysis specifically focuses on errors that students make – i.e., the entrepreneurial concepts that engineering students employ incorrectly and how their use differs from generally accepted ideas of correct use.

That focus has shown itself to be valuable in other areas of engineering education (Adam et al., 2016; Miller et al., 2006). Such a focus is *also* absent from prior work on entrepreneurial expertise because, as described earlier, experts are assumed to not make errors. Overall, the value of this analysis is understanding the details and processes of entrepreneurial decision-making in the same way that has been previously performed with experts (Sarasvathy, 2008). Such an analysis with engineering students is novel and important to test the notion that expert theories of entrepreneurial decision-making can effectively explain engineering students' decisions.

The second key implication emerges from the patterns of errors themselves. Work in other areas of engineering education have focused on conceptual change and misconceptions (Streveler et al., 2008). The resulting lists of common errors made by and misconceptions held by engineering students have proven useful in several areas – including thermal sciences and forces. As one example, work by Steif (2004) presents a list of common errors students make when learning static force analysis techniques. While simple in concept, such a list provides a shared resource for researchers to create taxonomies of student understanding, communicate about student learning, develop interventions, and assess changes in understanding (Steif & Dantzler, 2005). All of these uses rely on a priori work to identify and describe errors themselves. However, there is a lack of identification and description of similar errors made by students in entrepreneurship education work[4].

[4] Uses of the term misconceptions exist in entrepreneurship research. However, the use of term typically indicates a critique of perceived errors in assumptions in other research (e.g., Hunter, 2012) or to discuss myths and media misconceptions about entrepreneurship present in the research or media representations of entrepreneurs. It is not

The limitations of the approach in my dissertation are twofold. First, understanding student thinking does not solve the limitations of using expert-referenced theories in education and education research. By its nature, my approach can only (1) highlight how the existing approaches influence the field's understanding of engineering students as entrepreneurs or (2) identify areas where students' understanding of entrepreneurship needs to be addressed by educators. Second, because the sample is limited to two institutions, and a relatively small sample size, further work needs to be conducted to establish generalizability and further explore the differences to experts that I find.

However, the step of identifying, describing, and considering any consistent structure in the errors is necessary first. Doing so allows researcher to understand differences between students' and experts' decision-making more holistically. Understanding the differences enables potential improvements to the use of theories of entrepreneurial expertise in engineering education and also provides avenues for improving the theories themselves by addressing the implications of assuming competence to using the theories as a lens for research.

used in accordance with the learning sciences conception. The focus of the existing work is on biases in knowledge production rather than learning, and is discussed in section 2.4.

2. BACKGROUND

This chapter summarizes four areas of prior research; the Theory of Effectuation (ToE), mythicization of entrepreneurial research, studies that illustrate the current state of engineering entrepreneurship education, and research on a specific class of learner errors - misconceptions. The contributions of each of the four areas to my dissertation are as follows. ToE is a theory that describes expert entrepreneurial decision-making and exemplifies how expert entrepreneurial decision-making is described in literature. However, as mentioned in Chapter 1, I do not adopt ToE as a theoretical framework or a lens for interpreting engineering students' entrepreneurial decision-making – i.e., a traditional use of a theoretical framework (Borrego, 2007). Instead, it provides a reference point to compare engineering students' decision-making against that of expert entrepreneurs and investment bankers.

The section on mythicization describes scholarship that critiques the processes and theories of entrepreneurial success that result from entrepreneurship research. Mythicization both illustrates why caution is warranted in adapting theories from entrepreneurship literature to entrepreneurship education *and* why it is so common that such adoption occurs uncritically. My review of mythicization particularly focuses on the field's reverence for successful individual actors and how this can influence the theories that form the basis of entrepreneurship research and entrepreneurship education. The review of existing literature regarding engineering students and engineering entrepreneurship education describes current practices. It specifically focuses on how theories that purport to explain entrepreneurial success, and which suffer from the mythicization problem, are adopted into engineering curricula. Finally, a review of the research on misconceptions in engineering education highlights possible difficulties that could arise from entrepreneurship theory's focus on expert-expert comparison, societal and scholarly myths about entrepreneurs, and the ways engineering education uses entrepreneurial theory. In short, if the patterns of errors that engineering students make in my study meet the definition of misconceptions, that is evidence that engineering entrepreneurship education should embrace other learning theories less grounded in replication of expert behavior.

2.1 Theory of Effectuation,

Beyond a more thorough explanation of its content, explaining the history of ToE and its use in entrepreneurship education is useful to my purpose. Doing so highlights what ToE is intended to accomplish and the limitations this type of theory development in explaining errors in students' entrepreneurial decision-making. The Theory of Effectuation (ToE) describes how expert entrepreneurs approach the unique problems that early-stage ventures encounter when starting and growing (Sarasvathy, 2008). ToE is an example of an expert-derived theory of entrepreneurship, and was developed by studying the decision-making of expert entrepreneurs using a verbal protocol grounded theory methodology. The theory compares the decision-making of expert entrepreneurs (i.e. those with the experience of starting a highly successful business) to expert investment bankers so as to identify the 'best' way to make a given decision in the early stages of a company's growth (Sarasvathy, 2011; Sarasvathy et al., 1998). Since its first publication, ToE has become widely adopted, critiqued, discussed, and analyze in the management discipline and entrepreneurship education (Arend et al., 2015; Fisher, 2012; Perry et al., 2012; Read et al., 2009).

ToE proposes that the entrepreneurs' decision-making differs from traditional business decision-making by relying on a different logical basis for decision-making (Sarasvathy, 2001; Sarasvathy et al., 1998). According to Sarasvathy, traditional management approaches are centered on prediction and determinism as the basis for decision-making (Sarasvathy, 2001; Wiltbank et al., 2009). Conversely, entrepreneurs eschew prediction and an assumption of determinism for a focus on learning and control. As Sarasvathy explains, the two approaches reflect different types of decision-making but do not detail the outcomes of either approach. Rather, Sarasvathy notes that the two approaches can create fundamentally different outcomes. Her work is grounded in classical works of economics which broaden the definition of entrepreneurship beyond the creation of a single business and include the co-creation of business ventures, markets, and other changes in economies and societies holistically (Sarasvathy & Dew, 2005; Schumpeter, 1921, 1927). The foundation of ToE is developed by differentiating how business techniques approach probability (Sarasvathy, 2001; Sarasvathy & Dew, 2005); with traditional business decision-making working from either frequentist or Bayesian perspectives to leverage a priori probabilities to identify opportunities to create value. Conversely, expert entrepreneur's decision-making rejects the value of determining probabilities and instead seeks to create something new where a probability cannot be known a priori. Sarasvathy likens expert entrepreneur's approaches to Knightian uncertainty –

economist Frank Knight's idea that some possible outcomes in business cannot be assigned probabilities with any meaningful accuracy but can seem as highly probable only in hindsight (Knight, 1921)[5]. Sarasvathy connects Schumpeter's work on entrepreneurial creation to Knight's conceptions of uncertainty to explain the different logic of learning and control that she observed expert entrepreneurs employing.

In ToE, Sarasvathy labels the two types of expert decision-making *causal* (i.e., expert investment bankers) and *effectual* (i.e., expert entrepreneurs) logic. Causal decision-making reflects traditional business decision-making techniques that predict the future and make decisions based on those predictions. The causal approach is a means-end analysis where a goal is pre-defined (given) and then resources (means) are selected that enable that goal to be achieved. Conversely, effectual techniques represent the decision-making patterns of expert entrepreneurs. In effectual logic, identifying points of individual influence, rather than potential outcomes, is the basis of making decisions. An entrepreneur then selects from among the outcomes they imagine they can achieve with those means.

Sarasvathy explains that effectual and causal logic using a non-closed set of heuristics that build on theories of bounded rationality from economic studies of human decision-making (Sarasvathy et al., 1998; Simon, 1957). The heuristics currently associated with ToE are described in

Table 1. In her study, Sarasvathy identified five effectual heuristics that she found to be common among the group of expert entrepreneurs. The heuristics represent differing elements or tools for solving highly uncertain business problems. ToE proposes the effectual heuristics as data driven explication[6] of a phenomenon that had previously been undescribed, proposed as

[5] The details of Knight and Schumpeter's work is beyond the scope of my dissertation. However, some readers may find a brief description useful to understand normative processes in economics. Formally, Knight differentiates between two types of uncertainty: Risk based uncertainty is where one can assess risk from a known or knowable probability distribution of all possible outcomes. The other type, commonly called Knightian uncertainty, refers to cases of uncertainty where no plausible or knowable probability distribution exists. Relevant to ToE, Knightian Uncertainty notes that probabilities as knowable only in hindsight, giving the potentially false appearance of a probability-based strategy if decisions are viewed as successful. Prior to Sarasvathy's work, research in business generally treated actions under Knightian uncertainty non-specifically, adopting terms such as 'intuition' or 'creative destruction' to describe the outcomes without describing the underlying decision-making processes (Knight, 1921; Schumpeter, 1927). Both sought to acknowledge that entrepreneurs possessed some effective and potentially consistent method but noted that it could not be understood from a probability paradigm and risk-based uncertainty.

[6] For the purpose of ToE, throughout this section I am using *explication* to refer to work laying out the finer details of ToE itself and differentiate that from more colloquial audience specific tailoring (i.e., explanations) of the theory that have appeared in other sources (e.g., Effectuation 101 [SEA, 2011]). In doing so, this section should be taken to

indescribable, and labeled "intuition" by Knight (1921). Because these heuristics represent decision-making methods for engaging with common business situations on which research from a classical management perspective exists, the effectual heuristics are comparable to a parallel causal approach to the same situation. From such literature and research on investment bankers and MBA students, ToE is able to contrast the effectual heuristics with a set of causal heuristics that represent traditional decision-making approaches in business (Chandler et al., 2011; Sarasvathy et al., 1998).

Table 1 Causal and effectual heuristics (Sarasvathy, 2011)

Issue	Causal Heuristic	Effectual Heuristic
View of the future	Define goals and gather resources to support those goals	Assess what you have on hand, use those resources to pick a viable goal
Tolerance of risk	Focus on what has the highest return for a given calculation of risk	Focus on taking actions that only risk what you can afford to lose
Approach to others	Analyze competitors for their weaknesses	Partner with potential competitors to learn and understand
View of the unexpected	To be avoided, shows a lack of proper planning or preparation	To be learned from, highlights opportunities to learn and adjust
Basis for acting	Focus on what you can predict	Focus on what you can influence

Since its first publication, ToE has become highly influential in how entrepreneurs, entrepreneurship, and entrepreneurial decision-making are studied (Perry et al., 2012). Studies that employ ToE in education have typically focused on using the theory to classify students' entrepreneurial decision-making as either causal and effectual or to develop interventions to encourage the use of effectual techniques (Bureau & Fendt, 2012; Chandler et al., 2011; Mäkimurto-Koivumaa & Puhakka, 2013). The theory itself has also been extensively discussed and critiqued (Arend et al., 2015).

One key point of Arend's critique of ToE connects directly to the concerns with expert-derived theories of entrepreneurial expertise, described in my introduction. Arend et al., (2015) observed that ToE, as described by Sarasvathy, does not describe the quality of the expert

specifically refer to Sarasvathy's description of the theory from its primary texts and my use of those texts as a canonical description of ToE.

approaches and does not empirically demonstrate that they are better. Rather, Arend et al., noted that ToE provides a description that is untestable and provides no functional ways to evaluate the quality of the application of heuristics or the competence of someone who is using them (Arend et al., 2016). However, despite an ongoing conversation about the completeness and appropriateness of ToE, minimal further development of ToE itself has occurred (Arend et al., 2016; Read et al., 2016; Reuber et al., 2014; Sarasvathy, 2001). Instead, ongoing work has been the *use* of ToE towards other goals – e.g., studying whether the use of effectual techniques predicts venture success (Nelson, 2012; Perry et al., 2012).

2.1.1 Use of ToE in entrepreneurship education

Two aspects of the existing research on ToE are critical to my dissertation. First, how ToE has been used in entrepreneurship education, both inside and outside of engineering. Those uses connect to the problem I described in the introduction and the critiques from Arend and colleagues. Second, the original work on ToE serves as the basis for the methods that I use in my dissertation.

Critical to framing ToE's use in entrepreneurship education is that it is both expert-derived and expert-comparative. In other words, the description of ToE does not seek or contain a description of novice entrepreneurial behavior or a progression from novice to expertise (Fernandez & Duval-Couetil, 2017b). Instead, Sarasvathy's explanation of ToE differentiates one form of expertise (i.e., entrepreneurial expertise) from another form of expertise (i.e., traditional managerial expertise). In doing so, she focuses on what expert entrepreneurs do, and what they do not, not *how well* they do so (Arend et al., 2015). Sarasvathy (2008) explicitly presumes the expert entrepreneurs she studies act with full knowledge of both causal and effectual techniques and correctly execute the techniques she observed. While heuristics are seen as fundamentally generalizable (Tversky & Kahneman, 1974), their nature as 'cognitive shortcuts' that do not take a consistent form affects how they are studied (Sarasvathy et al., 1998). Being rooted in an expert-centric approach to studying entrepreneurship gives ToE properties with significant implications when the theory is applied to education.

One way that ToE has influenced entrepreneurship education is in the creation of multiple new tools to measure students' decision-making. For example, Dew, Read, and Sarasvathy (2009) reused Sarasvathy's original protocol to compare MBA students to experienced entrepreneuers. Their results showed that MBA students are less likely to use effectual techniques and instead "are

focused on limiting the downside" (pg.302), a causal approach. The authors attributed those findings to the educational experiences MBA students were concurrently experiencing, where grounded in teaching and accurately applying causal heuristics. As with the original ToE study, Dew et al., did not address the way in which MBA students or experts chose heuristics. Rather, they focused on which heuristics students chose, presumed such a choice to be informed, and treated an increase in effectual heuristics as evidence of developing increased entrepreneuerial competence.

Similar presumptions occur in two studies developing instruments to measure ToE. Chandler et al. (2011) developed a self-report instrument[7] based on ToE to measure the use of effectual and causal logic by various people in various contexts – including a proposal that it be used as part of entrepreneurship education. The instrument was composed of a series of items presented a choice between effectual and causal approaches to making entrepreneurial decisions. The items were asked without a specified decision context and were phrased as post-hoc self-reports of a *group's* decision-making process during the early stages of a venture (e.g., "We analyzed long run opportunities and selected what we thought would provide the best returns" pg., 379). During its development, the instrument was tested on several groups including entrepreneuers, employees of early-stage companies, and MBA students.

Another instrument that used ToE as a basis to measure decision-making in students specifically was developed by Valliere (2015). The measurement goal was, again, to determine whether students were more likely to use effectual or causal heuristics. The instrument placed students in a single scenario (starting a coffee franchising business) and asked individual questions about how one would make decisions in that scenario (e.g., "I will only spend resources I have available and I am willing to lose" pg. 28). The instrument was tested with a large pool of undergraduate students from diverse majors, not just in business and entrepreneurship. From that testing, students showed a small but statistically significant preference for effectual over causal

[7] This paper's process and terminology related to developing measurement instruments also exemplify one difference in the norms that exist between education and entrepreneurship noted by Huang-Saad et al., (2018). Chandler et al., (2011) refer to the instrument as 'validated' based entirely on quantitative testing. Referring to an instrument as 'validated', is one of several statements that parallel 'myths' about validation of *educational measurements* highlighted by Douglas and Purzer (2015) writing for engineering educators. The differences in establishing measurement validity are important because it is common practice for engineering entrepreneurship education to adopt instruments from entrepreneurship (Purzer et al., 2016). While processes for validating instrument development are beyond the scope of my dissertation, this example highlights a specific example of how practices in transferring knowledge between entrepreneurship and engineering education can introduce confusion and ambiguity.

heuristics. That result is in conflict with other results, but also uses an even less entrepreneurially experienced population – undergraduates as opposed to MBA students.

A different approach to measuring ToE is found in work by Bureau and Fendt (2012). They performed an analysis of artifacts created in an introduction to entrepreneurship course, rather than a research-focused study. Their results show that the use of effectual heuristics increased after students completed the course. The course explicitly sought to teach the effectual heuristics themselves as the best way to do entrepreneurship, but did not provide instructions in causal heuristics or the logical basis for either set of heuristics. As with the other studies mentioned, Bureau and Fendt (2012) did not address how, or how competently, the effectual techniques were used nor did they address any causal heuristics. Instead, they provided one scenario in which they coded the number of effectual heuristics only. Bureau and Fendt's results parallel research showing that as entrepreneurs gain experience they are more inclined to adopt effectual techniques both at the heuristic and logical level (Nelson, 2012). From the body of work on students and effectual heuristics, Nelson questioned whether effectuation influences entrepreneurial success or is simply an indicator of an overall developing expertise as individuals encounter the limitations of causal techniques and develop alternatives. He openly questioned whether entrepreneurship education should seek to teach effectual heuristics as the right way to think entrepreneurially, or guide students to a deeper understanding of multiple ways to solve a business problem and how to consciously evaluate the appropriateness of each approach.

In summary, the empirical work on ToE with students has focused solely on identifying which heuristics students use. The results of those studies provide an incomplete picture of how students use those heuristics, but do suggest that students use the heuristics differently than expert entrepreneurs. Bureau and Fendt (2012) showed that teaching the effectual heuristics can increase their use. Dew et al. (2009) also showed that MBA students in the midst of learning causal techniques use less effectual heuristics than expert entrepreneurs. Meanwhile, Valliere (2015) showed that undergraduates are more likely to use effectual than causal heuristics in one specific scenario. Lacking in this research are deeper answers about whether students' use of the heuristics really is reflective of the way experts use them – in conscious selection, in quality of execution, and in realistic scenarios. None of the empirical data reviewed establishes a conscious choice of the heuristics by students, the high quality use of heuristics, nor can it inform efforts to understand the progression from novice to expert entrepreneuer. This lack of data is in stark contrast to

Sarasvathy's initial ToE study where experts explicitly described their choice of effectual over causal heuristics, and their evaluation of why causal heuristics were inappropriate in the given context.

However, there are ongoing discussions about how to include ToE in entrepreneurship education. Multiple authors have argued that effectuation and causation must be taught side by side (Agogue et al., 2015; Mäkimurto-Koivumaa & Puhakka, 2013). Agogue et al. argued that expert entrepreneurs co-create entrepreneurial actions by using effectual and causal approaches together, rather than solely relying on effectuation. That perspective reflects one proposed evolution of ToE – that experts use causal and effectual heuristics together while evaluating their appropriateness for a given decision (Fisher, 2012). Separately, Mäkimurto-Koivumaa and Puhakka (2013) argued that students must know both techniques to be maximally effective in different scenarios. They argued that both sets of heurstics are independently useful and so must be independently understood to select the best approach to make a given decision.

Importantly, both Agogue and Makimurto-Koivumaa call for educators to frame effectual and causal heuristics as situationally, rather than universally, appropriate. That framing requires students to be able to evaluate whether situations call for causal techniques or effectual techniques and act accordingly. Their call for *situated* use of effectual heuristics, rather than simply *the* use of effectual heuristics, as part of developing entrepreneurial expertise highlights a conscious choice of one set of heuristics over another as part of becoming an expert effectual entrepreneur. The early development work on ToE explicitly notes that such conscious and reasoned rejection of causal heuristics is a pre-requisite to the expert's use of effectual heuristics (Sarasvathy, 2018).

However, the existing literature on students' use of effectual and causal heuristics lacks investigations of how and why students choose effectual heuristics. Whether in the abstract (e.g., Chandler et al.) or in a specific scenario (e.g., Valleries or Dew et al.), the research prioritizes measuring the number of effectual heuristics chosen and their increase as a positive outcome of learning (c.f., Bureau and Fendt).

The result is that how to appropriately current uses of ToE in education are problematized by unanswered questions about whether students' use of a choice of a given heuristic reflects expert decision-making. There is a gap between empirical work conducted on students where the goal is to evaluate whether student and expert use of the same heuristics reflects the same decision-making. In its place is work showing only the increased use of effectual heuristics and work

arguing for the need to teach proper use of both effectual and causal techniques. However, neither the empirical work nor the calls to teach both sets of heuristics calls for teaching and evaluating how to use the effectual or causal heuristics *well* (i.e., in a situated way). Further, the work on ToE itself as a theory still does not possess information on how to actually use the heuristics in some notionally correct way (Perry et al., 2012; Reuber et al., 2014). This means that the gap between underlying knowledge and choice of heuristics still exists in ToE research. Therefore, understanding whether and how students make errors in executing the heuristics remains an important and unanswered question that can benefit entrepreneurship education where an assumption of expert use of the heuristics is implausible.

2.1.2 How ToE is used in my study

To be explicit, I use the work on ToE in two ways in my dissertation – methodologically and as an expert-comparison. First, I use the think-aloud protocol that multiple researchers have used to study multiple groups as part of the development of ToE the foundation for data collection (Dew et al., 2009a; Sarasvathy, 2008; Sarasvathy et al., 1998). Second, I use Sarasvathy's original, extended, description of the decision-making of expert entrepreneurs and expert non-entrepreneurs to illustrate errors in students' decision-making in the results section. This section briefly reviews prior uses of the protocol in literature prior to a description of the specific implementation and methods in the next chapter.

The think-aloud protocol was developed for Sarasvathy's original study to identify qualitative differences between the decision-making of expert investment bankers and expert entrepreneurs (Sarasvathy et al., 1998). The analysis in that original study used the verbal protocol data as part of a grounded theory methodology to describe and support ToE's core theoretical tenants (Sarasvathy, 2008). However, the grounded theory approach to analyzing protocol data has not been repeated or replicated (Arend et al., 2015).

In place of grounded theory, later studies retain the protocol but adopt quantitative approaches to data analysis – typically involving coding the use of ToE's effectual and causal heuristics. Dew et al., (2009) used the verbal protocol to collect data from MBA students as a comparison of expert and novice entrepreneurs. Their comparison, on which Sarasvathy is a co-author, codes and then counts the number of effectual and causal heuristics used by both groups. The MBA students, who they refer to as novices, used less effectual heuristics and more causal

heuristics than expert entrepreneurs. They hypothesize that this is because MBA students have been recently instructed in how to use the techniques that underpin the causal heuristics, but have not been instructed in the use of the effectual heuristics that the expert entrepreneurs use.

Wheadon M. and Duval-Couetil (2016) employ a similar approach to Dew et al., but with engineering students. In a pilot study, they use a shortened version of the protocol and focus on coding effectual and causal heuristics. The goal is to use ToE as a theoretical framework to evaluate whether engineering entrepreneurship education increases the use of effectual heuristics – because such an increase is presumed to be indicative of entrepreneurial learning. As with the work by Dew et al., no work to evaluate the credibility of the coding scheme or of ToE heuristics as viable descriptors of student thinking is performed.

The fact that no prior work has evaluated whether the expert heuristics proposed in ToE are credible as a heuristic description of student thinking bounds how I can use ToE in my dissertation. Without such evidence, I cannot use ToE as a lens – and instead my dissertation in part functions as an evaluation of the credibility of ToE as such a lens. While prior empirical studies of students' choice between effectual and causal heuristics make this choice, it is one specifically warned against in meta-studies of engineering entrepreneurship education (Purzer et al., 2016, & Huang-Saad et al. 2018). Instead, I use ToE as a *comparative reference* to illustrate how students' thinking differs from both expert entrepreneurs and expert non-entrepreneurs using the same verbal protocol. In the results chapter, I describe students' errors separately from ToE and then compare students' errors and decision-making to the descriptions of both expert investment bankers *and* expert entrepreneurs that ToE contains.

2.2 Mythicization of entrepreneurial research

The term mythicization has been adopted in entrepreneurship literature to describe the ways in which the decision-making, attitudes, and even personality characteristics of successful[8] entrepreneurs are assumed to be valid, correct, and valuable for entrepreneurship researchers to

[8] i.e., expert entrepreneurs – I use the phrase expert entrepreneurs in other portions of my dissertation, for simplicity and in keeping with the terminology used in ToE and the field. However, in this section I specifically use *successful entrepreneurs*. Using successful is in keeping with the discussion within mythicization literature in entrepreneurship and reflects that success of one or more businesses is often conflated with individual expertise when developing entrepreneurial theories. That conflation includes ToE where success via measures of financial wealth accrued through entrepreneurial activity is the primary proxy for assessing expertise.

describe (Ogbor, 2000). Extending beyond simple descriptions, scholars argue that the foundational narratives about entrepreneurship need to be reconsidered because they negatively impact research and teaching of the discipline (Anderson & Warren, 2011). The discussion of mythicization argues that stereotypes about certain types of entrepreneurs have come to form the fundamental basis for research about entrepreneurs. Rather than simply a case of bias, the stereotypes have become embedded myths that form the foundation for the field's research and theories. The literature argues that certain stereotypes about entrepreneurs have become so entrenched that they create a reality from which other research about entrepreneurs and efforts to educate entrepreneurs now emerges. In sum, literature on the mythicization of entrepreneurship explains why ToE does not address accuracy or details of how successful entrepreneurs use the heuristics in the theory, and why that such issues are lost in the creation of entrepreneurship curricula.

Describing successful entrepreneurs and what they do is a common focus in entrepreneurship research (Ogbor, 2000). Such descriptions are typified by attempts at novel perspectives of description and accurate reporting as opposed to an analysis of the quality of decision-making or the details of implementation of a decision-making technique. Ogbor's critique jointly addresses the ideology, process, and outcomes of entrepreneurship research that result from such a focus. They argue that the current body of research on successful entrepreneurs is based on "a process of 'power-based reality construction' [and reflects] how people become trapped by ideas that serve specific sets of interests" (pg.609). The process of reality construction becomes mythicization when the actions of successful (i.e., powerful) entrepreneurs are discussed using language and narratives that influence, and even become, 'facts' in entrepreneurial research and education (Omid, 2000).

Ogbor (2000) focuses on how power and language construct a shared reality that reproduces myths about successful entrepreneurs as facts through ongoing discourse. His work takes a critical and post-modern perspective on the dominant narrative within management and entrepreneurship research that seeks a *scientific* or post-positivist identity for the field. They are critical of scholars insisting that entrepreneurship research currently meets the test of science (Ogbor, 2000, p. 606). Critical readings observe that existing work on entrepreneurship reports inherently and often explicitly white, western, male norms in descriptions of entrepreneurial prowess and simply treats them as the science of entrepreneurship (Ogbor, 2000; Sarachek, 1978).

Later work has emphasized analysis of certain specific characteristic norms and the way they are manifested. For example, the explicitly gendered nature of characterizations of entrepreneurs in media that legitimize narrow models of entrepreneur (Wheadon, J. & Duval-Couetil, 2016, 2019).

The result is an entrepreneurship research field whose underpinnings are "an ideological spirit rather than a scientific foundation" (Omid, 2000). These underpinnings mean that the resulting research does not meet the tests of science, but rather seeks the credibility of science for narratives that reify the actions of powerful societal figures and societal myths about entrepreneurship. Multiple scholars note the close parallels between entrepreneurship research's uncritical treatment of successful individuals and Horatio Alger-esque myths of success as the result of virtuous behavior. Those parallels represent another way in which the actions of successful entrepreneurs are assumed to be both good and correct, because the outcomes of their work are seen as virtuous by society.

A key outcome of the mythicization literature is a set of myths about entrepreneurs that exist in the public sphere and influence research. Primary among these is the myth of entrepreneurship as a Darwinian ideal, within which the ideal entrepreneur survives and should be studied/replicated as brave risk taker and as a strong individual - i.e., a hero (Ogbor, 2000). This myth ignores non-successful entrepreneurs as providing no value to the field's knowledge except in studying what went wrong. Ogbor compares these representations to "the historical literature of America about the 'first' white-male European who 'discovered' and 'conquered' the land of opportunity, symbolizing the heroic representation of positive American male model of aggressiveness, assertiveness, and the conqueror" (Ogbor, 2000, pg. 617). Other researchers tie these myths explicitly to media representations of entrepreneurs, noting themes of magic, larger than life characters, rags to riches stories, wealth, and maleness, or to the 'Horatio Alger myth' of rugged individualism and self-control. These myths are problematic not because they exist in society, but rather because research begins from the myths uncritically. Entrepreneurship as the morally correct path to personal success becomes the pretense that motivates entrepreneurship research and also validates its results if the right entrepreneurs are studied (Nicholson & Anderson, 2005; Sarachek, 1978). Nicholson and Anderson end their study of entrepreneurial myths in newspapers by noting:

> [W]hat is most intriguing about the metaphors and mythmaking is the range of language conjured up to build these stories of entrepreneurship. Entrepreneurs are described so vividly, so much larger than life in both their heroics and their

> villainies. These descriptive metaphors bear little resemblance to reality, yet, in spite of this, these are the images portrayed in a respected newspaper (Nicholson & Anderson, 2005, p. 168)

The result is a general discourse that treats entrepreneurs as uniquely prepared, ingrained, or situated with characteristics that represent an idealized version of entrepreneurship and entrepreneurs – a created identity that has propagated across research discourse as well (Anderson & Warren, 2011, Wheadon, M. & Duval-Couetil, 2016; 2019). Other entrepreneurs – those of color, of a different gender, or students of lesser experience – are compared against such model myths to define normatively correct models of entrepreneurship[9] based on their alignment with dominant groups. The adoption of myths or metaphors as reality in discourse about entrepreneurship does not just influence research and media; it also directly influences education both in content, presentation, and even the interpretation of underlying pedagogical theories of the field (Bridgman et al., 2016).

The risk in such mythicization is that ToE and other theories give great deference to correctness of the actions of entrepreneurs because society values their work (Fernandez & Duval-Couetil, 2017b). When the resulting research becomes imbued with myths and Omid's (2010) "ideological spirit," warnings about generalizing to novice entrepreneurial decision-making become bleaker. Theories like ToE describe, and provide the trappings of science, to certain individuals and then call that scientific theory (Arend et al., 2015, 2016).

The resulting theories of entrepreneurship presume that successful entrepreneurs are right, not because there is evidence but because those individuals are successful. Mythicization scholars argue that such theories fundamentally cannot interpret non-expert behavior, because they purely describe rather than interpret expert behavior (Bridgman et al., 2016). The result is a body of research that conflates description of the actions of successful individuals with theory development

[9] E.g., Ogbor (2000) describes how collective action within the Civil Rights Movement to support, defend, and grow minority owned businesses is largely ignored in entrepreneurship research. Instead, those actions are treated as the domain of political rather than business or economic research: *"there seems to be a double rejection and a double acceptance of ethnic and/or racial issues. Although issues about race and/or ethnicity have been very prominent in the discourse, most of the existing research has treated the participation of minorities in entrepreneurial praxis as dysfunctional to theory development. What has been repressed or neglected in the discourse is how societal racial and ethnic biases have created the particular conditions in which minority business owners have found themselves"* (Pg. 619) They describe theory developed from societally dominant perspectives is used to study causes (e.g., economic and psychological) and processes of non-dominant entrepreneurship, sense-making from white-washed theory. *"Not surprisingly, over two-thirds of research on minority-owned businesses from 1962 to 1995 are prescriptive, describing programs to assist minority-owned businesses to act in ways prescribed by the dominant culture"* (pg.619)

(Arend et al., 2015). Doing so situates theory and tools, such as the heuristics in ToE, as scientifically correct rather than only representing a description of what a sample of people with power in society do (Arend et al., 2015; Ogbor, 2000).

2.2.1 How mythicization affects my study

Mythicization of entrepreneurship research provides two critical pieces of context for my dissertation. The first is in bounding how I can use existing theories that purport to explain entrepreneurial expertise. The second is in providing a list of potential influences on student thinking that my research must be attuned to. Third, mythicization provides a lens to understand how theory is used in existing engineering entrepreneurship education efforts.

First, mythicization suggests that researchers use of ToE to make meaning of novice entrepreneurs needs to be approached with caution. Prior to using ToE to describe novices, a comparison of novices' decision-making to the assumptions in ToE is important. One of those assumptions, that ToE explicitly assumes no errors in describing successful entrepreneur's decision-making, grounds my motivation for studying students' errors. The empirical measures of ToE described in the previous section ignore that assumption and adopt the approach critiqued in mythicization. That is, they focus on which heuristics are selected and do not evaluate why those heuristics are selected. Doing so embodies Ogbor's critique of treating the actions of successful entrepreneurs as inherently correct and in need of replication by novices to perform expertise (Fernandez & Duval-Couetil, 2017b). In engineering education, Huang-Saad (2018) problematizes blind adoption of entrepreneurship research when engineering entrepreneurship education adopts assessment tools – because research designs in entrepreneurship are heavily influenced by the mythicized entrepreneur and seeking to share their brilliance.

The second way that mythicization provides context for my dissertation through describing the types of myths, biases, preconceptions, and stereotypes about entrepreneurs that students may have been exposed to. While Ogbor focuses on mythicization in entrepreneurship research, Nicholson and Anderson (2005) provide a detailed list of narratives about entrepreneurs that are present in media. Lacking deep knowledge or experience with business formation, engineering students' base of knowledge *may* instead reflect these myths in the errors that they make in their entrepreneurial decision-making. For that reason, I use the description of myths about entrepreneurs as a lens to understanding student errors in the discussion chapter. Evidence that

students adopt and rely on myths about entrepreneurs in their decision-making has significant implications for entrepreneurship education and is not addressed in current literature.

The third role of mythicization is in helping to situate my study within the current work on introducing entrepreneurship into engineering education. Specifically, mythicization provides a lens into how and why certain problems with the use of entrepreneurship research in engineering education have become commonplace.

2.3 Literature on engineering entrepreneurship education

The extant body of literature in engineering entrepreneurship education demonstrates why my dissertation fills a critical gap in the field and illustrates specifically why looking at errors in students' entrepreneurial decision-making is important. The body of literature surrounding engineering entrepreneurship education continues to rapidly grow and seeks to address many facets of the development and practice of such curricula (Huang-Saad et al., 2018b; Purzer et al., 2016). However, both Huang-Saad and Purzer note specific problems that the field must address, and that my work is a first step towards.

It is useful to reconnect the theory of effectuation's genesis and the problem of mythicization to engineering entrepreneurship education. The theory of effectuation was developed from a study of expert entrepreneurs that presumes competent implementation of the strategies they select and seeks to descriptively differentiate their decision-making from that of other business experts without entrepreneurial experience. The expert-comparative and expert-descriptive approach to theory building is one manifestation of a set of common tropes that mythicize a heroic entrepreneur whose actions are inherently good and intelligent and who must be studied, understood, and taught. This section reviews the tendency of current efforts in engineering education to presume the transferability of such expert-comparative and trope laden theories in entrepreneurship literature. Papers reviewed in this section show how theory and measurement tools are frequently transferred *without* evaluating their validity with student populations, without considering the purposes of that theories' development, and without assessing assumptions about knowledge and expertise that are embedded in those theories (Huang-Saad et al., 2018; Purzer et al., 2016).

The following subsections focus on three aspects of the literature on engineering entrepreneurship education. The first describes the work and key findings of two metastudies of

engineering entrepreneurship education, which highlight the problem described in the previous paragraph. The second focuses on literature describing the development of educational interventions in engineering entrepreneurship education. The third describes empirical work on student and faculty perceptions, interests, and knowledge related to entrepreneurship and the associated role(s) that entrepreneurship should play in engineering education (Reeves et al., 2014). To explicitly reiterate, this section does not detail an existing body of work on which my work *builds*. Rather, it highlights a potential blind spot in existing work that my dissertation seeks to illuminate, and which may suggest approaching prior work with increased scrutiny.

2.3.1 The meta-studies

Helpfully, two recent meta-studies of engineering entrepreneurship education articulate concerns about the relationship between engineering entrepreneurship education and entrepreneurial theory. These articles, by Purzer et al. (2016) and Huang-Saad et al. (2018) both report on systematic literature reviews and focus on assessment practices. Both highlight that studies of engineering students' and entrepreneurship education have drawn on a wide body of theories of entrepreneurial expertise and have taken many research approaches. However, both also highlight that basic work to validate theories and tools transferred from other fields is frequently lacking and the adoption of those theories and tools is weakly defended. In this section I describe each meta-study and its key findings as they relate to my research.

Purzer et al., reviewed 29 articles that focus on methods of assessment that are found in literature focused on entrepreneurship education. They identified 51 different methods of assessment dominated by project deliverables (13 of 51) and self-report surveys (24 of 51). They frame their paper by noting that prior studies have found "a derth of high-quality instruments in entrepreneurship, especially those that are directly relevant to engineering and…classroom context" (pg. 4). In their findings they note that many of the self-report instruments were not developed for research about entrepreneurs rather than educational purposes. Further, the instruments are rarely tested on engineering students prior to being employed as a valid method of understanding engineering students' entrepreneurial learning. Constructs that the authors identified in self-report surveys included business planning, leadership, teamwork, communication, design, and entrepreneurial mindset (which they note has varying definitions). They noted that only 10 of 51 assessment instruments provided any direct evidence of validity, with 6 of those 10 focused

primarily on instrument development. At least 10% of the assessment tools were borrowed partially or directly from the business field.

Borrowing of knowledge and theories between disciplines is not inherently bad. However, if differences between fields are not attended to, can become an avenue by which the limitations of expert-comparative studies and mythicization in entrepreneurship research influence engineering entrepreneurship education. Purzer et al. (2016), focused primarily on process aspects of improving assessment quality, with their final recommendation being "Utilizing Research and Theoretical Frameworks" in more rigorous ways (pg. 31). Such an advocation is in line with general recommendations for assessment and research in engineering education, but the use of theoretical frameworks is an area of educational innovation where research suggests classically trained engineers struggle (Borrego, 2007b; Douglas & Purzer, 2015). Lack of comfort with theoretical frameworks and the research norms of other fields makes such borrowing a higher risk to research quality and potential blind spots about the applicability of findings or theories of entrepreneurship to engineering students.

Huang-Saad et al. (2018) built on concerns about disciplinary exchanges, norms, and goals. They focused more broadly on assessment of entrepreneurship research in higher education as a whole, but wrote specifically to the audience of engineering education researchers. They reviewed 359 empirical studies and looked at variables including purpose, theoretical basis, instruments and variables collected, and evidence of quality. Throughout, they repeatedly returned to the ongoing drift away from 'entrepreneurship' education being primarily grounded in business formation (Pittaway & Cope, 2007). Such a drift is trans-disciplinary as Pittaway and Cope describe, but is perhaps particularly salient in engineering education, which lacks the attachment to entrepreneurship research found in business schools. The drift is perhaps most visible in the emergence of the term *entrepreneurial mindset.* That term is reflective of the shift from business formation to learning how to think like an entrepreneur in many contexts as the foundational learning goal of many programs (Clough, 2004; Fayolle, 2013; Kriewall & Mekemson, 2010; Wheadon & Duval-Couetil, 2015). Such a drift tracks with the highly varied definitions of entrepreneurship seen in engineering students and faculty as well as the variety of program goals (Duval-Couetil, 2013; Reeves et al., 2014; Wheadon & Duval-Couetil, 2015).

In setting up their work, Huang-Saad et. al. detail the development of entrepreneurship education in business schools, from its cross disciplinary growth starting in the 1990 to its rapid

growth in engineering in the early 2000s. As do Purzer et al., Huang-Saad et al., note the variety of methods, theories, and influences – alongside a lack of defensible use of theory. They argue that prior work has committed a 'critical omission' by failing to analyze how theory is manifested in assessment or entrepreneurship education at large:

> none of these three papers detailed the current theoretical approaches being used to guide entrepreneurship education research, a critical omission as 'linking research to relevant theory' is one of the fundamental guidelines for conducting high quality education research (pg. 267)

Theory, in entrepreneurship, entrepreneurship education, and engineering entrepreneurship education are at the heart of Huang-Saad's study. They noted that only 50% of studies cited any theory as part of their work. Noting that they coded generously, they identified 153 distinct theories referenced 473 times in the approximately 180 articles that apply theories. The three most common theories were the Theory of Planned Behavior, Social Cognitive Theory, and Model of Entrepreneurial Events. Only the 3rd most common, appearing in approximately 2.5% of studies, is a theory specific to entrepreneurial action of decision-making. In total, only 11% of studies utilized any theoretical framework, with few using one specific to entrepreneurship or drawn from entrepreneurial research. Looking specifically at engineering education, only 1 study (of 26) explicitly employed a theoretical framework, 6 referenced some external theoretical framework, but 38% relied on an existing measurement instrument.

In their discussion, Huang-Saad et al., (2018) noted certain challenges in theory development and use that are inherent in any emerging field like engineering entrepreneurship education. However, they also noted the need for specific improvements – including warnings referencing clear links to expert-referenced and mythicization risks in entrepreneurship research. The authors state:

> Research housed within the multidisciplinary field of entrepreneurship reflects a wide range of research traditions and norms communicated through various publication venues. This systematic review offers an opportunity to identify the relevant publication sources, reflect on the different traditions and norms for scholarship across fields, and identify the most effective research strategies for entrepreneurship education research moving forward.

Their call is for greater theory – but also a greater focus on what is good theory. Good theory for entrepreneurship education cannot simply rely on theories to explain (or tell grand stories of) entrepreneurial expertise. They end by noting three specific implications for engineering

education. First, more than 2/3rds of articles they identified seek primarily to describe entrepreneurship programs – the most common purpose. Second, the lack of connections between theory and practice is present across entrepreneurship education, but especially prevalent in engineering education. Third, the range of variables, measures, and theories lacks a focus on cognitive growth and links to learning theory.

2.3.2 Entrepreneurship interventions in engineering education

The implications that Huang-Saad et al., noted directly connect to the current state of theory use in engineering entrepreneurship education and risks of mythicization and expert-descriptive theory development. Adoption of theory without evaluation persists in engineering education despite critiques of the theories and teaching them as *Fact* within the business field (Bridgman et al., 2016; Ogbor, 2000). As examples will highlight, connections between theory and practice are rarely interrogated, fully developed, or described. When evidence is collected, there are potential concerns with it. As the previously discussed meta-studies highlight, a large body of published work exists primarily to describe interventions created for engineering entrepreneurship education. Examples of these studies show how theories of entrepreneurship from management-centric scholarly work are used to create entrepreneurial learning in engineering. This section is not a critique of individual work in engineering education. Rather, it is meant to illustrate how the common tactic of adopting theories derived from studying experts manifests in engineering education. And, how it is rarely accompanied by attention paid to differences in disciplinary norms and/or theories not developed with education in mind – a concern expressed previously by Huang-Saad et al. and others (Fayolle, 2013; Grey, 2004; Huang-Saad et al., 2018).

2.3.2.1 Developing an entrepreneurial mindset

Kirkpatrick et al. (2016) used KEEN's '3C's' as a theoretical framework of entrepreneurial expertise to introduce concepts of entrepreneurship into a summer undergraduate program focused on design for underdeveloped countries. They describe the entrepreneurial theory they implement, termed *entrepreneurial mindset,* as follows under the heading *"developing an entrepreneurial mindset"*:

> Various authors have studied the skills and entrepreneur possesses that allow them to become successful. These have been found to include curiosity, an ability to see

> connections, and recognition of the possibility to add value. We propose to engage a student's curiosity, build connections between courses and real engineering, and help the students recognize the value in their classes and their own work. Curiosity as a trait has been studied and contemplated by many in an effort to employ curiosity to learning. In fact, some have divided the concept of curiosity into separate compartments including an "entrepreneurial curiosity". Research has also suggested that curiosity can help learning within an appropriate level of arousal. Too much arousal causes anxiety, not enough arousal causes lack of interest. We aim to keep the students "interested" hopefully without straying into the significant anxiety range. (pg. 2)[10].

Kirkpatrick et al. identified three areas of research on entrepreneurial processes – curiosity, connections, and creating value. These represent the so-called 3Cs that the KEEN network uses to define an entrepreneurial mindset (KEEN,2016). The term is also frequently employed in engineering entrepreneurship education (e.g., Rayess, 2016; Haynie et al., 2010). KEEN describes the 3Cs mindset as working in tandem with an engineering skillset to create entrepreneurially-minded engineers. Notably, the 3Cs definition represents an evolution of KEEN's earlier definitions of entrepreneurship, but no information on the scholarly process of that evolution is publicly available.

KEEN's earlier definition of an entrepreneurial mindset, however, can be found in work by Kriewall and Mekemson (2010). They visualized attributes of an entrepreneurial engineer using a pyramid – with engineers at the bottom, "intrapreneurs" in the middle, and entrepreneurs at the top. The three corners of the base represent "most engineers who graduate from college – those who are, in a traditional sense, 'just engineers'" (pg. 5). The three corners are: Technical Fundamentals, Customer Awareness, and Business Acumen. Business acumen, again. is presumed to be a characteristic of all existing engineering graduates. It is defined to include: basic understanding of business and finance, understanding of economics and capital, ability to assess and manage risk, leadership, understanding the role of management and organizational structure, understanding org, and making decisions with incomplete information. In describing the pyramid, and the associated areas of skill and acumen, no linkage is made to empirical data or other existing scholarly work:

> The added skill differentiating intrapreneurs and entrepreneurs from engineers is that intrapreneurs and entrepreneurs will have a keen sense of service to others and will constantly be concerned with how their solutions benefit other people. They will value and help promulgate the free enterprise system. Like all engineers, they

[10] Internal citations are removed for legibility.

> will value and promote high standards of engineering and business ethics. They will possess personal character attributes typical of entrepreneurs: intuition, integrity, tenacity, courage, and honesty (pg. 7)

KEENs articulation of entrepreneurial theory is widely used, but what makes it notable for my dissertation is its unambiguous and explicit employment of mythicization of an individual entrepreneur (Robert Kern, its founder) to build theory. It's wide use largely arises from the extensive role that KEEN plays in funding work throughout their network of partner schools to introduce entrepreneurial mindset into engineering education. An expectation of becoming a KEEN partner school, and associated funding, is the adoption of KEEN's vision and definition of entrepreneurial mindset. Kriewall and Mekemson provide background for their definition of entrepreneurial mindset by detailing the story of Robert Kern and the mission of the KEEN foundation to implement his vision for entrepreneurial education in engineering:

> Though the [KEEN] initiative began in 2005, the story of its origins, along with that of the Foundation, dates back to the 1950s, when Robert Kern, a young mechanical engineer, along with his wife Patricia and one assistant, started a generator manufacturing business in a garage in Wales, WI. Despite many setbacks, this business eventually grew to … one of the world's largest independent manufacturers of complete engine- driven generator systems. … Over the course of his leadership at Generac, Kern has upheld a culture of constant innovation, which has led to the company's success and survival through challenging times. … Kern recognized the threats to his business: a recession, an oil embargo, and increasing production of Japanese-made engines. He foresaw that Generac's survival in such an environment demanded a shift in its attention to a new customer base, so Generac began producing industrial-scale generators. Kern encountered challenges in finding native talent when implementing his business strategy; he was forced to recruit abroad in order to find innovative and entrepreneurial engineers. (pg. 7)

Kriewall and Mekemson's development of theory foregrounds Kern's entrepreneurial narrative and includes several specific themes (e.g., individual foresight, struggle, overcoming challenges, and hard work as a determinants of success). Those themes are explicitly identified as types of entrepreneurial myths that Ogbor and others describe. Kriewall and Mekemson's definition of an entrepreneurial mindset also mythicizes entrepreneurs' motivations:

> A common misconception of entrepreneurship is that it is motivated by personal wealth generation, sometimes referred to as greed. Perhaps for some generation of personal wealth is the primary motivation for innovation; however really successful entrepreneurs, even those who are in business to make money, are social entrepreneurs. (pg. 14)

However, the point of this section is to talk about how theory is *used* in engineering entrepreneurship education rather than a critique of the individual choices of which theory to use.

As noted, Kirkpatrick's course adopts KEEN's definition of entrepreneurial mindset as it's theory of entrepreneurial success. The 3C's & entrepreneurial mindset definition Kirkpatrick adopts is widely accepted within the engineering field as a framework for teaching engineers to be entrepreneurial (Huang-Saad et al., 2018; Purzer et al., 2016). KEEN as an organization funds and supports many engineering universities in introducing engineering entrepreneurship. That is not to suggest individuals bias towards funding agency's wishes or theory. Instead, the same mythization of entrepreneurs that Kriewall and Mekemson employed in theory building becomes a source of credibility to provide expertise in building curricula. Then, as Ogbor (2010) describes, the reuse (e.g., Rae & Melton, 2017) and continued study of a theory (e.g., Wheadon & Duval-Couetil, 2016) within academic literature creates a legitimizing effect. As the theory becomes accepted, its use by others becomes more easily defensible, and the cycle of legitimization continues.

2.3.2.2 Other theories of entrepreneurial expertise

Other examples of engineering entrepreneurship education use different theories of entrepreneurial expertise that highlight other problems with how theory is adopted and used. In addition to citing KEEN's theory, Kirkpatrick also introduces another theory about entrepreneurial success used by others to develop courses – the book *The Innovator's DNA* (Dyer et al., 2011). Neeley et al., (2016) use gaining five skills from *The Innovator's DNA* as foundation for developing entrepreneurial competence. The five skills are: associating, questioning, observing, experimenting, and networking. In their paper, Neeley et al. describe the definitions of each of the five skills from Dyer et al.'s book and then how their multi course engineering business minor seeks to develop those skills.

As with ToE, *The Innovator's DNA* again represents an entrepreneurial theory that is developed by the comparison of two groups of experts. Dyer et al. argue that the five skills they identify differentiate highly innovative and entrepreneurial business executives from other business executives (Dyer et al., 2011). Again, as with the development of ToE, Dyer et al. are explicit about the goal of differentiating two types of expertise. They are also quite clear about the deference with which they approach their study subjects "we stand in awe of visionary entrepreneurs like Apple's Steve Jobs… How do these people come up with groundbreaking new

ideas?" (Dyer, 2009). In their study they report what these visionary entrepreneurs[11] do differently than their less-visionary, but still successful, peer executives. Their goal is to generate a relative differentiation of two different types of expertise through their actions that individuals can use to amplify their existing business skills or develop a culture of innovational DNA in organizations that they lead.

In describing the genesis of their program, Neeley et al., (2016) express concern about reductionism in developing entrepreneurial education – i.e., entrepreneurship theories are reduced to composite skills. They specifically critique research by Mathis et al. (2014) that sought to unpack Innovator's DNA into specific teachable and assessable discovery skills.

> The authors [i.e., Mathis et al., 2014] present the results of a content analysis of innovation case studies that seeks to establish which of the discovery skills is used most often by experts as well as the order in which they are most often used. Their quantitative analysis does yield some suggestive results… such as "that educators look into spending more time on activities that use these skills and [f]aculty could have students practice Socratic questioning during team projects and presentations." While these conclusions and suggestions are reasonable, they are also generic and lack depth. (Neely et al., 2016, pg. 6)

In place of unpacking and teaching the skills in Innovator's DNA, Neeley et al. as a model for systematic education across many courses in the minor, and state: "By implication, the skills portray 'broad education' as a cornerstone not only of engineering education but also of education for entrepreneurship and innovation." (pg. 2).

The tension between Neeley et al. and Mathis et al. is in how to use the theory proposed in *Innovators DNA* to develop engineering entrepreneurship education. Neeley believes it to be useful directly, and structuring their program around encouraging the broad development and employment of skills differentiate visionary innovators and entrepreneurs. Mathis approaches the theory as proposing broad categories of differentiation that must be decomposed into individual teachable and measurable skills and concrete abilities. Notably, neither addresses the teaching of skills that are shared by both expert groups. The tension between Neeley and Mathis exemplifies the difficulty in building education from entrepreneurship research that describes differences between different groups of experts: When a theory is not meant to, and does not attempt to,

[11] More precisely – they ascribe organizational culture, organizational action, and individual action to the visionary individual. This represents another form of entrepreneurial myth – the conflation of the company and its founder.

describe skills shared by all experts or the learning process by which one type of experts differentiated themselves – how should educators use that theory?

2.3.2.3 No clear theory while developing curricula from theory

While the two examples above represent how engineering educators adopt theories of entrepreneurial expertise, they represent typical implementations in the field. Both Kirkpatrick and Neeley clearly describe the theories they use, a significant improvement that has been repeatedly called for in entrepreneurship education (Fayolle, 2013, Fiet, 2010). Beyond this typical usage of theory are examples at either end of the spectrum of theory use. Some examples provide no grounding in theories of entrepreneurship and examples that seek to address the need to unpack expert-comparative theories for educational use. The problem of engineering entrepreneurship education interventions that do not clearly ground their theory of entrepreneurial expertise is noted by both Huang-Saad et al. (2018) and Purzer et al. (2016).

Examples of the concern with poor theoretical grounding include work by Rayess (2016) and Chau (2005). Rayess describes the development of a first-year engineering design course. They state that the course design seeks to address calls for introducing "entrepreneurial attitudes to the everyday practice of engineering" (pg. 1). However, throughout their description of the course, its objectives, and its assessment, no further references to, nor description of, any theory of entrepreneurship is apparent. While some of the content reflects typified themes of entrepreneurial education, such as venture creation, their statement of course objectives focus on communication ("The course is intended to train the engineering student to communicate with customers/end-users and management.) and systems thinking ("The course is also intended to force the engineering student to think in terms of systems and not focus solely on particular technology details."). How these relate to or contribute to entrepreneurial development is not described in the paper. Similarly, Chau outlines a problem-based learning course to develop innovation and entrepreneurship skills. They note that the course has an "unstated objectives …of [apprenticing] students to a particular industrial working environment for development on entrepreneurship" (pg. 229). They provide no explanation of what innovation and entrepreneurial skills are, and no supporting justification about how they link to entrepreneurship.

At the opposite end of the spectrum, work by Makimurto and colleagues (Makimurto-Koivumaa & Puhakka, 2013), Makimurto-Koivumaa & Belt, 2016) directly connect theories of

entrepreneurial expertise to the development of entrepreneurship education. In situating their work, they explicitly articulate the relationship between entrepreneurship research and its relation to entrepreneurship education that they rely on (Makimurto-Koivumaa & Puhakka, 2013). They note that there must be a clear transition from research about entrepreneurship to research on what promotes entrepreneurship and eventually to pedagogies that support entrepreneurship. The end result of their paper is a model curriculum detailing the role of different areas of learning and the role that theories in each of those areas can play in scaffolding learning.

Later, Makimurto are unusually explicit in that they directly link their effort to develop entrepreneurship education curriculum to a theory from entrepreneurship research, specifically ToE (Makimurto-Koivumaa & Belt, 2016). They address directly how ToE describes of two types of expertise and note that both sets of heuristics can be valid and useful. They also note that both are complex and representative of a unique type of expertise. In applying their model curricula to ToE, they note that students, as novice or naïve entrepreneurs, must learn to use both types of heuristics proposed in ToE. They cite articles that propose the expertise Sarasvathy observed is more accurately placed in the ability to evaluate and adopt a situationally appropriate set of heuristics, rather than merely heuristics used by entrepreneurs (Shane & Venkatamaran, 2000; Fisher, 2012; Haynie et al., 2010).

2.3.3 Engineering and perceptions of entrepreneurship

In parallel with literature about implementing theories from entrepreneurship in education, there is a body of work in engineering that looks at student and faculty perceptions of entrepreneurship. These beliefs and perceptions are important as they represent precursors and pre-requisite knowledge that frames students' decision-making. However, results in this area of research also highlight several problems mentioned earlier. First, they show that the primary outcomes students and faculty perceive from entrepreneurship education are often unlinked from business formation, exemplifying some of the concerns about how theories of entrepreneurship are used. Second, the beliefs and perceptions by students, educators, and even researchers at times incorporate myths about entrepreneurs. Doing so is not a critique but rather simple evidence that these individuals exist in a society where they are exposed to particular narratives about entrepreneurship. However, if there is evidence that these narratives affect students, it *does* suggest

the critical importance of framing entrepreneurship education in a way that does not presume the only goal is filling gaps in knowledge.

These studies are useful to my dissertation because they connect the work reviewed up to this point to the final section of my literature review – misconceptions and conceptual change. The available research suggests that student (and at times faculty) perceptions and beliefs related to entrepreneurship align with the myths described earlier, and generally take a highly summative approach to theories of entrepreneurial expertise in studying beliefs and perceptions.

At a foundational level, Reeves et al. (2014) directly examined at faculty and student definitions of entrepreneurship. The study asked students who self-selected in to entrepreneurship education courses in pursuit of a minor in entrepreneurship to respond to a survey, with analysis focused on one question "in your own words, without referencing any online material, define entrepreneurship". They found that engineering students definitions were more likely to include financial and intellectual independence than instructors, as well as more likely than instructors to explicitly include starting a business. Conversely, faculty were more likely to aspects typically seen as necessary to start a successful business, such as opportunity recognition, resource management, and taking action. Overall, the manifestation of what was created suggests students' views are relatively simplistic (e.g., "entrepreneurship is starting and developing your own business" pg.5) in comparison to faculty. Students were more likely to specify the creation of a business, but less likely to mention the creation of a product, service, or other form of venture. Conversely, faculty surveyed typically mentioned business or venture formation alongside the creation of a product or service. The findings suggest that definitions are consistent with generally accepted conceptions of entrepreneurship, but that faculty and students' answers differed in ways that reflect their level of personal and professional experience with entrepreneurship. What these definitions do not answer, however, is what engineering students perceive themselves as gaining from their entrepreneurship education experience.

Work by Taks et al., (2014) in the *Journal of Engineering Education* focuses on what learning outcomes occur, and in doing so directly demonstrates how differences in theory building between engineering and entrepreneurship can introduce some of these problems. They performed a phenomenographic analysis of students experiences in completing an entrepreneurship course. In describing what is taught in the course they explain that:

> Conceptual theoretical knowledge is explicit, universal, and formal in nature. In other words, it contains concepts, theories, and other types of information that can be easily accessed in texts or presented by the teacher to bring about deeper understanding. (pg. 575)

They described the conceptual theoretical knowledge component of their course as including:

> Entrepreneurship, organizational and management theories, idea and opportunity creation, using reading and writing tasks, analytic tasks beginning with team activities, followed by feedback and reflection (pg. 577)

While their study is about students' perceptions, these two statements link the prior section identifying risks when theories are used to build courses. No specificity about what theories, their presumptions, developmental population, or component knowledge is specified in the paper – but such detail is largely out of their scope. However, that makes it difficult to understand what the content of the knowledge proposed as *explicit, universal, and formal* is, pre-requisite knowledge that is necessary to learn that knowledge, and the credibility of the sources of the knowledge.

In their findings, they identify four categories of growth that occurs through completing entrepreneurship education. Those categories include steps towards self-directed learning (e.g., learning how to learn information about a new topic independently), preparation for professional work (e.g., reading research papers & applying analytical techniques to make decisions), paths to self-employment (e.g., being prepared to start a company), and developing leadership competence (e.g., how to lead a multidisciplinary team). They authors noted some gender differences in outcomes, especially male students entering with a greater sense of confidence and plans for self-employment. That gender difference is similar to gendered aspects of entrepreneurial myths (Wheadon, M. & Duval-Couetil, 2016).

The study highlights the variety of learning that can result from experiencing entrepreneurship education – but depends on self-reports about content knowledge. Towards their professional work category, the authors observed that many participants "considered starting up one's own company unrealistic, but saw the skills acquired in the course extremely useful due to their relatedness to real-world activities (Taks et al., 2014, pg. 585). Such a finding generally aligns with the stated goals of many modern engineering entrepreneurship education programs (Duval-Couetil & Reed-Rhoads, 2012). While they do not evaluate actual mastery of concepts, they note that students self-report that the experience helped them understand management issues and the internal functions of a company. Such self-reflection is important, but as discussed in Purzer et al.

(2016) – it is important that self-reports be paired with data establishing levels of mastery as part of the assessment process.

The findings in Taks are generally consistent with other research in engineering education. Work shows that faculty believe an entrepreneurial mindset is useful to engineering students whether or not they start a business (Zappe et al., 2013b). Those faculty noted issues with prior knowledge about basic business concepts as one challenge, and see outcomes like greater comfort taking risks as a more important outcome than actually starting a business. Work by Duval-Couetil and Wheadon (2013) looked at recent alumni, triangulating Taks' research on students and Zappe's on faculty. They focused on what value recent alumni perceived from their entrepreneurship education experiences, and how that value has contributed to their career development. The findings identify several general outcomes including self-efficacy, self-directed learning, problem-solving, and communication. Students mentioned outcomes that seem unquestionably important – including team work, help obtaining a job, and seeing the big picture of their work. Some students mentioned an entrepreneurial mindset explicitly. The results show concrete evidence that engineering students believe their entrepreneurship education experiences were valuable. However, the value achieved does not align with or emerge from theories of entrepreneurship that focus on how to best make business decisions.

That type of misalignment is important because it suggests a need for different theories to inform engineering entrepreneurship education to maximize the value students perceive. Rather than the perceptions being in anyway wrong, students' perceptions reflect that entrepreneurship education may be employing the wrong theories to help them achieve the maximum value in the areas where entrepreneurship education is proving useful. The perceived value students achieve differs from their definitions of entrepreneurship – begging the question of whether theories should align with their definitions of entrepreneurship or the learning outcomes they most value. Just as critical is Zappe et al.'s (2013b) finding that pre-requisite knowledge about business is significantly lacking.

No identifiable studies of engineering students' perceptions explicitly explore students' perceptions of their business knowledge and skills. The existing studies, instead, take an emergent approach to what students see as important. This leaves a still gap around what engineering students know, don't know, and are wrong about in regards to business and entrepreneurship.

Drawing from other areas of engineering education, unpacking concerns about pre-requisite knowledge through the lens of misconceptions and conceptual change may be beneficial.

2.4 Misconceptions

The final area of prior research that is helpful to frame my dissertation is a specific class of error that is referred to in educational research as a *misconception*. Misconceptions refer, informally, to errors that are not made based on lack of knowledge but rather because of some prior knowledge that is incorrect and operationalized to draw incorrect inferences about a topic. Formally, I adopt Chi's work that defines misconceptions as ontological miscategorizations of concepts wherein an ontological shift is necessary to achieve a correct understanding (Chi, 2005). Work to correct such miscategorizations generally frames the shifts as *conceptual change* to reflect the need to *change* extant beliefs or models of the world as opposed to 'simply' filling in a gap in one's knowledge (Chi, 2008a; Henderson et al., 2018). In the following two sub-sections I review educational theory that has developed the modern explanation of and processes for studying misconceptions and then review foundational work on misconceptions that engineering education.

The work on misconceptions provides a tool to assess links between the errors I identify in my study and research on mythicization of entrepreneurship and existing work on engineering students' entrepreneurial knowledge. As described earlier, mythicization of is a social phenomenon about cultural representations of entrepreneurs and entrepreneurship - not purely a research problem. As such, myths about entrepreneurs in media and in society represent information about entrepreneurial concepts that engineering students may be exposed to, and which may explain some errors. Identifying myths about entrepreneurship that create misconceptions on which engineering students rely can aid the educators and educators. Such a use of misconceptions about thermal concepts, forces, physics, and circuits have been extensive and proven useful (Streveler et al., 2008). However, no identifiable work has sought to identify misconceptions that engineering students have about entrepreneurship. Instead, as described in the previous section, much of engineering entrepreneurship education work adopts expert-comparative theories of entrepreneurship that focus on what one does over why (Haynie et al., 2010). For these reasons, I return to the discussion of misconceptions in the discussion chapter as one tool to interpret my results.

2.4.1 Misconceptions in educational theory

The study of misconceptions has a relatively long history. One of the earliest studies to use the term misconception to define a specific type of error is Tversky and Kahneman's (1974) study of statistical reasoning. They found that many people rely on probability heuristics that mis-implement basic statistical concepts. One example of a misconception they identify in human heuristics is of the chance of individual outcomes – conflating essential characteristics of a coin flip with how a series of coin flips will play out.

In particular, there are interesting characteristics of Tversky and Kahneman's early work on misconceptions for my study. First, they identified that certain misconceptions were equally likely to appear in the thinking of expert statisticians and those with no statistical knowledge (Tversky & Kahneman, 1974). Second, the appearance of the misconceptions was much more likely when used as a thinking tool towards some larger goal as opposed to when asked to directly address a question where the heuristic would result in the wrong answer. For my dissertation, those characteristics reinforce the need for caution with using expert-comparative theories of entrepreneurship that assume competent execution. They also suggest the need to look indirectly for misconceptions in realistic thinking exercises (Chi, 1997; Ericsson & Simon, 1998). The need to be conscientious about how conceptual understanding is measured is highlighted in the difference between the technique for engineering entrepreneurial assessment discussed in the previous section, and work in engineering education to develop concept inventories to measure misconceptions (Jorion et al., 2015; Streveler et al., 2008).

Over time, misconceptions research has settled on the aforementioned phrase *ontological miscategorizations* as a key marker of misconceptions. By ontological miscategorizations, Chi is describing situations where someone assigns a concept to a category of reality (e.g., events or objects) that is misaligned with its fundamental attributes (Chi, 2005; Chi et al., 1994). Chi uses examples such as "a canary is an hour-long" (1994, p. 30) to illustrate what a miscategorization looks like when written out as opposed to being employed in abstract thought. The illustration highlights what Tversky and Kahneman observed – the difference between misconceptions employed in thinking and misconceptions directly encountered (Chi et al., 1994; Tversky & Kahneman, 1974). As a proposition for explaining the types of miscategorizations that can occur, Chi use a taxonomy of processes, matter, and mental states to demonstrate specific miscategorizations from example studies. That taxonomy helps explain many miscategorizations

in physics such as the treatment of processes in physics as an inherent property of matter by children (e.g., red is hot). The identification of miscategorizations, in this way, relies on establishing the compatibility or incompatibility of a naïve conception of a concept with an objectively true or expert understanding of the nature of the conceptual phenomenon (Chi et al., 1994). While specific categories of ontological miscategorization are mentioned, those are not exclusive categories of ontologies for which misconceptions can exist.

One specific ontological miscategorization that has seen significant focus is students' understanding of processes. Misconceptions between sequential processes and emergent processes have been identified as particularly robust (Henderson et al., 2018; Miller et al., 2006). Henderson et al. describe sequential processes as one wherein steps are inherently coordinated, preplanned, and organized with a stable end goal whereas emergent processes are those processes wherein the coordination of events is ad hoc, independent, and *emerges* from the combination of many different actions (Henderson et al., 2018, p. 28). The authors note that "More specifically, there is a tendency for learners to assign predicates to a sequential process ontology when they should be conceiving of these attributes with an emergent process ontology instead." (pg. 27). Henderson et al. suggests misconceptions around sequential and emergent ontologies are particularly robust (and common) because they occur over time and can be difficult to fully link to learners being far more familiar with sequential ontologies than emergent ones. The result is that when a new process is observed, its basic entities are mapped to the dominant sequential ontology. Notably, this description is quite similar to some of the myths about entrepreneurship – particularly the idealization of a successful entrepreneur as the person who make success happen as the leader of a sequential process without consideration of the outside factors that may have led to the emergence of a successful venture independently. Process misconceptions are particularly interesting to entrepreneurship because entrepreneurship occurs over extended time, interacts heavily with contextual factors, and has generally resisted meaningful assignment of probabilities of outcomes – making cause and effect study difficult (Knight, 1921; Sarasvathy, 2001).

Because misconceptions relate to miscategorizations rather than lack of knowledge, a different terminology for addressing them is necessary, with the term conceptual change being widely adopted (Chi, 2005; Streveler et al., 2008). Conceptual change refers to the process by which ontological miscategorizations are corrected and the incorrect ontological predicates that students rely on are addressed to eliminate incompatible concepts or "a change in the explanatory

framework from one ontology to another" (Chi et al., 1994, p. 42). She also identifies three potential processes by which conceptual change can occur to address misconceptions: Belief revision, mental model transformation, and categorical shift (Chi, 2008). Each addresses categories of learning that do not begin with an absence of knowledge nor end through the addition of new knowledge, as such approaches are unlikely to affect the underlying misconception. Chi (1994) also suggests conceptual change as particularly appropriate as a theoretical lens to understand seemingly contradictory results from studies of learning as well as a design tool for use to measure and arrange curricula.

In engineering education, both the study of misconceptions and discussion of conceptual change have found significant purchase because of the necessity of engineers integrating knowledge and processes (Streveler et al., 2008). However, studies of misconceptions, conceptual change, or even the nature of conceptualizations of entrepreneurship are largely absent (Haynie et al., 2010). A likely predicate ontological predicate to such conversation is reconsideration of the epistemic tenants of entrepreneurship research and faculty' conceptualizations of teaching, as some have argued (Bridgman et al., 2016; Fayolle, 2013).

Theories of conceptual change and misconceptions are particularly important to my dissertation as a link between students' errors, mythicization, and ToE (as an example theory of expertise). At a broad level, my research purpose of looking at errors informs whether ToE's assumption of competent heuristic execution is responsible with students, much less experts (Haynie et al., 2010; Tversky & Kahneman, 1974). If it is established that it is not, a key question is are students' errors due to lack of knowledge or are related to ontological miscategorizations about the nature of entrepreneurship. One potential source of miscategorizations could easily be the myths described earlier, which provide a source of knowledge about entrepreneurship employed in society and by media that engineering students are exposed to. However, despite the large body of work on misconceptions in engineering, described in the next section, and on engineering students as entrepreneurs, described in the previous section, integrating the two is a novel approach.

2.4.2 Misconceptions in engineering education

A significant review of work on misconceptions in engineering was performed by Streveler et al. (2008). In the review, the authors first review foundational studies on learning conceptual

knowledge. Then, they review literature on concepts that have proven difficult in the process of learning engineering. Two areas of that literature, studies to identify specific misconceptions or conceptual difficulties in engineering, and of tools to measure those with engineering students, are useful to my dissertation.

Work on misconceptions or conceptual difficulties in engineering have generally focused on three areas – thermal sciences, DC circuits, and forces (Streveler et al., 2008). While Streveler categorizes existing work by conceptual area, it is important to note that the underlying misconceptions often reflect students' mis-assigning fundamental attributes of those concepts in ways that change their processes of action as well (Chi, 1994, 2005). That is, the concepts where misconceptions occur are interwoven with students' understanding of processes.

While prior work in engineering education has focused on specific concepts, other areas of misconceptions research have identified process misconceptions as equally important (Chi et al., 1994). Streveler et al. note that in each of the areas mentioned, there exists a large body of work identifying and cataloging misconceptions that often predate work in the area in engineering education. They highlight work by Duit that lists a "massive bibliography of student misconceptions" (pg. 285) and includes hundreds of articles on thermal science misconceptions alone. While many of those articles study students who are not yet begun engineering courses, other work shows that many of the misconceptions are maintained by engineering students (Miller et al., 2006). Rather than a broad review of the many studies, here I focus on key examples that highlight characteristics of the work in the field.

One of the misconceptions that Streveler et al., (2008) highlight is proportionality of force and velocity as opposed to force and acceleration and connect it to the observable characteristics of human interactions with objects:

> Perhaps the most widely cited misconception in mechanics pertains to the student belief that force is proportional to velocity (Clement, 1982). According to this belief, bodies are naturally at rest, and external exertion is necessary if they are in motion. Such a belief is not in the least surprising. Everyone has the experience of pushing an object along the floor, applying a force even to move it at constant speed. The obvious interpretation is that force causes velocity, and the body stops moving when no force is applied. (Streveler et al., 2008, pg. 283).

Clement's (1982) work used data from written tests and video taper problem-solving interviews. He describes first-year science and engineering students as relying on a set of prior beliefs about phenomenon he labels "conceptual primitives" (pg., 66). However, no discussion of

ontological miscategorization was yet present, or necessary, in studying students' errors. The conceptual primitives about force and velocity that Clement identified are particularly important in statics courses, often one of the first courses that a student takes within an engineering department (Steif, 2004). Steif builds on the preconceptions identified by Clement and develops a broader set of errors and misconceptions observationally from his "man years of observing student errors in statics" (pg. 4). The result is a list of errors and misconceptions about forces that are common in students taking engineering statics courses. Steif linked several to misconceptions identified in earlier courses in introductory physics – suggesting that many are robust across multiple courses.

Like Steif and Clement's work, Adam et al., (2016) demonstrates observational approaches to identifying errors and misconceptions are common. The authors performed a detailed analysis of engineering students' process of solving one rolling dynamics problem. They note in their methods the use of a think aloud protocol "to get a multitude of rich explanations from the students" (pg. 6). Adam et al. see the rich explanation as critical to understanding and exposing misconceptions – noting that they are typically best understood in the context of their use. Such deep exploration of thinking to identify errors and misconceptions is one common use of think aloud protocols (Chi, 1997). The use of think aloud protocols provides an interesting link between misconceptions and Sarasvathy's ToE work, with both relying on rich data about thinking that is placed in a realistic context to understand and identify the underlying patterns of thinking without pre-selecting frames that assume correct and rational behavior (Simon, 1957; Simon & Ericsson, 1980). Whether the thinking is right, as in ToE, or wrong, as in Steif; Clement; and Adam - observing work on complex or multistep problem solving is a powerful tool to unpack conceptual understanding. Adam et al.'s work is notable in being a qualitative analysis of engineering students' misconceptions, which are largely absent in literature. While prior studies on similar problems using physics students exist (Bowden et al., 1992), Adam et al., do not rely on pre-existing lists of misconceptions and generate engineering specific ones.

While similar to the work around force misconceptions, the thermal science misconceptions literature in engineering education is useful for highlighting an ongoing area of development in misconceptions literature and its limitations. Examples of misconceptions about thermal sciences include the conflation of heat and temperature as equivalent, temperature as a determinate of how something feels to the touch, and expectation of temperature changes during a

phase change (Streveler et al., 2008). As with the work on forces, much of the work on thermal science misconceptions in engineering education relies on lists of misconceptions identified by other sources. Using such lists, scholars seeking to assess whether engineering students possess and retain the misconceptions during courses that should disrupt them (Miller et al., 2006). Miller et al. used the Thermal and Transport Concept Inventory (TTCI) to study engineering students, with the results showing that many retain misconceptions from prior coursework throughout their engineering career. In one example, 30% of senior chemical engineering students employed a misconception equating temperature change and heat change.

The TTCI represents one of a class of instruments called *concept inventories,* that are specifically designed to measure conceptual misunderstandings (Jorion et al., 2015). Exemplified by tools like TTCI and FCI, concept inventories represent a tool in engineering education to quantify the presence and correction of student misconceptions and also a curated list of known errors. The work by Steif, described earlier, linked many of the errors he identified to concepts covered by the *Force Concepts Inventory* (FCI) (Hestenes et al., 1992). Other work to develop engineering specific concept inventories is ongoing with the *Heat and Energy Concept Inventory* (HECI) one example (Prince et al., 2012). The HECI development process is clear on the importance of a pre-existing list of errors and misconceptions for the development of high-quality test items. In the item development stage Prince et al., relied on pre-existing work to identify conceptual misunderstandings to test. The HECI, as well as work on a statics concept inventory, are part of a process of developing concept inventories that are more specific to engineering than existing tools like the FCI and TTCI (Steif & Dantzler, 2005).

The precision of language in engineering education misconception work is worth noting. Frequently, the terms *error* and *misconception* appear to be used interchangeably, with both error and misconceptions being connected to work by Chi and others defining the phenomenon. Such usage is apparent in Steif's (2004) work. In that work, observations are written as a list of errors, with the later classification of certain errors as misconceptions not being described in detail. The work by Adam et al., (2016) similarly adopts the term misconceptions but does not define it. Streveler (2008), and Miller (2006) describe the links between the term misconception and work in conceptual change described by Chi, but again do not introduce a formal or explicit definition of misconception into the literature – nor separate misconceptions from what some call simple errors. Of the work reviewed in this section that is published in engineering education outlets, the

only one that explicitly defines misconceptions is the HECI development work (Prince et al., 2012). The HECI work details the ontological miscategorization definition from Chi. Chi also notes that flexibility in language about what is a misconception has been common in related research, which was a motivation for developing a clear definition (Chi, 2008a; Chi et al., 1994). These examples highlight one role that misconceptions play in engineering education, identifying and classifying a specific type of common errors, while also highlighting a potential weakness in how precisely key terms (e.g., misconception) are used by the field.

In that way, the articles above also help illustrate how my dissertation connects to and expands existing work on misconceptions in engineering education. My study shares key characteristics with existing work in the field – using qualitative think aloud protocols to identify misconceptions that are relevant to engineering learning. The existing work also highlights misconceptions about processes – especially ones where what is directly observed can mislead about realistic ontological properties and properties of emergence (Miller et al., 2006; Prince et al., 2012). These process misconceptions are similar to the manifestations of entrepreneurial mythicization described earlier. That is, the observable characteristics of entrepreneurs being treated as causal in place of process related reasons that can emerge from individual decisions (Ogbor, 2000; Omid, 2000).

However, two aspects of my study are important to acknowledge to appropriately situate it in the existing misconceptions literature. First, it was not designed to identify misconceptions. The effort to identify errors and potential misconceptions emerged during the analysis phase. Second, all other areas of known research that have identified misconceptions have looked at concepts related to natural phenomenon. Those fields are characterized by an objective treatment and external characteristics of the relationship between researchers and their subject (i.e., truth). In these fields, truth (e.g., the correct form of the fundamental laws of thermodynamics) is truly independent of the researchers. However, the epistemic and ontological basis for truth is an open question in the field of business and management (Ogbor, 2000). While researchers typically treat the field as similarly *scientific*, many including Ogbor would disagree. Philosophical bases aside, the discussion of errors relies on establishing a defensible identification of truth, and labeling errors as misconceptions relies on clearly establishing defensible ontological categories from which someone is deviating. That business and management concepts are not natural phenomenon does

not change the ability to clearly establish appropriate and inappropriate ontological categories in entrepreneurship. These issues are further addressed in the discussion.

3. STUDY DESIGN AND METHODS

To answer the research question posed in Chapter 1, this study used a verbal protocol method of collecting data and an emergent thematic analysis approach to analyzing it. The details of those approaches, their grounding in existing literature on studying student thinking, and information about the study sample and epistemic perspective are organized into 5 major sections. First, I describe the context of the study, including the population and the sample of engineering undergraduates with whom data was collected. Second, I describe the data collection, including the history and development of the verbal protocol and the specific processes used during the protocol collection process. Third, I describe the epistemic perspective used throughout the analysis. Fourth, I describe the analytic method itself, including the overarching methodology (thematic analysis), the specific actions I took in each stage of the methodology, and how those actions align with guidance for conducting thematic analyses. Finally, I address my potential bias as a researcher and steps taken to ensure the trustworthiness of the results. Hereafter, I use the term *participant(s)* specifically to refer to students from whom data was collected while *students* refers to the general population of engineering students. All data collection occurred using an IRB-approved protocol.

3.1 Study context

3.1.1 Population

The population for the study included undergraduate engineering students from two institutions in the Midwest. The choice of multiple institutions increases diversity in the data set and broadens the potential to understand how patterns of errors might manifest differently, or different patterns might emerge, among engineering students with varying undergraduate experiences.

The first institution is a small college specialized in teaching engineering[12]. It has approximately 2,000 coed students and was founded in the late 1800s. It has maintained a high-level ranking against peer institutions in most national rankings of engineering programs for at

[12] For the purposes of blinding both university populations, I am not providing citations to numerical data about the two universities where data collection occurred.

least the last 20 years. The college's demographics are typical of undergraduate engineering programs, with a majority white and male population and drawing a plurality of the population from within its state. The college has multiple opportunities for entrepreneurship learning. These include an entrepreneurship minor that embedded in school's engineering management program. It instructs approximately 40 students from various engineering majors per semester. The minor requires completing five courses; two required and three electives. The college also has an entrepreneurship living and learning community and on campus funding opportunities for student ventures.

The second is a large, research-intensive, doctoral granting, public university. It has approximately It has approximately 33,000 undergraduate coed students (~30% engineering) and was also founded in the 1800s. It has historically maintained a high-level ranking in most national rankings of engineering programs against peer institutions. The university's demographics in engineering programs are similar to undergraduate engineering programs. Unsurprisingly for a public institution, it draws the majority of its undergraduate population from within its state. The university has a multitude of opportunities for entrepreneurial learning. Prime among these, is an entrepreneurship certificate program, which is open to all majors. The certificate requires, 2 introductory courses, 2 elective courses, and a capstone experience. Approximately 400 students per semester begin the certificate program via enrollment in the first of the introductory courses. The university also has many other programs including business plan competitions, pitch competitions, faculty entrepreneurship support, and others. The program is administered through the provost's office, but house in and operated by a center for entrepreneurship with a sizeable staff.

For the purposes of my study, the population was defined as any student enrolled in an undergraduate engineering program at one of the two institutions. Within that population, students are divided into sub populations based on two dimensions; (1) their institution, and (2) entrepreneurial learning experience at that institution. Recruitment did not consider the number of completed entrepreneurial courses – only none or not none. Those two dimensions result in four sub populations (see Table 2). Recruiting sought to balance the number of participants purposefully across the four sub populations.

While the diversity is useful to my purpose, the balancing of participants among populations was intended for other uses of the data set that are beyond the scope of my study and did not occur for statistical power or other comparative reasons.

Table 2 Subpopulations for purposes of recruiting

Entrepreneurial Coursework	University	
	Public	**Private**
Yes	Sub-population 1	Sub-population 2
No	Sub-population 3	Sub-population 4

3.1.2 Recruitment and sample

Recruitment of participants occurred via emails sent by faculty members in engineering and entrepreneurial teaching roles at both universities. Faculty forwarded an email to their students (Appendix 2: Recruitment email) inviting students to a study of 'thought patterns that engineering students employ as they solve problems.' The email did not mention entrepreneurship in an effort to reduce self-selection bias in the sample. Any student who responded was contacted by a study facilitator to coordinate an in-person data collection session at their university. They were provided with a consent form draft in advance, and then a process of informed consent and consent documentation occurred in person prior to the interview. While some potential participants did not respond to the scheduling email from the study facilitator, all students who scheduled an interview attended, completed the study, and are included in the participant pool.

The sample represented highly varied amount of entrepreneurial education, exposure, and experience. However, as noted in the introduction, the collection of protocols from a diverse sample of students was not motivated by making formal comparisons across the levels of experience[13]. Rather, protocols from a diverse sample (e.g., with and without completing entrepreneurial coursework) increases the opportunity to capture errors in those who are not completely naïve. Observing some errors might necessitate, for example, that students are aware a concept exists to use it improperly. In my study, the collection of protocols includes engineering students with variable experience, education, and exposure to entrepreneurship serves my research question by diversifying the types of errors that may be observable. Students with no experience

[13] Comparative analysis based on demographics, education, exposure, interest, experience, and other variables is an important future goal that can utilize the results of this research, as is described in Chapter 5.

or exposure to entrepreneurship might not make errors on business and marketing concepts because they are simply unaware of the concepts. Students with some exposure, or exposure to the specific entrepreneurial myths described in the literature review, might select the wrong concept or might use the concept improperly. Similarly, students with more experience might be aware enough to select an appropriate concept but make errors in its implementation. Because the purpose and research question in my dissertation is focused on identification and is descriptive, rather than comparing who makes what error, the diversity in student experience serves the goal of diversifying the types of errors that may be identified and classified.

A breakdown of the final participant pool using the sub population groups appears in Table 3, but a binaric breakdown of course exposure does not fully represent participants' entrepreneurial exposure and experience. The amount of entrepreneurial coursework participants had completed varied from one course to a completed entrepreneurial certificate program. Other aspects of entrepreneurial exposure were also collected via a survey after protocol collection. Of the participants, 11 self-identified that they had a family member who was an entrepreneur, 19 self-identified having a friend who was an entrepreneur, and 5 self-identified as having entrepreneurial experience. Participants self-identifying as having direct entrepreneurial experience noted starting a lawn mowing business, producing aftermarket vehicle components, developing an app, and being a resident assistant for an entrepreneurial learning community. Conversely, participants who did not self-identify as having entrepreneurial experience included participants who worked at a venture capital firm that invests in startups and a student who flipped used cars as a side business. Further, 38 of 40 reported having completed an engineering internship. Participants' average age was 21.4, aligning with junior- and senior-aged U.S. college students. The sample included 28 (70%) male and 12 (30%) female participants. That gender ratio is not different ($\chi^2(1,40) = 1.49$, $p = .22$) from available data on the gender ratio of engineering students (e.g., 22% of 2018 B.S. engineering degrees were awarded to women [Roy, 2019]) and the gender ratio of the two institutions. Data on race and ethnicity were not collected.

Table 3 Participant breakdown by school and coursework

Entrepreneurial Coursework	University	
	Public	**Private**
Yes	10	8
No	10	12

3.2 Data collection

This section describes the verbal protocol used to collect data, including its history and modifications made for this study and the protocol collection process used. For both the protocol and the collection process, data collection decisions were grounded in the previously described work by Sarasvathy (2008). Throughout this section, any deviations from Sarasvathy's methods are described.

3.2.1 The verbal protocol

The protocol used was derived from the protocol created by Sarasvathy (2008) for a grounded theory study of experienced entrepreneurs' decision-making. In entrepreneurship, verbal protocols are increasingly used as a tool to study decision-making of experienced entrepreneurs (Sarasvathy, 2008). Verbal protocols have also been used in engineering education to compare the design practice of students and experts (Atman et al., 2007) and assess conceptual and procedural knowledge using the same data set (Engineering, 2007). The methodological history of verbal protocols is notable in my study specifically because Sarasvathy's mentor in conducting the original research study was Herbert Simon, who is commonly identified as one of the original developers of the verbal protocol method. The study protocol (see Appendix A) is a modification of Sarasvathy's protocol originally developed to compare engineering students' thinking to the experienced entrepreneurs in Sarasvathy's study (Wheadon & Duval-Couetil, 2016). Wheadon and Duval-Couetil modified the protocol in two ways for use with engineering students. First, they shortened the length due to concerns about study fatigue. Second, they removed several tasks that pilot testing showed did not effectively capture the thinking processes used by engineering students. The protocol contains 9 tasks (see Figure 1 for an example) that participants work through within a single context: starting a business to develop and commercialize an entrepreneurship education video game. The protocol is similar in concept and layout to case-study pedagogy, a common tool in entrepreneurship education (Bridgman & Cummings, 2016).

To support the tasks given to students, at several points in the protocol, participants were given information. Participants could use that information to complete the tasks, but were not required to. Sarasvathy's prior work, described in the literature review, identified critical differences in whether or not experts used that information. While expert business strategists in

Task 3: meeting payroll

With a little bit of money that you've saved, you have started building the company. You priced the product at $80 and you are selling about 300 units per month. Feedback from customers makes you think that with a few improvements, you could sell at $140 per unit. Creating the prototype for the new product takes you to the limit of your available funds.

You estimate that you'll be short around $50,000 to continue payroll for the next 3 months necessary to get your new prototype into a big-time computer game convention, where you will be able to make connections with people from the industry and greatly boost sales.

You have 4 options:

- Borrow from your spouse's (or significant other's) parents – they aren't super wealthy, but could scrape together $50,000.
- Borrow from old college and work friends.
- Convince your parents to take out a mortgage on their house.
- Convince your employees to wait out the period without pay.

Why did you choose the option that you did? What makes other options less attractive?

Figure 1 Example of one task from the verbal protocol

her study carefully analyzed the information provided in the protocol for meaning and patterns, expert entrepreneurs dismissed the information as not useful (Sarasvathy, 2008). By extension, Wheadon and Duval's (2016) modifications sought to highlight this choice in student participants. Overall, the topics covered in the verbal protocol tasks included:

- Choosing between early-stage funding options
- Assessing, evaluating, and using market research
- Deciding between exit opportunities
- Making product development decisions

3.2.2 Protocol collection process

The protocols were conducted in person and matched Sarasvathy's (Sarasvathy, 2008) study when specific procedures were such information was specified. When Sarasvathy did not specify procedures, researchers relied on literature for suggestions on best practices (e.g., Chi, 1997; Ericsson & Simon, 1998). Two facilitators conducted all of the protocols with one collecting 33 and the other collecting the remaining 7. To minimize potential differences between the two facilitators' administration of the protocols, the administrators practiced the protocol with each

other and listened to each other's recordings to standardize facilitation (e.g., the frequency and form of reminders to participants to verbalize their thinking).

In keeping with Sarasvathy's process, the facilitators began the data collection sessions by explaining the protocol to the participant. The protocol explanation included the context, length, and number of tasks, as well as an overall explanation of a verbal protocol process. The participants were free to ask clarifying questions, take notes, and re-read the questions during the protocol. In some cases, the researchers requested that participants further explain their thinking as a response to things participants said. Ericsson and Simon (1998) suggested that this is a reasonable approach, but also considered that such elicitations may subtly shift or cause subjects to reframe their own thinking. The pilot study suggested that participants tended to simply give an answer without explaining their thinking and that such prompting provided meaningful increases in the richness in the data (Wheadon & Duval-Couetil, 2016). Such richness is important to understanding how participants arrive at a decision because such decisions may look similar to that of experts but come from entirely different reasoning. During the protocol, the researchers reminded or encouraged participants to continue verbalizing their thinking whenever they stopped speaking. While prompting was not explicitly mentioned by Sarasvathy, it is a common and suggested best practice (Chi, 1997). This was a pre-planned practice that was reinforced and rehearsed by the facilitators to minimize the potential for biasing.

The facilitator audio recorded each session, which was transcribed by a professional transcriptionist. Each participant was randomly assigned a pseudonym from a pre-generated list prior to transcription. The transcripts contained both the researcher and participants' speech at the word level. The facilitator read the tasks and instructions aloud in each protocol, which were not transcribed for efficiency. I reviewed two transcripts for accuracy, one from each of the researchers who administered the protocols. That process identified no corrections beyond small grammatical changes (e.g., your vs. you're) or details that the transcriptionist had noted lack of clarity due to audio quality or cross talk. The data set collected during the study includes (1) audio recordings of the protocols, (2) transcriptions of the audio recordings, (3) interviewer notes, and (4) data from a demographic survey that participants completed at the end of the protocol (see Appendix). Using Braun and Clarke's (2006) terminology, this information is the *data corpus*.

The collected protocols ranged in length from 26 minutes to 1:02 with a mean time of 37 minutes. There were no constraints on the time students could spend on the tasks. The time students spent was significantly shorter (t (36) = 35.1833, $p < .0001$) than the hour and a half average protocol length reported by Sarasvathy (2008), although the protocol used in this study was shortened from the one used in the original effectuation study (Sarasvathy, 2008). The length of the protocol did not significantly differ between the two researchers who administered the protocols (t (38) = 0.48, $p = .63$), the participants' university (t (19) = 0.27, $p = .79$), or the participants' completion of entrepreneurial coursework (t (38) = 0.68, $p = .50$).

3.3 Epistemic perspective

Because my research question necessitates making assertions about whether participants' statements are correct or incorrect, I adopted a realist epistemic perspective in my study. The realistic perspective is based on the idea that reality is external to the mind and observable, and is more compatible with thematic analysis (Braun & Clarke, 2006). In a realist perspective, there is a real and knowable world with knowledge that can be established external to an individual's beliefs and construction (Angen, 2000; Maxwell, 2012). Employing a realist perspective is appropriate for this study's purpose because identifying errors requires students' actions be compared against a notional 'correct' action. Correct, as used throughout this study, derives from such an external, knowable perspective – i.e., definitions of concepts in academic literature, media, and educational texts that can be cited.

Adopting this perspective is not the same as a claiming that I played no role in interpretation of data, that I can assert an unsupported definition of what is conceptually correct, or that participants do not hold individual beliefs and a constructed worldview. Further, it does not prevent critical analysis of the definitions and use of concepts that participants employ. Rather, the realist perspective focuses the thematic analysis on comparing the participants' use of business principles in the verbal protocols against how those principles are normatively understood and defined. Those normative understandings are described and cited in the results from credible examples of expert understandings (e.g., textbooks and peer-reviewed scholarship) that represent the business field's conception of reality. This perspective is appropriate because that conception of reality is encoded throughout society (e.g., written into law), and accepted as linguistically and socially correct, not because expert understanding is infallible.

Previous studies using the verbal protocol in this study adopted a pragmatic epistemic perspective, which is also consistent with other verbal protocols (Sarasvathy 2008). As noted in section 1.1, prior use of a pragmatic perspective is part of why my study is necessary. The pragmatic perspective is grounded in the question 'is this observation useful,' drawing on a constantly changing reality and focusing on what can be observed that builds understanding (Dewey, 1938; Read et al., 2016). However, the use of a pragmatic approach can make it difficult to identify the theoretical perspective and epistemic commitments used by researchers (Koro-ljungberg & Douglas, 2008). For that reason, it is not one of the perspectives typically used in thematic analysis (Braun & Clarke, 2006). Further, as noted, my research question necessitated identifying and making meaning from participants' errors. Asserting correct and incorrect requires a normative or quasi-objective notion of the concepts that participants used to make decisions in the protocol. Therefore, the adoption of a pragmatic perspective would have limited the interpretation of the results.

3.4 Analytic method

3.4.1 Methodological framework

My analysis of the data followed the thematic analysis process described by Braun and Clarke (2006) designed to identify patterns within qualitative data. They describe such patterns as those that "go beyond the semantic content of the data, and starts to identify or examine underlying ideas, assumptions, and conceptualizations" (pg. 84). While identification of themes is a part of many parts of qualitative analysis, Braun and Clarke position thematic analysis as a methodology itself. Their explanation of the methodology establishes a five-stage analytic process beginning with data familiarization and ending with defining and naming of themes. In that process, the outcome space is not just the themes and evidence in support of them, but deep description and the development of any appropriate structure within the themes themselves to most accurately represent the meaning apparent in qualitative data. Braun and Clarke specifically call for researchers to document their process as an active and organic one where researchers identify their role in making meaning from the data throughout the analysis, rather than a passive process where themes and meaning 'emerge' from the data. Towards that goal, the following section details my

actions throughout the analytic process in significant detail to provide transparency about the meaning making process.

In the field, the flexibility of the methodology has allowed its use a variety of topics and data sets. Ong, Jaumot-Pascual, and Ko (2020) used thematic analysis as the analytic method for analyzing results of a systematic literature review about women of color in undergraduate engineering programs, Jesiek, Borrego, and Beddoes (2010) used thematic analysis to analyze transcripts from sessions about the future of engineering education in the areas of educational policy, stakeholders, and industry. Thematic analysis has also been used to study multiple aspects of the student experience, including interviews on students' construction of engineering identities (Holmegaard et al., 2016) and reflective diaries on paired peer learning about engineering in K-12 outreach. This body of literature reflects that thematic analysis is an established methodological framework for complex data, that it can be used to analyze data from students, and that it is flexible enough to support analysis of many types of qualitative data.

Thematic analysis is specifically appropriate for my dissertation because the research question seeks *patterns* in student errors. A methodology focused on identifying patterns in data is critical to establishing that such patterns are evidence that an individual mistake is not an instance of pure chance or of a single student. Such patterns indicate that a mistake *may* represent a common, and in my case incorrect, way that engineering students understand a certain concept. Being able to identify recurring patterns over singular instances is foundational to the value my findings have for engineering entrepreneurship education. Evidence in the form of recurring patterns represents an opportunity for educators to develop targeted interventions or perform future related research that identifying answers in the singular would not support.

3.4.2 Stages of thematic analysis

The thematic analysis methodology came into play to make meaning of the data after data collection were complete. This section, the last in the chapter, describes in detail how I implemented the methodology through the five stages suggested by Braun and Clarke (2006). The section describes the different stages of my analysis, in order, and details the actions, justifications, and outcomes that occurred from each. My goal in organizing the analysis section in this way is to make my decisions during analysis transparent and to include detail on both the process and

outcomes. Being transparent is a specific response to a common critique of thematic analysis studies – opacity in the exact process by which data become results (Braun & Clarke, 2006).

3.4.2.1 Stage 1: Familiarizing with the data

The familiarization stage involves situating the researchers to interesting details or potential patters for future analysis by reading and rereading the data. Braun and Clarke specifically recommend such a practice as an important precursor to thematic analysis, suggesting familiarization by "repeated reading of the data and reading the data in an *active* way – searching for meanings, patterns and so on" (Braun & Clarke, 2006, p. 87). Doing so attunes the researcher to the data itself rather than relying on preconceptions about what may be present or what the researcher is looking for.

In my study, the familiarization stage involved another researcher and I repeatedly reading and discussing what stood out to us as notable in the data. During that process, we both noted situations where participants seemed to misunderstand, misapply, or improperly validate their use of foundational concepts from the business world. Our observations became a topic of discussion for two reasons. For simplicity, we referred to these occurrences as *errors* during the familiarization stage, a label I continued to use throughout later analysis.

The first reason for discussion of this point was because we were not able to find previous literature that had addressed the errors. These occurrences were also not identified in prior work with the protocol and MBA students (Dew et al., 2009) nor in our pilot study (Wheadon & Duval-Couetil, 2016). They were also not discussed in Sarasvathy's original study. Instead, all prior analyses had focused on what concepts were employed by those completing the protocol and how the concepts employed differed by entrepreneurial experience or other characteristics. As critiqued by Haynie et al. (2010), the focus of prior analysis did not assess whether those concepts were employed reasonably or correctly – just that they were employed.

The second reason this observation was discussed during data familiarization was because we (both researchers) saw it as interfering with other approaches to analysis. When discussing and trialing different coding processes, both coders noted that the existence of these errors caused ambiguity when considering other theoretical approaches or applying theory-derived coding schemes. For example, the other researcher asked: How can I code a student's decision to focus on increasing profits with the same code as an expert if the student fundamentally misunderstands

what profit is and how it is calculated? Both researchers held concerns about the potential influence that ignoring errors might have on other inferences made from the data.

For both of these reasons, because the observation seemed to interfere with other analyses and because the observation had not previously been discussed (i.e., there was not solution available), pivoted data analysis. Without addressing the errors, we were not confident we could support other inferences made from the data. Therefore, our unexpected observation about participants' errors during the data familiarization stage drove us to focus on understanding patterns in those errors. Such focusing during the first stage aligns with Braun and Clarke's (2006) call for flexibility during data familiarization. That focus drove all decisions later in the analysis and the eventual results of my study.

3.4.2.2 Stage 2: Generating initial codes

After data familiarization, the second stage of thematic analysis begins structured engagement with the data (Braun & Clarke, 2006). Key in this stage is the systematic identification of text segments of interest in the data set. The goal is to identify "the most basic segment or element of the raw data or information that can be assessed in a meaningful way" (Boyatzis, 1998, p. 63). The outcome of this stage was a set of extracts from the data set that are of interest to the goal of understanding engineering students' errors.

Based on the observations about errors during the data familiarization stage, I developed an initial definition of 'error' appropriate for this stage and grounded in our data familiarization process. For this stage of the study, an error is defined as a (1) business, management, or entrepreneurship concept that (2) makes assumptions clearly at odds with well documented best practices, or demonstrates a misunderstanding or misinformation of the concept obvious to someone with knowledge of the concept. This definition establishes the concept of an error for this study in two parts – an idea or topic within the study's conceptual domain that is applied in a demonstrably incorrect way. As a baseline, we (both researchers) established the domain of business, management, and entrepreneurship concepts as those likely to be covered in an introductory entrepreneurship class or presumed as prior knowledge in such a class. We then used resources from authoritative sources such as journals or textbooks as evidence of the second test – that the students were wrong.

For the second stage, any segments of text we identified needed to contain both parts of the definition to be an error. The two-part definition excludes non-study-relevant errors such as mistakes in mathematical calculation (e.g., asserting that 2 + 2 = 5). Because the interest is in an identification and explanation of errors, rather than of the cognitive process, the definition used in coding is focused on the errors themselves rather than the underlying cognitive process. It also excluded statements (e.g., "I like video games, so I would invest") that were within the domain but could not be assessed as demonstrably incorrect.

We (i.e., myself and the other researcher) then applied this definition to all 40 protocols independently using qualitative analysis software. The result was a set of text segments, each representing a single 'error'. For each error that we identified, we added a description as to why the text segment was as an error and what concept the participant is errantly applying. One researcher identified 146 errors while the second identified 111. We identified errors in 38 and 37 of the 40 protocols, respectively, with the number of errors in an individual protocol ranging from 0 to 10. We identified twenty exactly matching errors (i.e., we coded identical text segments *and* provided the same explanation for why they were an error) leaving 237 unique errors.

After individual coding, both researchers participated in a rectification process where we reviewed all coded extracts, having blinded them of who coded the error. The criteria for including an error in the next stage of analysis was mutual agreement that the excerpt was an error and agreement on the description of the error. The final data set consisted of 95 errors from 32 protocols. The distribution of those errors appears in Figure 2. Each of the 95 extracts contained a quote from the participants' protocol and a brief description of the error. They are the data used for the next two sections of the thematic analysis.

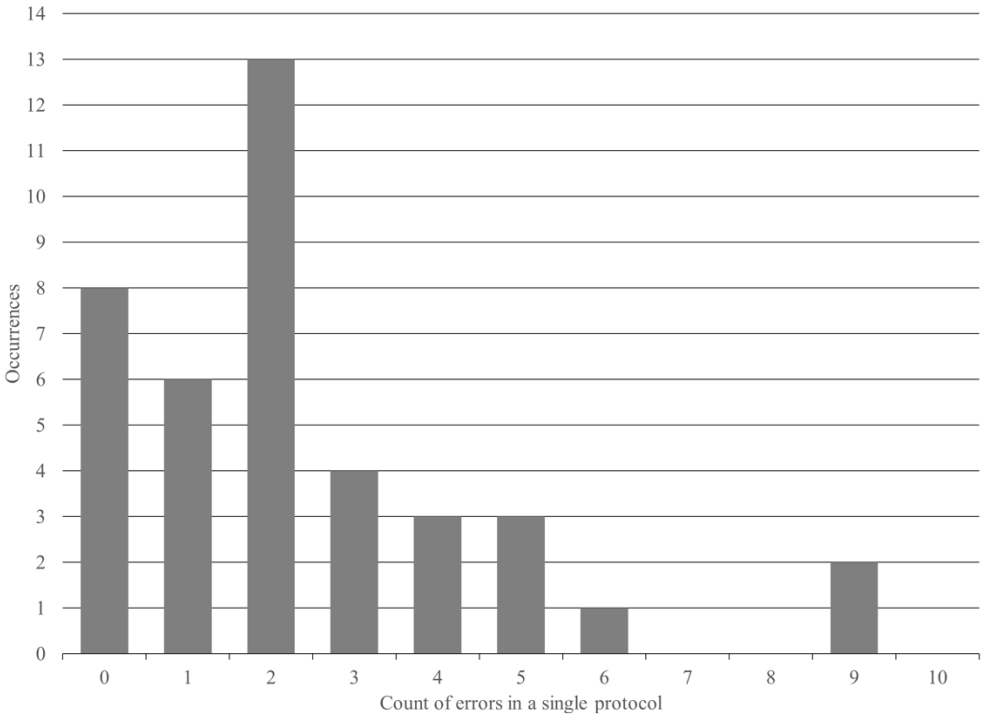

Figure 2 Histogram of number of errors identified per protocol

3.4.2.3 Stage 3: Searching for themes

In the third stage of the thematic analysis, I grouped the 95 individual errors from stage two into initial themes based on meaningful similarities. Such groups should represent "components or fragments of ideas or experiences, which are often meaningless when viewed alone" (Nowell et al., 2017, p. 8). Both Nowell et al., and Braun & Clarke (2006) identify two criteria for a theme; first, it should be related to the research question and, second, patterned within the data. Braun and Clarke also note that flexibility around the theme identification approach is appropriate. The goal of this stage was to find the most granular groupings that met both criteria for a theme. Those groupings can include the themes themselves, but can also include developing linkages between the themes and appropriate structures or taxonomies as appropriate.

I used the pile sort method to identify themes in the data. Pile sorting involves physically laying out each individual error from stage 2 randomly and then organizing them into physical groupings representative of the initial themes (Ryan & Bernard, 2003). Each error was assigned a random identifying number to reduce the potential for bias at this stage (e.g., from multiple errors that were coded the same protocol or presumed pseudonym gender). I then printed the errors, cut into individual slips of paper, and iteratively sorted them on a large table. In each sorting iteration,

I read and divided the errors into shared piles and then wrote a brief descriptive label for each shared pile on a sticky note. I then compared each error against the label of the group it was in and either kept or rejected as part of the group based on whether the error fit the description. I repeated the sorting pattern until a review of each error and its group label caused no changes in either group assignment or group label. The process took approximately eight hours over two days.

The outcome of the pile sort approach was four draft data-driven themes comprising 73 of the 95 errors. The 22 remaining errors did not match any other patterns in the data set, violating one of the two criteria for a theme. That does not mean that they were not errors, but rather they did not exist within a specific pattern in the data. Those 22 errors were retained for future stages of the thematic analysis as part of a "miscellaneous" theme, in line with best practices (Braun & Clarke, 2006). The draft theme names and descriptions appear in Table 4. Thematic analysis best practices note that "more instances do not necessarily mean the theme itself is more crucial" (Braun & Clarke, 2006, p. 82). For that reason, the table does not report the number of extracts grouped within a given theme.

Table 4 Summary of draft themes (Fernandez & Duval-Couetil, 2017a)

Draft theme	Summary description
Venture ownership and exiting	Some students struggle with the mechanics of basic principles in analyzing the choice between an initial public offering and an acquisition offer. Their statements suggest that they may conflate themselves as individuals with the firm as an entity and do not track their equity in the business over time.
Receiving investment	Some students seem to mis-assess the ease and process by which venture investment occurs. They believe that gaining venture capital (VC) funding is fairly easy and driven by their skills rather than the venture and its potential. Further, they seem unaware of what the implications are for control of companies typically involved in agreements attached to such investments.
Pricing and Market Research	Some students struggle to make appropriate use of pricing and market research data. Examples included seeming to see an increase in price as automatically causing an increase in revenue or assuming that an increase in revenue will definitively increase profit.
Market Share vs. Market Size	Some students seem to misunderstand markets and market sizes as well as the relationships between markets and the size of a company. For example, students seem to assume that the size of a market is not just directly representative of the size of the company (i.e., bigger market – bigger company), but that the market size is the company size.
Miscellaneous	All extracts that do not fit in another theme are considered miscellaneous.

3.4.2.4 Stage 4: Reviewing and refining the themes

Having developed a draft set of themes from the third stage, the fourth stage in thematic analysis is refinement of the themes, their descriptions, and representative quote selection. Braun and Clarke (2006) suggest multiple techniques for reviewing (i.e., gathering input) and refining (i.e., implementing that input) the draft themes. They divide the techniques into two levels – those that assess the coherence of the existing themes and those that involve returning to the entire data set to review the fit of the themes more broadly. This section describes the processes used to improve both aspects of the analysis.

I published the draft version of themes in a preliminary publication to provide an analytic pause point that required a thorough description of the current state of the analysis and opened my work for external feedback (Fernandez & Duval-Couetil, 2017). The publication resulted in feedback on the clarity of the theme description and the consistency of key representative quotes. I further reviewed the draft themes via one-on-one meetings with other researchers not involved in the study.

The external feedback informed two major changes: (1) refinements in the names and descriptions of the themes, and (2) introduction of a structure among the themes to accurately

reflect certain hierarchical characteristics that were increasingly apparent. Changes during refinement included the collapsing the *pricing and market research* theme and the *market share vs. market size* themes into a single theme because they overlap in students thinking, although they do not overlap in more theoretical treatments of the concepts. Other refinements included the creation of a set of secondary themes that reflect a set of higher-level concepts that students used consistently across the themes. Braun and Clarke suggest that secondary themes can be useful for documenting connections between the themes in concrete ways. To identify secondary themes, I reviewed the themes and the extracts looking for generalized types of errors that I saw across different business principles. As part of the refinement, I then reviewed the secondary themes with other researchers. That review focused on whether the secondary themes accurately represented the data and whether the descriptions of the secondary themes were coherent summarizations of patterns across multiple themes. My actions here reflect the structuring and taxonomic organization mentioned in the purpose section, and are further described in the results chapter.

The last action I took to refine the thematic analysis results was to recode the entire dataset using the near-final themes as a code book. Braun and Clarke (2006) suggest this for two reasons. First, to test the near-final themes against the data again, building on the idea that internal consistency, rather than increased instances, represents an indicator of theme quality. The second reason they identify is to find extracts that may have been missed or which best represent the diversity of expressions of each theme (Braun & Clarke, 2006). Once the recoding was complete, I considered the refinement of themes complete and shifted to the final stage of thematic analysis: Reporting the results.

I report the results in the next chapter, but it is critical to note that the selection of quotes was made specifically and solely to aid in illustrate themes to readers. The selection seeks to make the errors visible and coherent to the reader and does not indicate any particular characteristics of the source of the quote beyond that participants' particular error being particularly clear or useful. This is keeping with suggested practice of using quotes as evidence of the themes rather than as broader commentary on the results (Braun & Clarke, 2006). The selection of participant quotes should not, and cannot, represent other interpretations of the data that are beyond identification and explication of themes in the results.

3.5 Researcher positionality

Because there were multiple individuals involved in the data collection and analysis process, the researcher positionality section is broken into two paragraphs. The first paragraph describes my individual positionality as the lead researcher and author. The second briefly reviews the positionality and role that others played in data collection and analysis.

Relevant information about my positionality begins with being the child of a serial entrepreneur and software development engineer. After childhood, I entered college and attained B.S. and M.S. degrees in mechanical engineering. During these programs I participated in multiple engineering internships where I was exposed to aspects of business management and typical corporate policies around accounting and business planning. I also took courses in engineering management and introduction to business for engineers. I also undertook entrepreneurial activities including a side business performing CNC machining services. After graduating I worked for a Fortune 500 semiconductor company in a manufacturing role where I worked on primarily technical work. Upon leaving that role, I worked as an independent engineering consultant for small technology startups that focused on early-stage venture funded companies who contracted with the US Department of Defense. During that period, I also cofounded a venture funded clean technology company that focused on innovating commercial composting and fertilizer manufacturing. That company was later sold to a competing firm. In 2016 I entered a Ph.D. program in engineering education that led to this dissertation. Through that experience, I have been involved in teaching and researching multiple aspects of engineering education with a focus on entrepreneurship in engineering. I am familiar with, and have participated in, the extensive scholarly conversation around developing entrepreneurship education in engineering.

Through these experiences there are multiple things that may have affected my analysis and interpretation of data in this study. Globally, I have more experience with the appropriate use concepts that I am analyzing than the participants in my study. The effect of growing up with and using entrepreneurial outside of formal training may also affect how I interpret proper use of certain concepts. Additionally, my experience in teaching entrepreneurship may have pre-inclined me to identifying certain types of errors that I have seen students make before this study. Finally, simply put, while I am experienced with the concepts covered in the protocol, I am not an expert at the level of either group of experts studied when developing ToE. As such, there may be places where participants' and experts' actions actually align in an alternative form of proper use that I

am not familiar with. To counter these potential risks, I engaged with multiple other researchers in the completion of the study to gain secondary perspectives, described in the next paragraph, as well as a series of process steps, described in the next section, to increase the trustworthiness of the results.

In addition to myself, three other individuals were involved in the work on this study. Their backgrounds should be briefly acknowledged as well because they influenced the design and analysis of the protocol data. The first individual was an engineering education graduate student who originally designed the data collection scheme and collected some of the protocols. He holds an MS in engineering, published engineering entrepreneurship education research, and earned a master's in engineering education before leaving graduate school to take on an operations role at a California technology startup. The second individual was an undergraduate research assistant pursuing a degree in Computer Science at the Public University in this study and completed internships focused on market research analytics. He participated extensively in the first four stages of data analysis and coded all protocols alongside myself. Both of first two individuals had significant interest in, prior experience with, and planned future experiences with, entrepreneurial ventures – primarily technology focused ones. The third individual involved in the study is a professor and the director of the entrepreneurship education programs at the Public University in the study. Her research focus is entrepreneurship and entrepreneurship education inside and outside of engineering. She holds a Ph.D. as well as an MBA. Prior to working in academy, she worked as a market research and business strategy consultant. She was involved in the planning of the study and throughout the analysis stages, with the greatest involvement in the reviewing and refining of the themes.

3.6 Trustworthiness

In this study, I use trustworthiness as the appropriate term for evaluating rigor in the study, effectively the qualitative analog to validity concepts in quantitative research, as described by Borrego, Douglas, and Amelink (2009). This section reviews the efforts I undertook at each stage to reduce the potential for bias of the study and the body of evidence that establishes the quality of the results. Following the description of the practices employed is a summary of how each practice contributes to trustworthiness.

Nowell et al. (2017) provide a set of practices specific to thematic analysis that individually and collectively contribute to establishing trustworthiness. The practices are grounded in work by Lincoln and Guba (1985) establishing overarching criteria for trustworthiness. While Nowell et al. articulate the principle of trustworthiness as holistic, establishing trustworthiness relies in significant part on adopting specific best practices along with justifying why the researchers adopted those practices. Table 5 identifies the practices adopted in this study from the list provided by Nowell et al. (2017, pg. 4).

Of the processes suggested by Nowell et al. (2017), all but three are employed in this thematic analysis. Many of the practices (e.g., peer debriefing and researcher triangulation) are noted earlier in the thematic analysis section along with specifics of their use for this study. For practical reasons, this study did not employ member checking. Both the data collection and the analysis of the data occurred over an extended period for reasons beyond my control. The extended time made it infeasible to check interpretation with student participants who had graduated because permanent contact information was not part of the data collection.

In addition to the suggested practices, I employed several other trustworthiness practices from literature improve the quality of results. First, throughout the study, I grounded analysis decisions were grounded in the data, rather than a strict adherence to the initial analytic plan. For example, the initial analysis work pursued the use of Sarasvathy's (2008) coding scheme. During the initial stages we found that coding in that way was not tenable. Two coders working together achieved a maximum IRR of 0.72. Such a low value is significantly lower than the 0.90 Cohen's Kappa that Sarsavathy found when coding expert protocols. Analysis of issues with coding drove a discussion of the data, which resulted in a shift to understanding one aspect that negatively affected coding consistency: Participants' errors. That observation, grounded in the data, drove a shift in the analysis process to the thematic analysis approach seen in my dissertation.

Further, the overarching process aligns with the methodological literature, but the actions taken at each stage were driven by data or findings in the previous stages, as suggested by (Braun & Clarke, 2006). Second, the processes used during coding blinded all information about participants except pseudonyms and the post coding analysis blinded all participant information (e.g., gender, entrepreneurial experience, university affiliation). In addition to protecting identity, the use of those pseudonyms during analysis reduces the researchers' reliance on implicit patterns based on knowing students' prior experiences or identity in relation to entrepreneurial norms

(Sánchez-Escobedo et al., 2011; Schoon & Duckworth, 2012). However, some references made by students in the data (e.g., faculty names or specific courses) had the effect of un-blinding portions of the data and so may be a source of bias.

Table 5 Use of practices that provide evidence in support of the trustworthiness of the study's results (Nowell et al. 2017).

Stage	Employed	Not employed
Stage 1: Data familiarization	Prolonged engagement w/data Document theoretical and reflective thoughts Document thoughts about potential codes/themes Store raw data in well-organized archives	Data triangulation
Stage 2: Generating initial codes	Peer debriefing Researcher triangulation Use of a coding framework Audit trail of code generation Document meetings and debriefs	Reflexive journaling
Stage 3: Searching for themes	Researcher triangulation Diagramming to make sense of theme connections Keep detailed notes about development and hierarchies of concepts and themes	
Stage 4: Reviewing & refining themes	Researcher triangulation Themes and subthemes vetted by other researchers Test for adequacy by returning to raw data Peer debriefing	
Stage 5: Describing the themes	Peer debriefing Describing process of coding and analysis in detail Report on reasons for theoretical, methodological, and analytical choices throughout the entire study Description of audit trail	Member checking

Collectively, these practices provide evidence that the key concepts for trustworthiness are satisfied (Nowell et al., 2017). The first, credibility, refers to the "fit between respondents' views and the researcher's representation of them" (Nowell et al., 2017, p. 2). Evidence of credibility comes from the multiple researchers with experience in this space providing peer review of the analytic work, the employment of a clear and grounded process, the use of most of the processes outlined by Nowell et al., and the alignment of the themes with existing literature, as described in the discussion section. All of those elements provide checks on potential misinterpretation between participants' thinking and the interpretation of them in the study.

The second key concept, transferability, focuses on generalizability across cases *within* the study and the use of sufficient description to allow others to judge whether the results might apply to other institutions or groups of students. By providing information about context, the protocol used, and extensive quotes from a variety of students, readers have significant information with which to judge transferability and compare these findings to their own contexts.

The third concept, dependability, is the idea of a clearly documented and logical research process. Evidence of that dependability comes from the thematic analysis section by intentionally describing the actions, results, and decisions made at each stage of the process. Further evidence comes from the use of a methodological framework (i.e., Braun and Clarke's explanation of thematic analysis) and the use of a separate resource for identifying and implementing best practices (i.e., Newell et al.).

Finally, confirmability focuses on "establishing that the researcher's interpretations and findings are clearly derived from the data" (pg. 2). The evidence for this comes from the evidence for dependability as well as from the use of extended quotes across multiple participants from multiple programs and universities.

4. RESULTS

This chapter reports the results of the thematic analysis. In Braun and Clarke's (2006) terminology, the presentation of the results is the fifth and final stage of thematical analysis. The chapter begins with a summary overview of the results. Each theme is then described in a separate subsection. As a reminder, the research question my dissertation addresses is:

What patterns of errors are observable in engineering students when they work to make decisions typical of early-stage entrepreneurship?

The results chapter serves to establish two claims that are required to address the research question and meet the commitments of the thematic analysis process. Those claims are:

1. Engineering students employ entrepreneurial concepts in ways that are incorrect (i.e., the participants make errors)
2. Across participants, errors occur in patterns with consistent and identifiable characteristics (i.e., there are themes in the errors)

The description of each theme uses quotes, outside literature, and observations made during the protocol administration to defend claims related to them. The outside literature offers credible sources to establish a normatively correct understanding or use of concepts that participants employ. As described in the epistemic perspective section, establishing a normative understanding of these concepts is critical to establishing them as errors and necessary to meet claim 1.

An entrepreneurship textbook by (Barringer & Ireland, 2016) is used throughout the results as the primary external resource. That textbook is used at the Public University in their first introduction to entrepreneurship course. It represents the type of introduction to relevant concepts that the participants who have experienced some form of entrepreneurship education would be expected to have seen. However, as noted in section 3.1, such courses do not represent the diversity or limit of the exposure to entrepreneurship within engineering students in my sample. At the end of the description of each theme, I compare participants' errors to the behavior expected of both of the types of experts in Sarasvathy's ToE. This information is part of the results section specifically because it is critical to establishing claim 1 – incorrectness. In the comparison, I highlight how participants' errors deviate from either type of expertise in ToE.

The description of each theme presents quotes from multiple participants, allowing an explanation of similarities and differences between how a given error manifests in each

participants' protocol. In doing so, I am able to describe shared characteristics to clearly bound the core of a specific theme as well as highlight varying articulations of error within that shared theme. In doing so, the multiple examples provide evidence for claim 2 by showing that there is a pattern of similar errors across the data set and isolating what is the core of the error and theme.

Finally, it is useful to identify four conventions I used in the results chapter. First, as noted in the introduction, is the use of the term *error*[14] in the results section. That term is a specific choice to indicate evidence that the participants are wrong, but not assert that the errors represent misconceptions. Whether these errors are in fact misconceptions will be addressed in the discussion chapter. Second, I continue the practice from the draft themes by not reporting frequency data at any point, as is recommended by Braun and Clarke (2006). Third, the results chapter uses the phrase *some participants* consistently. This is to emphasize the not all participants made any single error and draw the readers' focus from frequency to meaning. Fourth, I selected the quotes to describe each theme to aid a coherent narrative about what is happening in the theme and why the theme is important. As a final note, pseudonyms used throughout the results are consistent and some quotes are reused when they are illustrative of more than one theme.

4.1 Results summary

The results section describes the specific themes of errors that emerged from my analysis as well as their structure. There were five key themes that show errors related to market research, options for outside investment, exits from an entrepreneurial venture, estimates of company value, and assumptions or perceptions about control of an entrepreneurial venture. In the themes, a three-level taxonomy also emerged. The first three themes reflect conceptual areas from the business field in which students made errors. In each of those three themes, examples of two specific manifestations are given. The fourth and fifth theme occur at a higher-level of abstraction and are the basis for a taxonomy as encouraged by Braun and Clarke. Those two themes relate to assumptions about characteristics of entrepreneurs and the entrepreneurial process that were intertwined with multiple conceptual areas. To help readers understand how the taxonomy

[14] Error, *noun* - 1a: an act or condition of ignorant or imprudent deviation from a code of behavior
b: an act involving an unintentional deviation from truth or accuracy
c: an act that through ignorance, deficiency, or accident departs from or fails to achieve what should be done

develops, I describe the first three themes and then provide an explanation and visualization of the taxonomy and the two higher level themes together.

As described in the introduction, and returned to in the discussion, structuring the field's understanding of the errors made by novices has value to researchers and educators. For my study, the value of connections between the themes above and narratives about entrepreneurs to which students are exposed are particularly relevant and addressed in the discussion chapter. Those narratives were introduced in the literature review and the connections to the results are explored in the discussion chapter. Across the descriptions of the themes, some of the errors made by participants may seem obvious to the reader when they are extracted from the full context of students thinking. Nothing in the chapter is meant to impugn participants, but rather represent correctable ways that those with minimal entrepreneurship experience can go awry.

Table 6 Summary of final themes

Theme	**Summary description *(Some participants…)***
(Over)Interpreting market research	Interpret information about markets by conflating that information with company performance, and over-extrapolating the success of their venture.
(Mis)Analyzing investment options	Analyze investment options by differentiating them based on incorrect personal beliefs about investor input, ability to retain control, and ease of access.
(Mis)Evaluating exits	Evaluate exits as a personal decision rather than business decision and presume they retain control and proceeds of any sale of the venture.
(Over)estimating value	Ignore information about the valuation of their venture that is given to them, and instead assume other financial information as measures of high value.
(Pre)Suppose control	Assumption that they possess, can assert, and will retain control as the founder of the venture, despite earlier having taken outside investment in exchange for equity.

Note: As described in section 3.4.2.4, the final themes use different names from the draft themes as a result of the reviewing and refining stage of the thematic analysis.

4.2 Interpreting market research

Market research refers both to the process of researching the commercial viability of a business or business decision and the information that is collected through that process. Typically, market research information is divided into two types[15]: *Primary market research* is information collected directly from potential customers about what they would pay for a product. *Secondary market research* is information that supports summative analysis about existing market spaces that

[15] The Barringer and Ireland (2016) textbook used by the public university describes both of these types and what they can and cannot tell someone about a business in detail.

a business might target. In Task 2 of the protocol, participants received two pages of realistic market research information. The first page provided the results of three primary market research surveys about potential customers. The results provided data on how much potential customers from different demographic groups were willing to pay for the company's product. The other contained secondary market research information - estimations of costs associated with different sales channels, the number of people in different groups, and the estimated value of existing markets in which the product might compete.

The errors occurred in how participants interpreted what the market research information could tell them about the business, or decisions that the information supported. The errors took two forms, which are collapsed under this theme because they both involve misinterpreting the market research information. In the first form, some participants conflate the market research information with information about their venture's success. In the second form, some participants over-extrapolate what other market research information can tell them about specific elements of their venture's performance (e.g., profitability). The two forms are similar enough that I grouped them under one theme – both centered misinterpretations of what market research can be interpreted to mean. The sub sections below describe the two forms in order.

4.2.1 Conflating market research with company performance

The clearest form of the misinterpreting market research error came in the form of some participants conflating information about the size of a potential market with the value of their company. The secondary market information provided participants with the size of several potential markets (e.g., the instructional technology market was shown as having a value of $1.7b). In multiple protocols, participants picked out that specific piece of information and incorrectly interpreted it as either potential or inevitable value of their company. The quotes here demonstrate this error in three different protocols:

> The family friend with the extensive experience in selling educational products would be – would probably be very good given that there was approximately $1.7 billion in instructional technology. **So that would be who he would be working with the most, and so if it's $5 million that he would be investing, and then the estimated value is 1.7 billion with 20% growth**[16], I guess this would be a couple of years down the road. It'd be even higher than that. The 20% per year for the next

[16] Throughout the results, when key parts of a quote need to be situated within a larger quote for context, those key parts are bolded for differentiation and to ease in the identification of the underlying error.

> five years could – at the end of these five years where it's expected to grow, it'd be worth – just like the rough numbers, **it'd be like $3 billion for a $5 million investment that someone gets 30% of** (Todd)

> Secondary market research – customer segment young adults ages 15-25 would be 20 million. So, estimated total size – like sold – 20 million would be sold (Sophia)

> so, let me just – 25, so then that's – change that to a 3.8. So, then that's four fours – that's 16 – four, five, six, and eight – that is a – still a billion dollar in sales. So, I think, yes, I do want to focus it on the adults (David)

The three participants all conflated the potential or future size of the company with the size of the market, just with different levels of explicitness. Todd calculates the size of the educational technology market as $3b in five years ($1,7b and growing at 20% per year according to the secondary market research information). He then conflates that market size information with the value of his venture, stating the value of venture as $3b in five years from a current valuation of $16m. Similarly, Sophia assumes that the company will sell 20 million units. That number is not arbitrary or an estimate, it is (as she notes) what the secondary market research information provides as the number of young adults nationally. Finally, David again assumes that the company's sales are equivalent to the size of the educational technology market. In each case, the underlying assumption is one of conflating a value in the market research with a de facto value for a characteristic of the company. Todd and David assume that their company will have the same value as the yearly sales of all educational technology – despite an entrepreneurial video game being only one type of educational technology. Looking at units sold rather than value, Sophia assumes that her venture will sell exactly one unit to each young adult.

Each of those interpretations of market research are explicitly warned against in the public university's textbook (Barringer & Ireland, 2016). The textbook authors note that entrepreneurs cannot assume 100% market share (i.e., as Sophia). They also warn against conflating the revenue and value of a company (i.e., as David & Todd did).

A final example of this form of the theme serves as a transition between participants conflating market information with venture information, and begins to show how participants use that information indirectly to over-extrapolate their venture's success. Abigail interprets secondary market research information about the costs to sell product through different channels (e.g., via the internet or retail) as if it represents income from those sales channels, rather than a cost to sell through them. In the data, this is the sole example wherein a facilitator noted and corrected such

an error mid-protocol[17]. The conversation began with participant Abigail reading part of the secondary market research aloud:

> Abigail: Because there probably – it wouldn't be as much as the up-front retail, because if you're selling to institutions, it'd probably be a package deal. So, the 2000 or 50,000 up front per unit that you sell to schools would probably make sense, and then –
>
> Facilitator Oh, so –
>
> A: Or not per unit, but –
>
> F: I was going to say, these are just what it costs you –
>
> A: Oh, to sell it.
>
> F: To sell in different channels.
>
> A: So that would be better if it's less expensive.
>
> F: Yeah, if you're selling it over internet, you have to pay 20,000 to [CROSSTALK] set up your page.
>
> **A: Oh, I was thinking profit or something.**
> (Abigail)

Abigail's statement of "profit or something" refers to treating information about a cost (clearly denoted, see APPENDIX) as a profit and using it to over-extrapolate any numbers about their venture's performance to be positive indicators of success. While Abigail's error was corrected mid protocol, this type of statement by some participants became a second reoccurring form of error participants made when interpreting market research.

4.2.2 Over-extrapolating venture success

The exact piece of information that participants would over-extrapolate varied, but the way in which they over-extrapolated did not. In each case, a participant identified a piece of market research information that did not and could not show profitability for their venture as evidence of profitability. As with the other form, that reoccurrence occurred both in participants who had and participants who had not completed entrepreneurship education – suggesting that the training on

[17] Participants making errors in interpreting information during the study was not part of protocol facilitation planning. Therefore, the facilitator had no reason or training not to make a correction here. The facilitator made a correction because he perceived the participant as having made an accidental misreading.

market research included in both institution's entrepreneurship programs does not prevent this error.

Being profitable is typically a long-term goal rather than a short-term reality in entrepreneurial ventures (Barringer & Ireland, 2016). However, participants repeatedly extrapolated various other pieces of information into evidence that their venture was making a profit. Examples of information used as evidence of a profitable venture include higher sales prices (Eric), popularity (Sophia), and the aforementioned use of cost information (Abigail). A quote from Eric highlights this extrapolation:

> I guess adults are willing to pay more for it. So I would focus on adults. **That just means that it's more profitability for me**. They value the product – like let's say – the majority of the percent is 100-150 at 38% which is the highest out of all the categories. They – let's assume mid-range is 125. If that's what they're willing to pay and I sell the video game to them or this simulator game to them at $100, that's 38% of people that I've sold my product to that believe that they've made $25 off of the – off of their purchase

Eric's statement is grounded in a correct observation, the market research he was provided shows that adults would pay more the most for the product. However, from there he builds a logical chain that incorrectly extrapolates that a willingness to pay a higher price will increase his company's profits. While an increase in price *may* increase revenue and *may* increase profit, neither is necessarily true and the inference he makes is not possible from the data he has. He also fails to consider that changes in price can affect the number of units sold.

While pricing decisions are complex[18], the Barringer and Ireland textbook emphasizes repeatedly that price and the number of units sold are inherently, and typically inversely, connected – which is the opposite of Eric's statement. In effect, Eric treats an increase in price as wholly independent from units sold (and costs) – and presumes that it will increase revenue.

Eric's extrapolation then continues by extrapolating an increase in revenue (via the increase in price) to an increase in profit – entirely ignoring costs of doing business. To state formally, profit refers to a situation wherein the revenue generated by a business exceeds the costs incurred in achieving that revenue. Participants were not asked to define revenue or profit, but there are repeated errors in the data that relate to the use of the term profit and deviations from its formal meaning. Typically, these came when they extrapolated from market research information

[18]That complexity can be seen in the fact that this topic is studied in multiple academic journals, including the *Journal of Revenue and Pricing Management* and the *Journal of Professional Pricing*.

provided to them to indicate that the company is profitable – typically when given information solely about revenue or potential revenue. Sophia, for example, is provided information about the revenue of the business and states:

> Personally, **I think the company is very profitable as-is. I think that we've made like leaps and bounds over just the past six years**. The fact that we're selling this many products to such a wide range of people (Sophia)

That some participants extrapolate profitability from market research or revenue data is notable because the participants were repeatedly given explicit information that the company was not making a profit. The revenue information includes a prediction that the company will break even within 3 years and that revenue continues to grow. Sophia did not reference any information provided to her to validate her assessment of the company as profitable. Instead, she pointed to other markers of a company's success (e.g., the volume of products sold and appeal to the broad interest in the company) as evidence that the company is profitable. This suggests that the issue is not confusion over the information in the protocol. In fact, and in contrast with discussing pricing in detail, the introductory entrepreneurship textbook does not describe the difference between revenue and profit. Instead, the book uses the term *profit* to explain other concepts (e.g., profitability [pg. 557]) suggesting that it is presumed to be common knowledge. However, in the data, some participants understand the base meaning of *profit* as something that they can extrapolate from market research information, which they cannot.

Collectively, the errors some participants made when interpreting market research are interesting for two reasons. First, because of the shared characteristics that makes them a theme. While each is slightly different in form, in each error a participant (1) employs market research information provided to them, (2) while conflating or over-extrapolating what they can infer from that information. The second reason is because of a shared characteristic in each conflation and over-extrapolation: All of the errors identified in the data <u>overestimate</u> a positive aspect of the company's performance. The overestimation of positive performance is not part of the market research theme, because it reoccurs in other contexts in the data as well. A more detailed description of that pattern in the errors is found in the value theme later. For the market research theme, what is key is that whether participants add the value of markets together, conflate revenue and profit, or presume profitability; this theme demonstrates that some participants interpret market research in erroneous ways. This evidence meets both claims laid out for a theme in the introduction to this chapter – the quotes can be clearly identified as incorrect when compared to

introductory entrepreneurship literature, and while not identical, share an underlying characteristic of occurring through the interpretation of market research information.

While the next chapter will discuss the implications and interpretation of the themes, to fully understand the theme of errors, it is useful to compare participants to experts in Sarasvathy's (2008) prior research. Those with expertise in traditional business strategy analyze patterns in market research data to maximize revenue, minimize cost, estimate the potential value of a company, and assess potential competition. Sarasvathy did not analyze the correctness of her participants use of the information, but does note that their decisions reflect what would be expected from such an approach. Conversely, expert entrepreneurs dismiss market research information entirely and employ a logically different approach of identifying and partnering with early-stage companies. That approach leads the expert entrepreneurs to predict larger valuations and the potential for broader market shares. In the quotes above, participants universally sought to analyze the market research data provided to them. That behavior is similar to the logic of ToE's investment bankers. However, the conclusions that they reached are factually unsupported by the data that they analyzed and the actions that those conclusions informed are much more similar to ToE's entrepreneurs. That is despite Sarasvathy's finding that the two rely on a fundamentally different logic to link their individual actions and conclusions.

4.3 Analyzing investment options

For the purposes of the protocol, *investment options* refer to the opportunity for the participant to receive an influx of capital to their hypothetical company. Such capital provides funds or resources that the company needs to grow or continue its operations. In exchange for capital, an early-stage company often provides the investor with an ownership stake in the form of shares in the company, options for shares, or convertible debt (i.e., promise of future repayment that can be converted to shares). Investment options can take many forms in an early-stage company. In decreasing order of frequency, those options can include one's own funds, loans from friends or family, loans from a banking institution, grants, and/or money in exchange for equity (e.g., from an angel investor or a venture capital firm) (Barringer & Ireland, 2016).

The errors related to this theme occurred when participants would analyze multiple investment options in the protocol. In this theme of errors, participants' analyses of their investment options incorrectly interpreted different aspects involved in garnering outside

investment. These include (1) misunderstandings of the mechanisms and norms of venture capital (VC) funding and (2) making faulty analogies to make assertions about different investment options.

4.3.1 Misunderstanding VC investment processes

While widely discussed and reported on, VC funding of companies is actually quite rare. Data shows a total of 3,718 VC investments in the US in one year, which includes both first-time and follow-on investments (Bain et al., 2017). First-round investments accounted for less than 40% of those investments. Further, that total does not describe the likelihood of progressing from an initial contact to a completed investment. Research suggests that only 0.1% to 0.5% of companies that VCs establish contact with actually receive investment (Teten & Farmer, 2010). One of the VC firms Teten and Farmer studied identified 2,000 target firms to review, met with 1,000, negotiated terms of investment with 25, performed due diligence research on 18, and invested in 10 – a 0.5% funding rate[19]. Networking on the part of founders is generally accepted as important to finding investment opportunities, but only inasmuch as it provides a connection; actually achieving investment from those connections is significantly harder (Barringer & Ireland, 2016).

Barringer and Ireland further note that contact between VCs and potential investments is rarely initiated from the entrepreneur's side or within the control of the entrepreneur. However, some participants perceived VC funding as something entirely within their control and of widely available as in this example from Isabella:

> I would pick the venture capitalists. **I think I'm like pretty charismatic, so it wouldn't be that hard to find them**, and it like – to me personally it's more appealing to work with someone I don't have a personal relationship with. Even in like school stuff you get pretty irritated with group partners and stuff, but at the end you can be like, oh, we argued about this, and I thought I was right, but in the end we did make a better final group thing… (Isabella)

Isabella's comment was coded as an error because it is an unrealistic simplification of the scope and focuses entirely on initial contact. In the task she is responding to, VC funding was specifically identified as available. However, Isabella did not perform any analysis of the valuation

[19] The Barringer and Ireland textbook (2016, pg. 339) characterizes the likelihood of VC investment thusly: "According to the 2014 National Venture Capital Yearbook, for every 100 business plans that are submitted to venture capital firms for funding, only 10 get a serious look and only 1 is funded….Venture capitalists are looking for the 'home run.' The result is that the majority of business plans do not get funded."

that she was told was being given to her or of the financial state of the company. Instead, she discusses 'finding' VC investment and notes networking as a factor and a single personal characteristic – her charisma – as key. She fails to acknowledge or consider the particulars of the funding that has been offered, and in her analysis of, seems to consider charisma, rather than financial considerations, as the driving factor in whether funding would be able to be found and offered. In her analysis, she foreshortens the process to finding a VC firm, and ignores any financial analysis thereafter – where data says most deals fail.

Others made statements that misperceive the realities of VC investment in other ways as part of their analysis. Eric's and Mia's error focused not on the likelihood of VC investment but on his control post investment:

> So as long as like – I would need her [note: the VC] to assure me that I'm in charge and that if I want to drop this at any time, like it's not going to hurt me – like that sort of agreement. It's not going to come back to bite me or anything like that (Eric)

> I think I would go venture capitalism. **That was my gut, because to me 30% of the company is still enough – or I guess I would still have 70%. Seventy percent is still enough where I have the – I still own the company. I still have the votes. They have a little bit of an opinion, but if I'm a little blip on their venture capitalism screen, they might say a couple of things to me once a year, but other than that, they're just kind of over – overlooking me.** The 30%, though, from a family friend concerns me, because then I see you on the weekends, and you're way more invested. I see you every day at work, and what if you and I don't agree on something and I pull my 70% weight? Do you take out your five million dollars? What happens then? (Mia)

Eric wants assurances of his ability leave from the company at any time. As Barringer and Ireland (2016) explain, one characteristic that makes a company appealing for investment by VCs is a strong and proven management team. The stability of founder and management team involvement are typically a significant component of evaluating early-stage investment opportunities because deep understanding of the company and market help guide success (Wiltbank et al., 2009). His statement is an error because it is completely at odds with norms on which VCs evaluate and carry out investment. Such an assertion might suggest Eric lacks contextual knowledge and experience with the norms of the VC world, making him potentially difficult to work with.

Similarly, Mia bases her analysis on misunderstandings of how VC's interact with companies they invest in. She perceives the VC as likely to let her run the company with minimal

oversight. However, her perception is at odds with both academic research on VC actions post-investment and lay resources on VC processes (Atanasov et al., 2006; Barringer & Ireland, 2016; Wasserman, 2003). In fact, her perception is common enough that Barringer and Ireland attend to it explicitly when discussing investment:

> As emphasized throughout this book, lenders and investors have a vested interest in the companies they finance, that often cause these individuals to become very involved in helping the firms they fund. It is rare that a lender or investor will put money into a new venture and then simply step back and wait to see what happens. In fact, the institutional rules governing banks and investment firms typically require that they monitor new ventures fairly closely (Barringer & Ireland, 2016, p. 311)

Her conception also seems to divorce the capital received during investment from the equity distributed in response – 30% given to one investor is different to her than same 30% given to another. She focuses on her control, but sees the different modes of investment affecting that control differently – albeit in ways that are out of line with the formal processes of investment. The second part of her statement, leads to the second way in which errors in analyzing investment manifested in some participants' protocols.

4.3.2 Faulty investment analogies

Some participants also relied on faulty comparisons to other experiences as part of their analysis and interpretation of investment options. Students relying on prior experience and analogies is a common learning and sense-making strategy (National Research Council, 2012). While the strategy itself is not bad, some participants comparisons highlight either improper conflation of meaning or other conceptual problems related to investment. Examples come from Robert, Sarah, and Mia (see previous quote) in decreasing levels of explicitness. Robert's and Sarah's examples are addressed here:

> **I'd probably ask for a loan from them rather than just straight up borrowing it**. I'd say I'll pay you back – I'll give you this much interest. I'd ask them to invest in the product. I would tell them about it and show them what's going on, and I'd ask them to invest – invest cheaply. It'd probably have a low interest rate, and hopefully my friends would agree with me and help me out. (Robert)

> I would probably – I'm leaning towards either the first or the fourth option. I'm concerned, because if I convince my parents to take mortgage or borrow from old college friends and work friends it could backfire, because I know – **some people if you give them money, they expect something in return later**. So, I think I

> would try to go with parents, because I guess they'll be a little bit more understanding with what I'm trying to do. So, I'd probably go with the first one. (Sarah)

Both Robert and Sarah make comparisons between the formal methods of investment and more personal financial interactions with people that they have a pre-existing relationship with. Roberts' analysis suggests he may understand underlying concepts of investment, equity, loans, and capital. However, that he divorces borrowing and a loan as separate concepts when he talks about "straight up borrowing" as differentiated from "a loan". "Borrowing", in Robert's parlance, does not itself contain an expectation of repayment or function as capital in exchange for equity. However, "a loan" does carry those expectations.

Sarah grounds her understanding of receiving investment from friends and family with social, rather than business, conceptions of borrowing. She apparently conflates friends and family fundraising with something where repayment is not expected. Friends might not expect a something in exchange for an investment in her company, but "people" do. She then subsumes her parents borrowing money from a third party via a second mortgage into her discussion of who does and does not expect something in return. While it is not unheard of for early-stage investment to be effectively a gift, it is uncommon and potentially problematic if not accounted for (Barringer & Ireland, 2016).

Again, some participants follow paths that are fundamentally different from both expert groups in Sarasvathy's work. Sarasvathy's business strategy experts analyze the investment options based on the valuation that each option provides and the potential ROI and capital needs of the business to continue to operate and grow. Conversely, the expert entrepreneurs evaluate based on valuation but also the expertise of their potential partners. In contrast, no participants addressed the investment options provided to them as representing a valuation (each option presented a valuation, see appendix), nor did any participants consider the domain expertise of the investors. However, the participants quoted above all provided analyses of the options – based on their own, incorrect, basis for analyzing how those investment options operate. Some participants relied on misperceptions of the ease or expected involvement of VC's – in ways at odds with literature. Others focused on ensuring they retained autonomy and control and analogies to personal (and familial financial) relationships as a logical basis for their decision-making – drawing comparisons that divorce their options from basic business practices.

4.4 Evaluating exits

In the final task of the protocol, participants were provided with three options related to *exiting* their entrepreneurial venture. Exiting in this context refers to actions that create significant changes in the ownership of a company. Such actions can include the removal of a founder, conducting an initial public offering of stock, or acquisitions of a business to another. Broadly, this area would fall under the mergers and acquisition area of management and business theory (Barringer & Ireland, 2016). However, there are particular characteristics related to exits in entrepreneurial companies that are often used to differentiate the decisions – i.e., the company is young, has taken significant outside investment to aid growth, or is focused on rapid growth as a core business strategy (Ogbor, 2000). As scholars of mergers and acquisition note, the process, details, and distribution of proceeds from an exit can become very complex and vary significantly but are characterized by those besides founders typically reaping the highest rewards (Atanasov et al., 2006).

In this theme, participants made errors related to control of the business after an exit or the amount of money that they would receive. The shared characteristic of how some participants incorrectly evaluated exits was viewing them through a lens of the exit being a personal rather than company decision. There are two basic forms of error in the exiting theme. In the first, participants assume that they would receive all of the money from going public or selling the company. In the second, participants assume they would retain significant control over the company after an initial public offering of stock (IPO).

4.4.1 Receiving all proceeds of an exit

Some participants presumed that they would receive all of the proceeds of any exit from the company. This is not just highly unlikely as a global matter, but at times directly contradicts earlier decisions those participants had made to take investment in exchange for equity. Examples come from Robert, Mason, and Frank:

> So, it would be – so – and also Disney wants to buy the whole – the entire company. I don't know anything about what they're going to do with it, and I don't have any say after what they're going to do with it at that point. So, it might – it might very well – it might go very well. It might go extremely well, and **I can't see a problem with having $420 million in my pocket, but it's really not** – it's really probably not optimal to give away the entire company to a company that is – doesn't really –

> isn't very good at educational software, because if they've been trying to get into the educational software market, clearly, they're not very good at it – maybe. (Robert)
>
> And Disney wants to buy us out at $450 million. **Mm-hmm - $420 million. And that would – I would assume that would go to me.** I'm not sure how that would work out. Yeah, I mean, it would go to the owners of the company. So, depending on who you might have given equity to along the way, but you'd get a big chunk of that. (Mason)
>
> I probably would be more involved with the transition to go with the Disney route, because I'd – **I would take a smaller cut of the 42 million – or the 420 million. I would take a subsidized price off of that** if I could help ensure that the transition is smooth, that my people are safe, that the vision of the company is preserved. (Frank)

Robert is analyzing the option of selling his company to Disney (see task 9 Appendix A). He first clarifies that Disney's offer is to buy the entire company and acknowledges relinquishing control. He then comments that he does not know what they would do after purchasing the company, identifies that he would no longer have any involvement, and that the company might continue to do well. However, Robert then evaluates the personal value of the transaction to himself saying "I can't see a problem with having $420 million in my pocket." Robert is treating the offer to buy his company as one presented to him – not to the company, which is also reflected in Mason and Frank's thinking.

Robert's statement is an error for two reasons. First, while not impossible, data on entrepreneurial venture exits suggest that it is highly unlikely for him to have maintained majority control, much less 100% ownership in the company. One study found average founder ownership at the time of an exit to be 11%, with a few outliers where founders maintained *majority* but not *total* ownership at that time (Atanasov et al., 2006). General warnings that such a situation is unlikely are described in the public university textbook (Barringer & Ireland, 2012). Second, Robert's statement is in explicit conflict with decisions he made earlier in the protocol. When given investment options, Robert chooses to partner with a family friend, exchanging 30% equity for a $5m. However, he does not seem to carry that decision to his later analysis of exit options, and instead is biased towards a $420m payday.

Interestingly, Mason makes the same conflation of personal and company profit and then pauses to reconsider his confidence in his statement. Mason's self-correction occurred even though he had not explicitly given away equity in the company in the investment task. The correction

itself was unique within the examples of the exiting theme - no other participant explicitly corrected themselves when they made this type of error. However, Mason still made the same initial statement about where the money would go as Robert, which further suggests that the assertion is an error that some participants make and is not some ambiguity of meaning where the participants mean to refer to the company as a whole receiving sale proceeds.

Participants did not always explicitly state they would receive $420 million; sometimes it was implied through other elements of their analysis. Frank offers to relinquish a portion of his $420 million to maintain some input or control over the outcomes of the company post-acquisition. While generous, this suggests he believes he would otherwise receive the entire value of the sale himself. Frank's interest in exerting control over the outcome overlaps with the second type of errors that participants made when evaluating exit opportunities.

4.4.2 Maintaining control post IPO

Some participants based their decision-making in the exiting task primarily based on mistaken ideas (and their personal interest) about continuing to control the company. Collectively, they perceive that an initial public offering of shares, as opposed to a direct sale to Disney, allows them to keep running the company exactly as they want. Examples come from Alexander, Anthony, and Avery:

> **Well, if you go public, you can obviously keep running the company the way you want to run the company,** and if you get bought out by Disney, I mean, everyone – most of the people would probably still be working there. You'll still have the product. You'll be – I mean, they'll own the whole thing. They'll still be employees of Disney. So, I feel like it really – that's almost more of a personal decision. Do you want to still do the entrepreneurship thing? Do you want – do you have another idea for a company you'd rather work on and spin that off and try to sell it to Disney? (Alexander)

> So, I'm more inclined to keep ahold of the company and see it through to – by just selling off some of the shares and from going public with it. (Anthony)

> I think in that aspect there's a couple – that's an interesting – I mean, as far as the first choice, I think by releasing stocks, you're kind of leaving it up to people who generally are already kind of invested in the company. (Avery)

Alexander makes several assertions (e.g., "most of the people would probably still be working there") about the Disney acquisition for which he has little evidence to either support or

refute. However, the one that is demonstrably an error is his first statement – "if you go public, you can obviously keep running the company the way you want to run the company." This assertion is problematic for several reasons. Most importantly, an IPO does not just involve the first sale of shares to the public. An IPO also frees all equity holders (e.g., early employees, investors, etc.) to sell their own shares and introduces significant new requirements for financial reporting and disclosure, corporate governance, and managerial requirements (Barringer & Ireland, 2016). Further, an IPO naturally creates a significant loss of control with the introduction of new investors, although some tech companies (e.g., Snapchat) have sought to counter this through issuing multiple classes of shares (Farrell, 2016). Although founders can retain significant influence, the level of control is neither "obvious", to use Alexander's term, nor absolute or even likely. Other examples of participants making this error include Anthony and Avery who significantly simplify how IPOs work in similar ways. Anthony refers to the IPO as a process through which he could maintain control, again presuming he has it. Avery presumes that those who would buy stock or own stock are invested in its success, a truism taken to mean – invested in its success. Why he would make that claim about an IPO but not about a purchasing company is unknown. All rely on the implicit assumption that prior to the IPO they held majority or total control over the company and/or control the majority of the venture's corporate board. As noted earlier, this is highly unlikely.

Robert's specific articulation of this error is interesting because he highlights a specific comparative analogy that participants may be familiar with. He conflates an IPO with crowdfunding when explaining how he would maintain control post-IPO:

> Because I'm not giving up the entire company. It's two million out of twelve million shares, and **crowdsourcing has proved to be a verifiable resource for other companies** (Robert)

Robert's statement is notable because it presents a specific analogy he sees as relevant and descriptive of the IPO option in exiting, but one which is inaccurate. His analogy ignores that crowdfunding participants have no corporate governance rights, little legal recourse, and generally are more akin to a method of (pre-)sales rather than investment[20]. The analogy also ignores prior equity that he has given away, but he finds it useful.

[20] Kickstarter, the largest and likely best-known crowdfunding site, explicitly bans crowdfunding campaigns from offering equity as an incentive because such an offer is in violation of Securities and Exchange Commission (SEC) rules around qualified investors (https://www.kickstarter.com/rules)

The participants who made errors in this theme generally suggest a blurred line between the participant as founder and the company itself. Several experts in Sarasvathy's study mentioned personal interest in running the company in their evaluation of the exit options. For the investment bankers, that interest was secondary to an analysis of the value of each option. For the expert entrepreneurs, the order was reversed. However, both groups clearly separated the company and its value from their individual potential benefit. The money received through an IPO or any other exit goes to the company, as it is the company selling shares or being sold to another entity. Despite the reality that IPOs often significantly benefit founders, the realization of the benefit is indirect (Atanasov et al., 2006; Barringer & Ireland, 2016). As with conflating revenue and salary, the participants conflate direct proceeds of the IPO with their own personal benefit as the company continues to grow. While there are other mechanisms for compensation, the value of the shares is as an asset (i.e., X shares valued at Y dollars) that must be sold to realize a liquid asset (i.e., cash). However, these participants seem to blur those lines – failing to separate the value of the shares they own from a singular payment they receive and can spend immediately.

4.5 Higher level assumptions as cross-conceptual categories

In the introduction, I noted that part of the purpose of this study involved evaluating and documenting any structure in participants' errors as part of the process of fully describing them. Introducing structure and even hierarchical levels is part of the thematic analysis methodology, if the identified themes support such inferences (Braun & Clarke, 2006). In the case of my results, the introduction of a taxonomic structure of the themes is both relevant and useful to understanding the final two themes and their relation to the first three themes.

The taxonomy of the themes appears in Figure 3. It has three levels: manifestations, conceptual errors, and higher-level assumptions. The three previously described themes fit into the middle area and represent areas of conceptual knowledge from the management and business field where participants made errors. In each of those three areas, two specific manifestations of those errors (the lower level of figure 3) were described and supported using quotes from student protocols. Each of the areas of conceptual error is independent of the others and links to specific areas of business knowledge that can be discussed independently. Each of the manifestation's also link to one area of conceptual error. While it is possible for a given manifestation to reflect more than one type of conceptual error, I identified no such cases in my data.

The two remaining themes are part of the upper level of the taxonomy; higher-level assumptions about entrepreneurs and entrepreneurship. The higher-level assumptions are different from the conceptual errors in that they are not related to a specific area of business concepts such as market research. Instead, they reflect considerations and constructs that are pertinent to multiple areas of business theory. In the results of my study, the two higher level constructs are how students make assumptions or assertions about the control or value of the venture described in the protocol. Control and value, as noted, are aspects of business decision-making that are relevant across many concepts within the field. In the data, students (over)estimation of the value of their venture was apparent in errors quoted in both the evaluating exits and interpreting market research themes. Similarly, students making assumptions or demands that centered their own supposition of their control of the venture as the founding entrepreneur, was apparent in the analyzing investment options and evaluating exits theme.

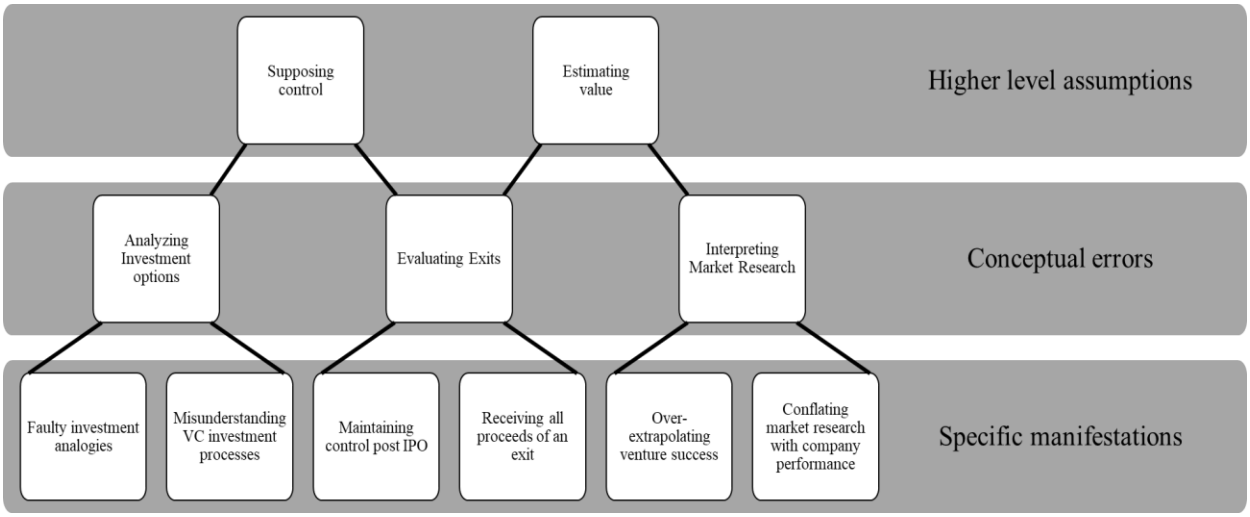

Figure 3. Hierarchical taxonomy of results

The two sections below describe each of those themes, in turn. As with the other three themes, quotes and resources are used to describe participants' thinking and to unpack why the thinking is an error that fits the theme. Readers may note that the quotes in these two themes are all repeated from the prior section. That is a conscious choice to show how the errors described in the first three themes also fit into the higher-level assumption themes. It is also helpful because the basic error in the quotes is already established. The higher-level assumptions are errors at a

more abstract level, and having that direct establishment in hand is useful for clearly describing the final two themes.

4.5.1 Estimating value

Valuation within the context of the verbal protocol refers to a negotiation or assertion of the worth of the company. As explained by Barringer and Ireland (2016), Within typical entrepreneurial ventures, a valuation of a company typically occurs when outside investment is taken. The specific valuation of a company is often negotiated as part of the investment process. From the details of outside investment, the value of a company can be established based on the abstracting the amount of money invested for a given share of the equity in the company. For example, an investment of $1 million for a 5% share of a company establishes the value of the company as $20 million at that point in time. There are many other ways of calculating valuation, including a discounted cashflow model, but the so called 'market valuation' approach is normal and is the method of valuation that Sarasvathy (2008) implemented in multiple parts of the protocol.

In multiple protocol tasks, when participants made estimating value errors, they were interesting for their consistency: Each inflated the value of the company in ways much greater than any evidence supports, and ignored evidence to the contrary. As is explained further in the discussion section, these errors represent a consistent unchecked pattern in some participants that entrepreneurial ventures, especially technology ones, are inherently extremely valuable. This pattern occurred in the use of several different financial markers Examples of this theme include:

> The family friend with the extensive experience in selling educational products would be – would probably be very good given that there was approximately $1.7 billion in instructional technology. **So that would be who he would be working with the most, and so if it's $5 million that he would be investing, and then the estimated value is 1.7 billion with 20% growth**, I guess this would be a couple of years down the road. It'd be even higher than that. The 20% per year for the next five years could – at the end of these five years where it's expected to grow, it'd be worth – just like the rough numbers, **it'd be like $3 billion for a $5 million investment that someone gets 30% of** (Todd)[21]

> so, let me just – [INAUDIBLE] 25, so then that's – [INAUDIBLE] change that to a 3.8. So, then that's four fours – that's 16 – four, five, six, and eight – that is a –

[21] The reuse of quotes in the estimating value and supposing control sections is an intentional choice. Reuse of quotes helps clarify how the higher-level categories described in this section are reflected in quotes previously described as errors related to different concepts.

> still a billion dollar in sales. So, I think, yes, I do want to focus it on the adults (David)

> So, it would be – so – and also Disney wants to buy the whole – the entire company. I don't know anything about what they're going to do with it, and I don't have any say after what they're going to do with it at that point. So, it might – it might very well – it might go very well. It might go extremely well, and **I can't see a problem with having $420 million in my pocket**, but it's really not – it's really probably not optimal to give away the entire company to a company that is – doesn't really – isn't very good at educational software, because if they've been trying to get into the educational software market, clearly, they're not very good at it – maybe. (Robert)

These quotes show how the pattern of overestimating value occurs across several of the themes already described. When that pattern occurs, the overestimates are not small in nature. Todd's example is particularly interesting because of where it occurs in the protocol. Todd is discussing taking investment from a family friend. Per the protocol (see task 4 in Appendix A), the friend has offered $5 million dollars in exchange for 30% of the company. That offer proposes a valuation of the company as approximately $16.7 million. However, Todd ignores that proposal as an estimated valuation of the company. Instead, Todd asserts the value of the company as $1.7 billion, based on the market research data alone. That assertion is approximately 100 times higher than the valuation that was offered to him. The full quote suggests that Todd understands that the offer is for $5 million for 30% of the equity in his company, but not that such an offer represents a way of establishing a value of the company. Instead Todd, as does David, draw on the estimate of the market's size as the estimate of value.

In David's quote, he overestimates the value of sales from the company. As does Todd, David assumes the entire market share, with both of them ignoring any potential costs and simply look at the upside. Such estimates of the value of the company are not just wrong because they are too large, they are wrong because they are explicitly countered by information in the protocol. Just as Todd ignores calculating the valuation proposed by the family friend, David ignores three separate instances where he was provided data on the amount of sales his company is making. Instead, he picks a larger number and relies on it (see Tasks 3, 7, and 9 in Appendix A).

As with Robert's estimate of his personal proceeds, the error here is a starting assumption that his company is highly valuable – an assumption that is maintained despite evidence to the contrary. Common to all three is that each treats treat information provided to or created by the participant as direct measures of the company's value instead of measures of other factors (e.g.,

revenue, market size, purchase offer) that relate to the company's interaction with the larger world. In doing so, the three participants' thinking is grounded in an assumption that the company is, or rapidly will become, highly successful.

These patterns result in conclusions that are again at odds with Sarasvathy's research subjects. Sarasvathy's (2008) experts immediately recognized the fairly basic financial information provided for what it could and could not tell them. Estimates of market size were disregarded by expert entrepreneurs as not relevant to establishing and growing the business. Offers of investment were immediately recognized as valuation of the company and compared against revenue as well as non-financial factors. The expert entrepreneurs in her study take fundamentally different approaches to decision-making and find the financial markers uninteresting. However, nearly universally in Sarasvathy's reporting, that disinterest is driven by a clear and deep understanding of what the financial markets can and (more importantly) cannot tell them. Compared to the enormous estimates of enormous value from some students, one participant in Sarasvathy's study began by stating "I don't think it could ever be a huge company' (Sarasvathy, 2008) and later went on to say "and therefore you could see a several hundred-million-dollar company coming from it" – a valuation still 10 times less than that assumed by several participants from the first task in the protocol.

4.5.2 Supposing control

The final theme relates to how students perceive control of the theoretical venture that is the basis of the verbal protocol. Control here refers to how much influence one possesses over major decisions in the venture – such as what products to begin offering, what partnerships to join, and whether to take an acquisition offer. Within both public and private companies, such major decisions occur within a hierarchy that begins within individuals and company leadership (e.g., a CEO) but also includes corporate boards, shareholder input, and other forms of oversight (Barringer & Ireland, 2016). Typically, boards are heavily involved during growth stage entrepreneurship – with representatives from investors holding significant sway and often replacing founders in cases of disagreement over the course of a venture (Atanasov et al., 2006). In a publicly traded company, a corporate board of directors is required and represents shareholders' interests.

Throughout the protocols, some participants focused their decision-making and motivation on aspects of control that rely on incorrect presumptions about corporate control. Statements to this effect occurred in, or were implied in, other decision-making by participants. However, for several participants the statements were made quite directly. Examples include:

> So as long as like – I would need her [note: the VC] to assure me that I'm in charge and that if I want to drop this at any time, like it's not going to hurt me – like that sort of agreement. It's not going to come back to bite me or anything like that (Eric)

> Well, if you go public, you can obviously keep running the company the way you want to run the company, and if you get bought out by Disney, I mean, everyone – most of the people would probably still be working there. You'll still have the product. You'll be – I mean, they'll own the whole thing. They'll still be employees of Disney. So, I feel like it really – that's almost more of a personal decision. Do you want to still do the entrepreneurship thing? Do you want – do you have another idea for a company you'd rather work on and spin that off and try to sell it to Disney? (Alexander)

The first quote, from Eric, also appears in the investment theme. As described in that theme, Eric's particular assertion of control – that he can "drop this at any time" is problematic within entrepreneurial contexts. He appears to assume that such a request for control is within his negotiating power as an entrepreneur seeking investment, almost certainly overestimating the control or power he holds in negotiating investment as well as in continuing work on the venture. The suggestion is in conflict with the most likely path by which a founder exits a venture funded business – being fired by his investors (Atanasov et al., 2006). Eric seems to misunderstand the variables at play in terms of control in an early-stage company by isolating control over his own decision-making from the venture. His focus on his control over his choices pre-supposes that his decision to leave if he loses interest as the key factor. His discussion of control is also never linked to the equity that the VC would receive in exchange for their investment. The two are treated entirely separately.

The second quote, from Alexander, also appeared in the exiting theme. Alex's analysis shows a lack of awareness of the governance structures at play with a public corporation. He makes a similar analysis to Eric when discussing whether he wants to run the company or Disney as the owner. However, Alexander's statement assumes that a publicly run company allows him full control to direct the company as he sees fit. As described above, that is incorrect.

In both of the situations, the participants' words suggest a significant overestimation of the control they as the entrepreneur possess, will possess, or even can possess. That overestimation

specifically presupposes that they have full control at the current point and is used as a key variable in decision-making in their company as different major events in the company's development (e.g., investment or an IPO) occur. Their analysis ignores generally delinks control from related financial considerations such as equity holding and the resulting control they have already given away by taking investment or by selling shares.

Interestingly, of all the themes of errors, discussion of control has closer surface-level analogs in Sarasvathy's (2008) expert studies. Both groups considered their interest, motivation, and ability to control the future path of the venture in their decision-making – as Eric and Alexander do. However, the experts thinking is still quite different and avoids Eric and Alexander's errors. The experts first analyze control in terms of what controls they have, both equity control and political capital within their venture. They acknowledge and discuss the role of their corporate board and how the influence they might or might not have in the formal decision-making. *Only after* analyzing such aspects of control present in the decision so do both groups of experts turn to personal considerations such as their interest in this type of company.

5. DISCUSSION AND CONCLUSIONS

My final chapter is divided into two subsections, a discussion section and a conclusions section. Primarily, I use the discussion to situate the patterns of engineering students' errors in entrepreneurial thinking to three areas of literature I introduced in the literature review – misconceptions, myths, and engineering entrepreneurship education. Then, I use the conclusions section to explicitly describe the contribution of this study, its implications, and important future work.

Broadly, understanding what types of errors students make is useful for improving any type of educational intervention. However, situating the patterns of errors in those existing areas of literature, the patterns of errors highlight new direction, and challenges, for research on engineering entrepreneurship education. In totality, I use the discussion chapter to explain how my results provide empirical evidence to support the theoretical concerns made in work by Huang-Saad et al. (2018), and Purzer et al., (2016). Prime among them is the lack of validity[22] of existing theories of entrepreneurship as theoretical frameworks for studying engineering entrepreneurship education. As a refresher, the research question driving my dissertation is:

What patterns of errors are observable in engineering students when they work to make decisions typical of early-stage entrepreneurship?

Towards answering that question, in the results chapter I used verbal protocol data from engineering students to establish two claims:

1. Engineering students employ entrepreneurial concepts in ways that are incorrect (i.e., the participants make errors)
2. Across participants, errors occur in patterns with consistent and identifiable characteristics (i.e., there are themes in the errors)
3.

[22] Throughout this chapter, I use the term validity in a general sense. My use encompasses terms typically used to characterize quality in both the qualitative (e.g., trustworthiness and credibility) and quantitative research paradigms (e.g., validity and reliability). This use of validity is focused on evaluating the credibility of arguments for using theories of entrepreneurial expertise (like ToE) as grounding in engineering education.

The results chapter provides credible evidence to support both of those claims – i.e., that there are common patterns of errors in engineering students' entrepreneurial decision-making. Summaries of those patterns are repeated in Table 7.

Table 7 Summary of error themes, repeated from Table 6.

Theme	Summary description *(Some participants…)*
(Over)Interpreting market research	Interpret information about markets by conflating that information with company performance, and over-extrapolating the success of their venture.
(Mis)Analyzing investment options	Analyze investment options by differentiating them based on incorrect personal beliefs about investor input, ability to retain control, and ease of access.
(Mis)Evaluating exits	Evaluate exits as a personal decision rather than business decision and presume they retain control and proceeds of any sale of the venture.
(Over)estimating value	Ignore information about the valuation of their venture that is given to them, and instead assume other financial information as measures of high value.
(Pre)Suppose control	Assumption that they possess, can assert, and will retain control as the founder of the venture, despite earlier having taken outside investment in exchange for equity.

To evaluate the validity of using theories of entrepreneurial expertise in engineering entrepreneurship education, and to explain the importance and contribution of the results, the discussion chapter situates comparisons of students' patterns of errors to the Theory of Effectuation (ToE) in three areas of literature. First, I situate the patterns of errors in the misconceptions literature to establish that students' hold misconceptions. That literature establishes that the patterns of errors are indicative of misconceptions about entrepreneurship and, by extension, that engineering entrepreneurship education should engage with conceptual change literature in curricular development. Here, comparison to fundamental characteristics of ToE helps illustrate that the patterns of errors strongly suggest an ontological miscategorization which should be confirmed through future work. Second, I situate the patterns of errors in the entrepreneurial mythicization literature to highlight similarities between the patterns and common myths about entrepreneurship. Here ToE provides a differentiation between two types of expert thinking and thinking based on myths about entrepreneurship. The mythicization literature is important to identify an area of research that engineering entrepreneurship faculty can use to predict or understand beliefs that students hold that they may wish to disrupt. Lastly, I situate the patterns of errors within existing research on entrepreneurship education. Here, ToE provides a representative example of the types of expert-derived and expert-comparative theories of entrepreneurship that are frequently used in engineering entrepreneurship education. That comparison shows how

participants' thinking does not comport with either type of expert logic in ToE - instead it often mixes from both. Evidence that students' thinking is different from both types of experts highlights the limitations in using ToE, and similar expert-comparative theories of entrepreneurship, as a theoretical framework to study engineering students.

5.1 The errors and misconceptions

Situating my results within the misconceptions literature is made more difficult because prior research has focused on misconceptions related to natural phenomena and concepts from scientific disciplines (c.f., Chi, et al., 2006). That is, fields with an objectivist approach to truth and discovery. In doing so, a normative, but not explicitly stated, standard has emerged for declaring a type of error to be a misconception. That standard is to identify the alternative ontology that students employ (Chi, 2008). Both the prior focus on misconceptions about phenomenon treated as objectively true, *and* the standard of identifying alternative ontologies affect efforts to interpret the themes of errors as misconceptions. However, it is important to also note that there is ongoing work to broaden discussions about misconceptions from solely focusing on errors on concepts to errors on processes as well – which shows that misconceptions are not limited to the facts of natural phenomenon (Chi, 2005; Miller et al., 2008).

In summary, it seems likely but cannot be clearly established from my results that engineering students rely on misconceptions about entrepreneurs and entrepreneurship in their decision-making. To reiterate from chapter 2, I adopt Chi's (2015) definition of misconceptions - thinking errors that manifest from *ontological miscategorizations* rather than lack of knowledge. As is described in the next section, the patterns of errors closely align with myths about entrepreneurs and entrepreneurship. That alignment and my data strongly suggest that students may rely on those myths as an *intuitive ontology* (Henderson, et al., 2018, pg. 26) about entrepreneurship, one which makes sense to students because it has been reinforced through the same myths that create it.

However, such a claim necessitates further evidence because of a key difference between my study and prior work in the field. The difference is primarily in how such alternative ontologies are identified. The primary method to date of identifying misconceptions is through the identification of alternative ontologies in studies of students problem solving (Chi, 2015; Henderson, et al.,; 2018). In the natural sciences, where most misconceptions research has

occurred, notions of a correct ontology are treated as objective, external, and accepted. That is, studying students' errors directly, and understanding their ontological differences from accepted practice, is the implied normative practice (e.g., Steif, 2008; Henderson et al., 2018) – although such a standard has never been directly articulated.

In contrast, my work relies on a less direct method of identifying alternative ontologies which has not been incorporated into misconceptions research. That is, it is a study of students' broad thinking, rather than specific areas where errors are known and accepted. This limits the ability to richly describe the errors and directly identify any alternative ontologies on which they rely. Instead, the identification of alternate ontologies relies on critiques of entrepreneurial ontologies (i.e., mythicization) and evidence that student thinking is similar to them. The indirect method is novel, but it is also necessary for any field that is not reliant on a paradigm where phenomena are described by an objective and external researcher. Because business and management do not have a defensible and generally accepted normative ontology, identifying misconceptions solely through differentiating students' thinking from accepted conceptual understandings is impossible, and an external reference describing and/or critiquing the ontology is necessary to establish an ontological miscategorization. *However,* independent of how the alternative ontology is identified, deeper evidence of students' ontological conceptions of entrepreneurship and the manifestation of those errors is useful to establishing a novel claim about misconceptions outside of natural phenomena. Establishing clear criteria for claiming misconceptions would be a useful future contribution to work that seeks to improve the handling of misconceptions and their usage, e.g., concept inventory development (Steif & Dantzler, 2005; Jorion et al., 2015).

Despite not yet being able to assert that the themes of errors are misconceptions, it is useful to link the *potential* misconceptions to the conceptual change literature. Chi is clear that misconceptions necessitate deeper forms of cognitive shifts as opposed to relying on exposure to new information to achieve correct conceptual understanding - that is, a different approach to education that does not rely simply on filling in knowledge gaps (Chi, 2008; Streveler et al.,, 2008).

The results are similar to one specific form of misconception discussed in work by Henderson et al., (2018) and by Chi (2005): The treatment of emergent processes as direct processes. As explained in detail in the literature review, direct processes are those in which components are distinct, dependent on each other, sequential, and predictable – if something

happens with one component, subsequent component actions can be *presumed*. Emergent processes, in contrast, are simultaneous, independent, continuous, and potential outcomes are unconstrained – if something happens with one component, subsequent component *may* happen. Chi describes a precise separation of the direct and emergent processes as "probably impossible" (pg. 161) but notes key characteristics and uses the analogy of a light switch vs. a hurricane to explain the difference. A light switch turning on a light bulb is a direct process; one can presume the light will come on if the system is functioning correctly and presume system dysfunction if it does not. A hurricane forming from a low-pressure area is emergent, it may or may not happen although a probability can be assigned to it and, in theory, it could be influenced.

In the patterns of errors, participants' thinking seemingly reflects an unconscious treatment of the entrepreneurial processes as direct rather than emergent. That is, potential outcomes such as profitability or success are incorporated into participants' thinking as inherent. Treating entrepreneurial success as a direct process manifests in several quotes introduced in the results:

> so, let me just – [INAUDIBLE] 25, so then that's – [INAUDIBLE] change that to a 3.8. So, then that's four fours – that's 16 – four, five, six, and eight – that is a – still a billion dollar in sales. So, I think, yes, I do want to focus it on the adults (David)

> Personally, I think the company is very profitable as-is. I think that we've made like leaps and bounds over just the past six years. The fact that we're selling this many products to such a wide range of people (Sophia)

> …I can't see a problem with having $420 million in my pocket, but it's really not – it's really probably not optimal to give away the entire company to a company that is – doesn't really – isn't very good at educational software, because if they've been trying to get into the educational software market, clearly, they're not very good at it – maybe. (Robert)

David's quote is representative of a several participants who presume 100% market share (i.e., no competition) and sales to 100% of the total market (i.e., every single adult) from market research data, i.e., that the company will be financially successful. Sophie presumes the company will be profitable (i.e., successful) based on her interpretation of the data showing growth as well as continued yearly overall losses. Robert presumes that the only reason another company would seek to buy his company is because his company is better (i.e., successful). Multiple participants actually maintained a belief in the profitability or value of their company, like Sophia, in the face of direct evidence during certain tasks that should refute that belief.

When analyzed using either of the types of logic described in ToE, the market research information presented to participants does not support the inferences participants make. To David's claim, the causal heuristics from traditional business decision-making support using the market research to estimate sales by assign probabilities. Such an analysis would use probabilities to estimate the impact of competition and of a less than total market saturation in estimating probable sales. The effectual heuristics of expert entrepreneurs dismiss the usefulness of the market research data because such probabilities cannot be accurately assigned and use other methods of engaging with emergence. In contrast, David neither assigns probabilities nor dismisses the usefulness of the data – instead presuming that data is *descriptive* of his company's success, a phenomenon repeated by other participants. Similarly, Sophia asserts the company is profitable, without data about costs – causal heuristics would conclude that is untrue, effectual heuristics would conclude being profitable is not relevant during the growth stage. Key to these examples is not that their thinking differs, David is not an expert and knowledge about how to properly use market research cannot be assumed.

However, misconceptions and conceptual change do not rely purely on gaps in knowledge or self-created alternate ontologies. What is key to the examples above is how the thinking differs from experts *as well as* the similarities of students' thinking to entrepreneurial myths and noted flaws in entrepreneurial research (Ogbor, 2000). Ogbor and others propose that mythicization has introduced epistemic and ontological simplifications into public discourse on entrepreneurship. If that is true, then such discourse would seem a likely source of intuitive, but faulty, ontological bases for entrepreneurial decision-making. The treatment of entrepreneurship as a direct process would be a logical extension of the hypothesis of entrepreneurial myths subsumed as an aberrant novice ontology.

Entrepreneurial success *is* a highly emergent process, one where success is far from guaranteed, and dependent on many decisions where the decision maker possesses limited control (Sarasvathy, 2001, 2008; Wiltbank et al., 2009). While research poorly represents that reality, the uncertainty of entrepreneurship is as accepted as the relationship between temperature and heat energy. Measures of successful entrepreneurial outcomes (e.g., high value, investment, and profitability) are potential or possible outcomes rather than certainty. VC investment may or may not happen, it can be influenced but not presumed. The company may or may not succeed, financial models can be created, but are inherently probabilistic (Knight, 1921). ToE (Sarasvathy, 2008)

describes two methods of interacting with emergent processes (i.e., entrepreneurship) – the causal logic approach of investment bankers where the most likely outcomes are predicted and effectual logic where opportunities to influence different potential outcomes are identified. Both approaches fundamentally seek to interact with potential outcomes in the most effective way, they do not presume an outcome.

Work on conceptual change has established the approach as an effective foundation for developing teaching and learning when it is not possible to assume total lack of prior knowledge (Chi, 2005, 2008; Chi et al., 1994; Henderson et al., 2018; Streveler, et al., 2008). Chi (2008) identifies three processes by which conceptual change can occur: belief revision, mental model transformation, and categorical shift. In the introduction to her work, she identifies and differentiates three conditions of prior knowledge that are encountered in a classroom – missing knowledge, incomplete knowledge, and conflicting knowledge. Belief revision is appropriate when existing knowledge is either missing or incomplete – a student might understand that profit is a metric of a company's financial performance, but not deeply understand its exact meaning. Here, the Public University's textbook might be revised to address the definition of profit and reinforce it in later examples, as opposed to presuming it is within students' prior knowledge. However, Chi identifies misconceptions about emergent vs. direct processes as grounded in conflicting knowledge that requires categorical shifts in ontological categorization. That shift is necessary because conflicting knowledge cannot be sufficiently solved by adding new information (Chi, 2005; 2008). Situations of conflicting information are less likely to be fixed by interactions with correct information, even when repeated. That is because the mental models resulting from conflicting information are internally coherent to students, even if they are externally incorrect. Instead efforts to directly refute and make visible the conflicting knowledge alongside representations of correct knowledge are necessary. Both new information to address missing or incomplete knowledge, and direct refutation of conflicting knowledge can aid in creating the conceptual change necessary to address students' misconceptions about entrepreneurship.

However, addressing conflicting knowledge is an issue as yet missing from the entrepreneurship education literature – in fact the specific conflicting knowledge at play is reinforced in both research and media myths about entrepreneurship. In other words, the mythicization of entrepreneurship, its focus on describing experts, and its focus on replicating success means a lack of contrasting cases that can be used to disrupt potential misconceptions or

even more surface-level aspects of decision-making (Ogbor, 2000; Omid, 2000; Sarachek, 1978). Going forward, conceptual change represents a fundamentally different way of teaching entrepreneurship that can be informed by myths about entrepreneurship, about pre-requisite knowledge and beliefs, and engages with the limits of entrepreneurship theory. Such an approach is increasingly, albeit indirectly, called for in discussion of entrepreneurship education literature (Fiet, 2010; Fayolle, 2013; Fernandez et al., 2017).

5.2 The errors and entrepreneurial myths

Whether or not the themes meet the misconception definition, they should be of particular interest to a number of stakeholder groups because the patterns are similar to the myths about entrepreneurs described in research. That there are similarities between the patterns of errors and the myths is not all together surprising, as the myths are common in public media about entrepreneurs, a likely source of students' prior knowledge about entrepreneurship. Therefore, the myths represent a logical, but not yet empirically supported, source of errors – representations of entrepreneurship that reinforce myths lead to what Chi calls "intuitive ontologies" about entrepreneurship over time (Chi, 2005; Chi & Slotta, 1993; Keil, 1979).

Primary among entrepreneurship myths is Darwinian idealism, within which the ideal entrepreneur survives and should be studied/replicated as brave, rational, risk taker and as a strong individual - i.e., a hero (Ogbor, 2000). Reliance on these myths is not reflective of a fault in students' thinking, but rather indicative of their exposure to it. Statements reflecting myths of individual entrepreneurial success are so dominant they have become points of conflict in US presidential campaigns. Laird provides an example, which is indicative of how the idealized narrative of individual founders is treated as sacrosanct in American society:

> In the heat of the 2012 US presidential campaign, Republican candidate Mitt Romney declared, 'To say that Steve Jobs didn't build Apple, that Henry Ford didn't build Ford Motors, that Papa John [Schnatter] didn't build Papa John Pizza. … To say something like that, it's not just foolishness. It's insulting to every entrepreneur, every innovator in America.' Romney was responding to his rival, Democratic incumbent Barack Obama, who had asserted that 'wealthy, successful Americans' required infrastructure and education to achieve their goals. 'Somebody helped to create this unbelievable American system that we have,' Obama claimed, 'that allowed you [business people] to thrive.' In Romney's telling of these American success stories, Jobs, Ford, and Schnatter deserve esteem as self-made men, as triumphant individuals. In Obama's telling, individual success and

> national prosperity require community support as well as individual effort. These competing symbolic narratives support opposing perspectives on what individuals owe their communities and should expect from them. (Laird, 2016, pg. 1201)

The following two subsections explain how the patterns of errors mirror some of the myths about entrepreneurs and entrepreneurship highlighted in literature. Specifically, it described how two of the themes of participant errors, Control and Success, parallel two myths about heroic entrepreneurs (Ogbor, 2000; Anderson & Warren, 2011; Dean & Ford; 2017). Similarities between participants' thinking and myths about entrepreneurship is not evidence of an error or a reflection of the quality of their thinking. Rather, it reflects connections between discourse and students thinking – highlighting one potential source of the conflicting knowledge described earlier. From these overlaps, educators can identify a new area of literature to help identify and understand problematic prior knowledge in engineering entrepreneurship classrooms and research.

However, key to understanding the relationship between these two myths and students' thinking is the relationship of the errors, students decision-making, and existing literature on decision-making strategies. Both of the expert groups in ToE employ decision-making strategies that are internally consistent, or rational links between uncertainty and the use of data to inform decision-making. The strategies both employ consistent, but different, perspectives on the validity of data, partnerships, competitors, and the value or risk of lack of certainty. Whichever perspective one of the experts adopted, both used that perspective to inform decision-making itself.

The investment banker strategies have significant support in literature, whereas the strategies employed by entrepreneurs had not been previously observed (Sarasvathy, 2000;2008). That the effectual strategies had not been previously observed is a source of critique of the effectual heuristics (Arend et al.,2015; 2016). However, the adoption of the heuristics in further research in part relies on the fact that researchers perceive them as coherent alternatives that can be compared against each other as to how each informs a given decision (Chandler et al., 2009; Koivumaa et al., 2013; Agogue et al., 2015; Makimurto-Koivumaa et al., 2013). Some have looked specifically at why the effectual heuristics have not previously been observed. Scholars suggest that the lack of prior observation reflects an over reliance on using known methods as a lens for what is correct, not because the effectual heuristics are fundamentally worse decision-making approaches than the causal ones (Agogue et al., 2015; Fisher et al., 2012). The choice of one or the other is subjective but, when used by experts, both represent an informed choice that the experts can articulate – a key differentiating characteristic of expert studies (Haynie et al., 2010).

The themes of errors in engineering students' thinking show a critical deviation from the effectual or causal heuristics – because they frequently represent claims about what data means or are used to validate incorrect claims gathered from the information. The errors are not ones of an informed subjective choice wherein students consciously select a different decision-making strategy from either type of expert. Instead, they represent interpretations from information, or simply claims about reality, wherein the myths about entrepreneurs appears to function as participants' lens on reality – i.e., an intuitive, and mythicized, ontology. That highlights a key difference between experts and novice entrepreneurial thinking noted by Haynie et al. (2010). To use Haynie's language, the difference is not the choice, but the how and why of that choice – which ToE's experts ground in first principals of business, and which the participants' errors seem to ground in myths about entrepreneurs. When incorrectly employing well-established concepts that are familiar to both types of experts studied by ToE, the errors are inadequately explained by referring to them as a different subjective strategy choice. The examples in the following subsections explain how the reliance on myths about entrepreneurs and entrepreneurship can be differentiated from a different decision-making strategy.

5.2.1 Entrepreneur as individual, independent, and exclusive decision-maker

The first myth is of entrepreneurs as individual actors who are responsible for decisions, effect success or failure, and are in control of their company. In some of the earliest academic research on entrepreneurship, Schumpeter sought to study the process of entrepreneurship to understand causal determinants of why certain entrepreneurial *organizations* were successful (1921, 1927). For convenience, his chosen unit of study was the individual at its head, not the overarching organization. That focus on the individual as decision-maker reflects a dominant trend in entrepreneurial research that extends to ToE. In ToE, studies of individuals' decision-making (both entrepreneurs and investment bankers) are used as proxies for studying organizational decision-making processes. More recent work seeks to disrupt this approach. Anderson and Warren (2011) note:

> [Our] theoretical framework accords entrepreneurial agents their due, but also allows us to recognize that the social structure, and entrepreneurs' relationships with that structure, its meanings, norms, beliefs and values, are an intrinsic part of the entrepreneurial process. In this way we can avoid the problems of methodological individualism, where too much explanatory power is attributed to

> an entrepreneurial agent at the cost of underestimating the constraints (and opportunities) of structure. (pg. 591

Their goal is an entrepreneurial discourse that decenters the individual so as to avoid "stereotypes and caricatures" (pg. 593).

However, statements across multiple patterns of errors reflect students' framing of their individual control as central to the entrepreneurial venture:

> I think I would go venture capitalism. That was my gut, because to me 30% of the company is still enough – or I guess I would still have 70%. Seventy percent is still enough where I have the **– I still own the company. I still have the votes**. They have a little bit of an opinion, but if I'm a little blip on their venture capitalism screen, they might say a couple of things to me once a year, but other than that, they're just kind of over – overlooking me. The 30%, though, from a family friend concerns me, because then I see you on the weekends, and you're way more invested. I see you every day at work, and what if you and I don't agree on something and I pull my 70% weight? Do you take out your five million dollars? What happens then? (Mia)

> So as long as like – **I would need her [note: the VC] to assure me that I'm in charge** and that if I want to drop this at any time, like it's not going to hurt me – like that sort of agreement. It's not going to come back to bite me or anything like that (Eric)

> **Well, if you go public, you can obviously keep running the company the way you want to run the company,** and if you get bought out by Disney, I mean, everyone – most of the people would probably still be working there. You'll still have the product. You'll be – I mean, they'll own the whole thing. They'll still be employees of Disney. So, I feel like it really – **that's almost more of a personal decision.** Do you want to still do the entrepreneurship thing? Do you want – do you have another idea for a company you'd rather work on and spin that off and try to sell it to Disney? (Alexander)

The example from Mia is particularly interesting because it employs two different observations about control to analyze investment choices. First, the variable of financial control is apparent in her analysis of a potential investments from both a family friend and a VC firm. She notes that both are offering her investment for a 30% equity stake, and she retains 70% - which means she has majority control of the company. However, she differentiates the 70% of one option from 70% in the other option. That analysis is grounded in a second variable of control: Investor engagement. Mia values the VC option over the family friend because she perceives herself to retain more influence and control – choosing perceived minimal VC oversight over the family friend's active engagement. Mia's focus in analyzing the investment options was maximizing her

control, she did no analysis of which option best served the interests of the larger business. Eric's approach is similar – seeking assurances that he is in charge, and that his personal autonomy would not be interfered with, despite taking VC money.

Alexander applies a similar focus on individual control to analyzing exit opportunities that is more explicit about the individual control myth. Rather than noting control as something that he is seeking (i.e., as Mia and Eric did), Alexander observes that individual control is something 'obvious' that he possesses. He approaches the IPO option as different from an acquisition because the later ensures someone else will have control, which he views as a critical point of evaluation. His evaluation of the relative value is notably 'more of a personal decision'. As noted in the results, his evaluation is actually similar to logic expressed by some of the entrepreneurs in Sarasvathy's (2008) original study – who used personal interest as part of decision-making in the exit task. However, while the experts contextualized their decision within the amount of the company they were likely to still own at that stage and the best valuation, Alexander does not. Instead, personal control and interest represent the totality of his analysis.

Each example bases decision-making on presuming they possess control and ensuring the participant retains control. None of the examples explicitly engage with or state that entrepreneurs are in control of their company, rather each internalizes the myth as a lens of analyzing decisions related to control.

5.2.2 Entrepreneur as wealthy from a successful venture

The dominant entrepreneurial discourse almost universally focuses on successful entrepreneurs for description and study – typically applying the expert label based on measures of financial success. Based on their financial success, these entrepreneurs are presumed to be behaving in economically rational ways – i.e., an assumption that correct decision-making and behaviors creates success (Dean & Ford, 2017). Research designs frequently seek to understand some new, previously unknown, rational behavior they exhibit. This concept has been repeatedly critiqued, especially for the ways in which it serves to delegitimize discourse that does not model norms from dominant groups – e.g., white and male entrepreneurs (Ogbor, 2000; Dean & Ford, 2017; Laird, 2017). Particularly, the focus of this myth is on personal financial success, through entrepreneurship, as a marker of correct entrepreneurship, rational behavior, and expertise.

As with the myth about individual control, participants' errors frequently grounds decision-making in their personal financial gain through decision-making. That is, seeking personal financial gain is not an outcome that students target, but rather an assumption from which they begin their decision-making, because it can be assumed from their entrepreneurial work. This phenomenon is most apparent in examples from the exit task:

> And Disney wants to buy us out at $450 million. **Mm-hmm - $420 million. And that would – I would assume that would go to me.** I'm not sure how that would work out. Yeah, I mean, it would go to the owners of the company. So, depending on who you might have given equity to along the way, but you'd get a big chunk of that. (Mason)

> I probably would be more involved with the transition to go with the Disney route, because I'd – **I would take a smaller cut of the 42 million – or the 420 million. I would take a subsidized price off of that** if I could help ensure that the transition is smooth, that my people are safe, that the vision of the company is preserved. (Frank)

> It might go extremely well, and **I can't see a problem with having $420 million in my pocket**, but it's really not – it's really probably not optimal to give away the entire company to a company that is – doesn't really – isn't very good at educational software, because if they've been trying to get into the educational software market, clearly, they're not very good at it – maybe. (Robert)

Faced with an offer of $420 million for the business, all three students begin with an explicit statement that sale proceeds would go to them. As Ogbor notes, what is at issue in mythicization is not what is correct but rather what is treated as rational - "a relatively coherent set of assumptions, beliefs, and values about a demarcated part of social reality, being illuminated in a selective and legitimizing way, restricting autonomous and critical reflection" (pg. 611). Notably, Mason corrects his statement after a moment of reflection – and notes that the income would be distributed based on equity. Frank and Robert do not.

Whether any of experts in the study of ToE make this error is not discussed, in Sarasvathy's (2008) work. That absence is in keeping with ToE's focus on expert-comparative theory building, as described in the literature review. The theory presumes expert competence, and uses the individual as a proxy for venture level decision-making. Therefore, substitutions of a singular pronoun ("I") for references to a hypothetical firm's decision-making are unlikely to trigger a critical reading of their accuracy by researchers. As would Mason's had he not made his correction.

In Ogbor (2000) and others argument (Omit, 2000), financial success, theory, myths, and legitimacy are intertwined – as they are in the examples from students. Absent Mason's moment of self-reflection, what legitimizes Frank and Robert's assertion that they would receive $420 million? One potential source of legitimacy is the success myth. That is, participants frequently hear of entrepreneurs who achieve enormously financially successful through creating a venture, so me becoming wealthy through my venture may seem plausible, or in fact normal – and rational (Nicholson & Anderson, 2005).

As such, the myths legitimize the errors identified in my study, and provide a defense of students' mistakes. That these types of errors have been identified in the broader research makes it more credible to interpret them as errors in understanding rather than happenstance. To both points, the parallels between the errors and myths are an important point of connection for engineering education because they are a source of students' pre-requisite entrepreneurial reality. Reiterating a point from the literature review: Myths about entrepreneurship are not just part of research in the field, they are also part of media representations of entrepreneurs. Researchers have long identified themes of magic, larger than life characters, rags to riches stories, wealth, and maleness in media representations of entrepreneurship (Wheadon, M. & Duval-Couetil, 2016; Nicholson & Anderson, 2005; Sarachek, 1978). The existence of such myths represent one of the sources of prior knowledge for students prior to beginning engineering entrepreneurship education. In such a reality, success and massive wealth are the norm, and an outcome of entrepreneurial decision-making that results in such wealth would appear rational.

5.3 The errors and engineering entrepreneurship education

To contextualize the meaning of my findings for engineering education, it is helpful to return to a non-engineering education discussion of ToE. In the literature review, I noted work by Nelson that suggested the use of effectual techniques is not itself a factor of expertise but rather an indicator of individuals experiencing the limitations of causal techniques and developing individual alternatives where they had not seen any work published. From that lens, the investment bankers are competent at applying the techniques, and the entrepreneurs are competent at evaluating their appropriateness. However, increasingly, engineering entrepreneurship education does not teach the causal techniques, or by induction their limitations (Makimurto-Koivumaa et al., 2013).

What the contrast above highlights is that the problems with how theories of entrepreneurship described by Huang-Saad et al., (2018) and Purzer et al., (2016) are real and can be empirically observed. That is, ToE does not provide a framework that can explain student decision-making – because students' decision-making is different than that of experts, and contains errors. Such errors, as described throughout my dissertation, are not accommodated in entrepreneurial theory because such theory presumes expert competence.

Empirical support for their theory-driven concerns highlights the need to re-evaluate existing practices based on existing critiques. The errors do not represent a new critique of engineering entrepreneurship education. Rather, my results and their context in mythicization and misconceptions are novel only because they provide empirical evidence of the critiques from Huang-Saad et al. (2018) and Purzer et al. (2016). That engineering students make errors, and that there are patterns in those errors should be expected, and should be accommodated by the theories used in learning and assessment (Streveler et al., 2008). Relatedly, that students rely on myths as they begin learning entrepreneurship is not particular surprising, but it is also an easy opportunity to improve practices in engineering education.

That opportunity comes from connecting existing research in and about engineering entrepreneurship education to my results. In the literature review (section 2.3.1), I detailed the theoretical concerns expressed by Huang-Saad et al., (2018) and Purzer et al., (2016). Those concerns relate to the adoption of theories of entrepreneurship in engineering entrepreneurship education that were not developed with educational purposes in mind. Later in the literature review (section 2.3.2), I highlighted examples of how entrepreneurship theory is typically used in engineering education. In doing so, I highlighted specific actions that related to the concerns detailed in Huang-Saad and Purzer's meta-studies.

My results show how those potential concerns become empirical realities – the use of expert-comparative and expert-derived theories do not coherently describe engineering students' entrepreneurial decision-making. Those two problems represent a general summary of the specific problems that Huang-Saad and Purzer detail. Use of theories that rely on both of those methodological traditions are troubled through my results because they, by design, do not account for errors and often evolve from the same myths about entrepreneurship on which students base decision-making. For the final time, comparisons to ToE are effective.

ToE and other theories that describe entrepreneurial expertise do not seek to, and as a result do not provide, a tool for identifying or interpreting errors or a process of learning. My results provide empirical evidence that students make errors in identifiable patterns, errors which are ignored by assumption in ToE. Such errors are not described within either of ToE's heuristics specifically because expertise and error-free thinking are explicitly presumed in the study design (Sarasvathy, 2008). Therefore, ToE cannot differentiate engineering student thinking from expert investment bankers nor differentiate engineering students from expert entrepreneurs. Because ToE lacks a description of novices, assessment using ToE as a theoretical framework is limited. It can compare surface-level characteristics of students as more like one of two types of expert, but only while assuming that both students and experts behave accurately and rationally (e.g., Dew et al., 2009). Such a comparison must presume that students act in an error-free way, because the definition of ToE does so. Therefore, using ToE in ways that privilege entrepreneurial ways of decision-making as a target outcome is not providing effective assessment data. That is because neither end of ToE's continuum is representative of engineering students' emerging knowledge and expertise – and by extension treating more of one end as better does not show growth towards expertise.

By extension, theories like ToE do not contain an evaluation of the quality or execution of either type of thinking. Whether students' reliance on myths and misconceptions about entrepreneurship is different from experts is difficult to say. While it is reasonable to assume that experts are less likely to make some of the errors that students make, there is minimal or no empirical evidence to that point – which has previously been highlighted as a problem for common business school pedagogies (Grey, 2004). Entrepreneurship scholars increasingly note that questions about *why that technique* in decision-making are just as important as questions of *what technique*, especially in understanding students' learning (Haynie et al., 2010).

While engineering entrepreneurship education still lacks an empirical understanding of the trajectory to entrepreneurial expertise, evaluating choice as well as execution provides a potential direction for building theory by focusing on how students implement a decision and why they made it. Such distinctions better differentiate students and experts than conflating engineering students and investment bankers as similarly different from expert entrepreneurs. This approach observes engineering students' development as entrepreneurs in ways that go beyond theories like ToE, and whether their decisions contain identifiable similarities to the decisions made by expert

entrepreneurs. It also continues the process from my dissertation of understanding the structural differences exist between students' and experts' entrepreneurial thinking begun by others (e.g., Dew et al., 2009; Robinson, Huefner, et al., 1991).

5.4 Conclusions

In the final section of my dissertation, I summarize a set of clear factual findings, implications, and future work that comprise the key takeaways from my study. Those three areas appear in the subsections below. The summary of findings and future work sections are general and reflect a focus on the study itself. The contribution and implications section is organized by the key stakeholder audiences the results are relevant too.

5.4.1 Summary of findings

The study identified five patterns of errors that engineering students make when making decisions that involve choices faced by early stage ventures. Specific business concepts where engineering students make errors include: Interpreting market analysis research data, analyzing different investment options to grow their company, and aspects of evaluating and understanding different exit opportunities. At a higher level, there were consistent struggles with abstract concepts of control and value of entrepreneurial ventures. The results support the conclusion that students do make errors, which is expected, and detail the patterns themselves which can inform further research. Situating the specific results in other literature also support two other conclusions.

First, the five patterns individually and collectively align with myths identified in entrepreneurship discourse– especially the mythicized nature of heroic individual entrepreneurship. That the patterns of errors align with myths supports the conclusion that students' prior knowledge about entrepreneurship is critical to understand and challenge in entrepreneurship education.

Second, the existence of such patterns of errors problematizes the applicability of existing theories of entrepreneurial expertise for teaching and research on teaching of entrepreneurship. Errors, especially consistent patterns of errors, are not accommodated in the development of most theories of entrepreneurial expertise, which build on the presumption of error-free execution. Instead, existing theories seek to differentiate expert entrepreneurs from other business experts using the assumption of error free decision-making and the identification of different techniques.

Neither the five specific patterns of errors here, nor in fact any errors whatsoever, are part of theoretical frameworks which are currently used to study developing entrepreneurial skill. Such frameworks are developed with the assumption of expert competence and do not search for errors in experts, making them limited in what they can tell the field about students – who do make errors.

5.4.2 Contribution and implications

There are significant implications in the conclusion that engineering students make specific, observable, and identifiable patterns of errors in their entrepreneurial decision-making, even if it is not particularly surprising. However, the contributions and implications are different for engineering education practitioners and engineering education researchers.

For engineering educators engaged in teaching entrepreneurship, the contribution and implications are threefold. First, the identification of the patterns themselves are a contribution to the field. The patterns of errors identified can be used to guide the development of interventions and projects that seek to disrupt students' prior knowledge and beliefs about entrepreneurship. The list of patterns of errors also provides a tool for evaluating knowledge assumptions made in entrepreneurship education resources (e.g., textbooks) and their appropriateness. It can also be used by instructors to attune their classroom interaction and feedback to subtle assumptions that may influence the claims students make about entrepreneurial work they are doing.

The second implication is that the existence of the patterns of errors creates further questions about whether expert-derived and expert-comparative theories of entrepreneurship are appropriate as a theoretical basis for designing courses. This point has been made previously, but is critically important. Work to decompose theories into teachable elements (e.g., Mathis et al., 2014) are not just useful, they are necessary as a conscious effort to convert descriptions of experts into workable content that does not presume expert level background knowledge. Without such work, the concerns posed by Purzer et al. (2016) and Huang-Saad et al. (2018) about entrepreneurship research's role in engineering entrepreneurship education are likely to continue to prove true.

The last implication for engineering educators is in the similarities between the patterns of errors and entrepreneurial myths. That similarity suggests that educators should do more to be aware of, and actively design courses to, disrupt myths about entrepreneurs that become part of engineering students' thinking. The myths represent one source of students' prior knowledge about

entrepreneurship. In these cases, simply teaching correct information is unlikely to be effective and adopting strategies from conceptual change theory are more appropriate (Miller et al., 2006).

For engineering education researchers who are studying entrepreneurship education, the contribution and implications are in how theoretical constructs from entrepreneurship are used. The immediate contribution is showing that engineering student-making is fundamentally different from both types of experts studied in ToE. That difference is critical to the applicability of the theory to describe student thinking. ToE describes both types of experts as displaying internally consistent logic that differs between the two.

That students are different from either type, because of the patterns of errors, limits the use of ToE as a tool for making meaning of student thinking. Prior research using ToE presumed that the preferred outcome of entrepreneurial education was the progression from using causal decision-making techniques (from expert investment bankers) to effectual decision-making techniques (from expert entrepreneurs) (e.g., Bureau & Fendt 2012). That students do not begin thinking similarly to the investment bankers' causal techniques means that the assumptions of a single dimensional progression built into the theory are invalid. ToE lacks a description of shared expertise between the two expert groups, but my results show that students lack such knowledge in ways that trouble the dichotomy in ToE.

While this study focuses on differentiation of students and one theory of entrepreneurship, the critiques from Purzer et al. (2016) and Huang-Saad et al. (2018) are again applicable. The implications are that researchers do need to clearly establish the legitimacy of a theory, theoretical framework, or assessment when adopting it from the field of entrepreneurship. As has been long noted, simply presuming theories generalize is inappropriate for entrepreneurship education work (Robinson et al., 1990). Engineering education researchers, generally need to engage with the differences between experts and students in understanding the applicability of constructs – rather than just presume that those constructs can explain the differences because they are derived from experts. A further implication here is that there is a need for engineering education researchers to better understand how engineering students develop entrepreneurial expertise in ways that do not solely rely on descriptions of expert entrepreneurs. Specifics of what the work could look like are described in the next section.

For the overall engineering education field, the implications of my results can be summarized as showing that students' decision-making clearly deviates from the assumptions that

were made during ToE's development. Whether in research or teaching, careful attention to the process by which theories are developed is important. Ensuring, rather than assuming, that a particular theory is appropriate, valid, and defensible for purpose prior to adaptation and adaptation in engineering entrepreneurship education. Further, if theories are accepted as valid, they are still unlikely to comprehensively represent engineering students' development trajectory. There is still a need to begin engineering entrepreneurship education by teaching the knowledge that can be easily assumed of the experts from whom theory frequently derives. For a theory such as ToE, where the baseline is experienced investment bankers, that lack of trajectory may prove immensely challenging to integration efforts in an engineering curriculum. This concern extends to research from business and management more broadly; theories designed to teach entrepreneurship within a four-year undergraduate business program naturally presume pre-requisite knowledge inappropriate for engineers – and vice versa. The empirical evidence presented here is an important contribution to confirm and demonstrate the theoretical critiques by Huan-Saad et al. (2018) and Purzer et al. (2016).

For the field, the current philosophical perspectives related to theory in engineering entrepreneurship education highlight a final implication of my findings. Taks et al (2014), quoted in the literature *review, describes theoretical knowledge as "*explicit, universal, and formal in nature" (pg. 575) when writing about engineering entrepreneurship education in the Journal of Engineering Education. Huang-Saad et al., (2018) might warn that such a description does not align with theories in entrepreneurship, a critique supported by Arend and colleagues when evaluating ToE specifically (2015, 2016). Theories about expert entrepreneurs may not meet the test Taks establishes – but theories in other areas of business and management might. However, there are problematic implications if all theory is presumed to meet that test rather than evaluated to see if it does. Critical in that evaluation is that, as demonstrated in my results, students' decision-making can contain surface-level similarities (e.g., attempts to make predictions using market data) that bely fundamental differences in rationality or quality (e.g., drawing factually unsupported conclusions from that data) from either of the sets of heuristics proposed in a theory like ToE. Conclusions drawn from surface-level comparisons can seem to validate theories from Taks epistemic lens and lead the field astray in understanding engineering students as budding entrepreneurs.

5.4.3 Limitations and future work

From my results, three areas of ongoing work are important, and all are based on the limitations of this study. First, is a shift in engineering entrepreneurship research from questions of what, to questions of why. Second, is deeper understanding of engineering students' thinking related to entrepreneurship and the presence of misconceptions. Third, are the implications and presence of myths about entrepreneurs in engineering students' thinking. In general, these areas of future work focus on expanding connections of my results to the other areas of literature that are described in the discussion. That is important because my study was not designed to capture the connections to mythicization and misconceptions or the depth of understanding of students thinking that the field needs. Instead, those issues emerged organically and need to be further explored.

The first area can be largely grounded in work by Haynie et al., (2010) who call for an approach to studying entrepreneurial decision-making that embraces metacognition, reflection and quality of execution alongside the choice of technique. This area of future work is relevant to both entrepreneurship and entrepreneurship education research. Scholars have increasingly noted that focusing on what expert entrepreneurs do provides only a surface-level understanding of their cognition and that a deeper understanding could aid both the entrepreneurship and entrepreneurship education researchers in their different goals (Fayolle, 2013). The opportunity is to build on my initial study and focus on deep analysis of students thinking on specific tasks of interest and exploring the decision-making process in significant depth with both novices and expert groups. Work by the Atman lab, which looked at multiple levels of students alongside experts in design tasks, could serve as a guide. Their work uses a verbal protocol as does my study, and provides examples of how such work could be quantified as well.

Future verbal protocol work would benefit from narrowing the number and scope of tasks, and instead focusing on those that could more richly explore the areas where my study showed patterns of errors. Doing so could meet Haynie et al's calls for understanding both the quality of the implementation of decision-making, as well as the metacognitive tools that students use in evaluating their decision-making. Haynie et al., provide other specific suggestions for research methods and frameworks that begin focus on gaining a deeper understanding of a single cognitive process than was possible in the broad range of tasks in my study. Such work should be designed and executed to focus on the execution of the techniques that individuals choose, and contain the

ability to evaluate or compare execution to experts to continue to assess the expert-competence assumption in much of the existing research.

A final opportunity in this work is diversification of the relatively narrow sample pool in my study. Any lack of diversity is not a weakness of the study, because unlike much of entrepreneurship research, I do not claim the patterns of errors either generalize to all populations or represent a complete set of errors. However, diversifying the sample is still important. Doing so could, and should, identify other error patterns as well as whether certain patterns are more or less present in certain groups. As efforts to identify and describe more errors continue, broader collections of errors and their structure (e.g., section 4.5) could help in program evaluation. Understanding what errors are present in what groups and how those errors are affected by different interventions could provide a more meaningful method of evaluation than the reliance on instruments built for populations other than students, which Purzer et al. (2016) identify as a critical concern for the field already.

The second area of future work builds on the potential that the patterns of errors in my study are misconceptions. As described in the discussion, my research design and norms of conceptual change literature makes the claim of the patterns as misconceptions. Future work should also focus specifically on continuing to develop an understanding of whether students rely on problematic ontologies in their understanding of entrepreneurship. Specifically, pursuing situations where students are known to commit errors, e.g., the patterns in my study, and further analyzing students' solutions to similar problems, could address more clearly whether they are relying on alternative ontologies. This work is particularly important because it more clearly establishes the approaches to teaching that can address the patterns of errors in classrooms. Further, understanding whether the patterns of errors exist at the ontological level has significant implications for how my and future lists of errors are used to develop interventions.

If the issues are ontological rather than informational, then it is likely that the ontologies are being used across concepts that were not observed in my study. That means that the patterns of errors identified in my study are likely more akin to reflective rather than formative in guiding intervention development (Roy et al., 2012; NRC, 2012). Looking for students' ontologies and any misconceptions can lead the field to a better understanding of the prior knowledge and prior knowledge gaps students bring to their entrepreneurship learning experiences (Chi, 2008). Designing interventions for belief revision and conceptual change rather than knowledge

transmission can better situate interventions in well-studied tools for the necessary conceptual change. Conversely, if the patterns of errors do not reflect underlying ontological struggles, different approaches to intervention design are more appropriate. Work to better understand the root of the patterns identified in my study would also contribute to the misconceptions literature more generally by taking studies of misconceptions beyond natural phenomenon. The work in this area likely should be qualitative in nature, and likely similar to the research designs suggested in the first area of future work suggested above.

The final area of future work is in the relationship between entrepreneurship students and entrepreneurial myths. While my study shows that the patterns of errors are similar to the myths, it does not yet establish that the patterns of errors are derived from the myths. Understanding engineering students' exposure to, understanding of, and adoption of myths about entrepreneurs is critically important to guiding interventions that address them. The first future work area specifically suggests identifying students' metacognitive tools. When those tools align with myths, further exploration could be useful to understand how and why students' metacognition comes to adopt mythicized entrepreneurs as a method of validating thinking. Further research using quantitative techniques could examine the extent to which students are aware of the myths and how much they believe them to be true. As with the other areas, this can help inform interventions – especially in how faculty pay attention to the diverse representation of types of entrepreneurs, and case studies used in classrooms. Other work could focus on using the myths to analyze existing interventions to see if they contain elements of mythicized narratives about entrepreneurship.

In summary, future work needs to focus on understanding students' thinking more deeply (area one), better understanding what is happening when students make errors (area two), and understanding the role that grand narratives of entrepreneurship have on students, teachers, and courses (area three). While each of these areas of future work are independent, all three share a common theme: They continue to explore the credibility of expert-derived and/or expert-comparative theories of entrepreneurship that mythicize successful entrepreneurs for use in education. That shared basis continues to build evidence to support the critiques of Huang-Saad et al. (2016) and Purzer et al. (2018) among others. Those critiques consistently call for work in the field that evaluates, rather than presumes, what experts do is a useful lens or appropriate content for teaching engineering entrepreneurship courses. My study provides initial evidence that these critiques are empirically defensible and that at least one theory does not represent student

behaviors. Future work that can speak to students' thinking generally, or evaluates the applicability of specific theories, will inform how entrepreneurship theory is used in engineering entrepreneurship education.

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APPENDIX A. VERBAL PROTOCOL

Verbal protocol tasks

Introduction

In this study, you will role-play as the lead entrepreneur in building a new company. The product is imaginary, but is technically feasible, and any information you receive will come from realistic research -- the kind that would be used if creating a real business.

In the scenario, you will be asked to talk about what you would do in different situations or when facing problems. In all of this, we are more interested in your line of thought than in you having a right or wrong answer. It is important that you think aloud while you work through the decisions and explain your reasoning rather than providing a nicely polished response. I will probably remind you to explain your thought process as you work through the scenarios.

At some points you may make a decision, but later in the scenario, a prompt may say that you've done something different. This does not mean that you made a bad decision, it is just a limitation of the scenario that we can't create later prompts based on every possible choice that people might make at each step.

Product description

In your spare time, you have created an entrepreneurship simulator video game. You believe that it could be used both for entertainment and entrepreneurship education. You have been inspired by news articles describing the increased demand for entrepreneurship education and think that the game might be a good way to meet that need.

The game itself provides a 3D environment in which players can choose among many different business types, models, and strategies. It forces players to make the kinds of decisions that an entrepreneur would be required to make in the development of a new business.

You have already done what is necessary to protect intellectual property, and have incorporated your company, *Entrepreneurship, Inc*. and called the game *Venturing*. In sum, you have created an initial product, and have taken legal steps to begin the business, but have not moved forward in starting the business yet.

Task 1: identifying the market

Now that you have a product, what do you think you need to know about the market? This could include, but is not limited to, who the potential customers, competitors, or partners are, or the ultimate size of the opportunity.

What do you do to find out what you want to know?

Task 2: what to do with market research

[give handouts, and remind them to think aloud as they read and consider the information]

Who will your primary customers will be?

Through what channels will you sell the product?

How will you choose a price for the product?

Based on all of this information, how do you decide whether there is enough potential value to start selling the product to the market you developed?

Task 3: meeting payroll

With a little bit of money that you've saved, you have started building the company. You priced the product at $80 and you are selling about 300 units per month. Feedback from customers makes you think that with a few improvements, you could sell at $140 per unit. Creating the prototype for the new product takes you to the limit of your available funds.

You estimate that you'll be short around $50,000 to continue payroll for the next 3 months necessary to get your new prototype into a big-time computer game convention, where you will be able to make connections with people from the industry and greatly boost sales.

You have 4 options:

- Borrow from your spouse's (or significant other's) parents – they aren't super wealthy, but could scrape together $50,000.
- Borrow from old college and work friends.
- Convince your parents to take out a mortgage on their house.
- Convince your employees to wait out the period without pay.

Why did you choose the option that you did? What makes other options less attractive?

Task 4: financing

Your prototype won "Best New Game" at the game convention. All the big box retail and online stores want your game. You estimate it will take 18 months to fully develop the new version and six months to roll it out in all the channels.

You estimate you will need $5 million to break even, and given your sales projections, it will take about 2 years before you reach that point.

You have 3 financing options:

Option 1: Venture capital firm from the digital entertainment industry offers $5 million for 30% of the company.

Option 2: A family friend with extensive experience in selling educational products wants to partner. He wants to invest $5 million for 30%, but also wants to work for the company for a $200,000 yearly salary.

Option 3: You continue to bootstrap the company with internal cash, growing at a slower pace.

Why did you choose the option that you did? What makes other options less attractive?

Task 5a: product redevelopment - sales

You have managed to break even, and while sales continue to grow, they are slower than what you expected.

What do you do to try to increase sales?

Task 5b: product redevelopment - information

You search online reviews and find that people who like the game aspect report that they just skip over all the educational stuff and wonder why it's even there. People that are interested in the educational aspect feel that the education part is inadequate and feels like an afterthought.

What do you do in response to this new information?

Task 6a: growing the company - personnel

At the end of your 6th year of business, you are selling 2 products

- *Venturing for Fun* ($80)—stripped away all of the educational aspects
- *Venturing for Profit* ($350)—enhanced educational aspects

You now have 20 people on your sales staff (up from the original 3), and you need to continue to expand the sales staff to approach larger colleges and graduate schools. Greg Thomas is an excellent seller, and has headed the sales team from day 1, has clearly not kept up with new changes in the product, and does not seem like the right person to lead in selling the new products.

What do you do?

Task 6b: growing the company - culture

You are trying to maintain an entrepreneurial culture in your company, but your partner is fostering a more corporate feel. He thinks it's time to go corporate and wants more formality, meetings, organization, etc. and feels that a more professional image would be good for the bottom line.

How do you deal with this? Is it time to go corporate?

Task 7: hiring professional management

You are now in the 8th year of the company. You have surpassed many growth targets, have about $30 million in sales, and expect a 50% growth rate per year over the next 3 years.

The board suggests hiring professional management to run the company so that you can focus on new growth and strategy. Assuming you have 3 potential candidates to interview for the position of COO, how would you prepare for the interview? What questions would you ask, what techniques would you use, what issues would you take into account?

Task 8: goodwill

An inner city school principal who works with 10 other schools in the area believes that *Venture for Profit* could be used to teach entrepreneurship, and help students develop skills in math and problem-solving. She wants to connect you with a team of enthusiastic teachers to develop elementary teaching materials to target students in her district.

The project will require an investment of roughly $1 million, and will take a substantial chunk of your time over the next six months. You also know that this inner-city school district likely won't be able to pay much for the software when it is completed.

What do you do?

Task 9: exit

In the 10th year of the company, you are doing $70 million in sales and project that you will reach $100 million within a year.

At this time, you see 2 possible directions for the company:

1. Take the company public. Your accountants suggest that you should offer 2 million (of your total 12 million shares) at $30 per share.

2. Disney, who has been trying to get into the educational software market, offers you $420 million for your entire company.

Which do you choose?

Why?

Handouts Provided to participants

Primary market research (you performed)

Survey 1: Given to people who downloaded a demo of the game online

Willing to pay ($)	*Young adults (%)*	*Adults (%)*	*Educators (%)*
50-100	45	26	52
100-150	32	38	30
150-200	15	22	16
200-250	8	9	2
250-300	0	5	0
Total	100	100	100

Survey 2: From prototype demonstration at local Best Buy stores

Willing to pay ($)	*Young adults (%)*	*Adults (%)*	*Educators (%)*
50-100	51	21	65
100-150	42	49	18
150-200	7	19	10
200-250	0	8	7
250-300	0	3	0
Total	100	100	100

Survey 3: Focus group with educators (high school and community college)

They are excited about the product but want to move past the "game" aspect and focus more on the educational aspects. With these changes they would be willing to pay $150, but as it is, they would pay $50-80 for it, with additional discounts for bulk purchases.

Secondary market research

Customer Segment	*Estimated total size*
Young adults ages 15-25	20 million
Adults over 25 who are curious about entrepreneurship	30 million
Educators	200,000 institutions

Market	*Estimated value*
Instructional technology	$1.7 billion
Simulation games	$800 million
(Both markets are expected to grow at 20% per year for the next 5 years)	

Costs to sell product in different venues

Internet	$20,000 up front + $500 per month
Retail	$500,000-1 million up front + support services after
Mail order catalogs	$50,000 up front + very little after
Direct sales to schools	Unknown—Need to recruit and train sales reps

APPENDIX B. RECRUITMENT EMAIL

Dear [NAME],

We are conducting a study to explore the thought patterns that engineering students employ as they solve problems. We are interested in comparing these thought patterns among engineering students who have participated in different programs and courses.

In order to study these thought patterns, we are interested in senior engineering students to be interviewed and recorded as they work through a series of questions. The interview will last approximately 30-45 minutes in which students will work through an open-ended set of problems. Please contact Nathalie Duval-Couetil if you are able to attend.

Sincerely,

Nathalie Duval-Couetil

natduval@purdue.edu