A First Principles Approach to Product Development in Entrepreneurship

William J. Makowski

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Thomas L. Martin, Co-Chair
William A. Schaudt, Co-Chair
Brook Kennedy
Steven Rowson
Christopher Williams

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ABSTRACT

The purpose of this dissertation is to explore an entrepreneurial framework that this dissertation calls A First Principles Approach to Product Development in Entrepreneurship. The goal is to improve safety for bicycle riders. This research project identifies, applies, and assesses product development methodologies in a way that is grounded in qualitative research. The framework that encompasses those methodologies was created to bridge the gaps between entrepreneurship, engineering design, and industrial design, where the framework was specifically applied to bicycle helmets and examined as a case study. The framework is intended for entrepreneurs, product developers, and researchers who are developing physical, capital-intensive products, where the key stakeholder who is describing a problem is also close to the purchasing decision. Parts of this dissertation describe a framework that is generalizable to other startups and other parts of this dissertation are specific to developing bike helmets.

Failure rates in entrepreneurship can often be between 30 to 75%. In addition, there are examples in motorcycling, football, and bicycling where companies are only designing and developing personal protective equipment (PPE) to the industry standard with little or no consideration for other relevant injury biomechanics. In response, this dissertation explores a series of product development methodologies, in a manner that is grounded in qualitative research, with the goal of improving safety for the rider and reducing the risk of failure for launching a new venture.

The first principles approach described in this dissertation begins with Customer Discovery which is a process of conducting interviews with key stakeholders, in order to challenge and support evolving hypothesis about a potential new venture. The process begins with deconstructing an initial idea into product, market, and customer risk hypotheses. Next, a process for creating and organizing questions, conducting problem interviews, and pivoting is described. During the problem interviews I found a Severe Problem of bicycle helmet fit for US Bike Parents. Then, I examined other aspects for identifying if an opportunity is worth pursuing, namely finding a gap in the marketplace, and observing industry trends.

After conducting the problem interviews, I developed and conducted brainstorming sessions with participants who experienced the Severe Problem. The goal for conducting the brainstorming sessions was to dislodge entrenched product ideas, explore the solution landscape, and find a solution that solved the problem the best and was the best opportunity for commercialization. For this dissertation I determined that a custom fit, 3D printed bicycle helmet was an appropriate solution. Next, I developed and conducted solution interviews to determine if the solution solved the participants problem, identify additional product features, and explore various pricing strategies.

Once a product brief was created, the next step was product development. Product development can have many variables which can affect how a new venture team should approach development. For this dissertation initial product development began with designing (ideating), printing (prototyping), and impact testing (testing) 3D printed mesostructures. However, during development the strategy was adjusted in response to production issues (iterating).

Now that some initial product development was underway, the next step for a first principles approach includes a critical reflection on different aspects of the new venture.

A critical reflection can include a feasibility analysis, which is a formative assessment of the potential new venture, an assessment of Customer Discovery, and the application of the Abstraction Ladder to evaluate the problem driving product development. For this dissertation, a critical reflection also included an evaluation of other product development methodologies, as well as continued application of the Abstraction Ladder to direct the critical evaluation of other foundational elements that relate to bicycle helmets and safety.

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GENERAL AUDIENCE ABSTRACT

Startups can and do fail. For an entrepreneur, product developer, or researcher with a physical and capital-intensive product idea, this dissertation can serve as a resource to bridge the gaps between business, engineering, and design and reduce the risk of failure when trying to create a startup. The process described in this dissertation describes how to evaluate the key elements of an idea and conduct a series of interviews with potential customers to find evidence that supports pursing that idea further, challenge the startup team to change some aspect of the idea, or drop it altogether. Once the startup team has found a problem, as well as a solution to that problem, this dissertation describes an approach creating that solution. Then this dissertation describes an approach for critically evaluating the foundational elements of the problem and the solution. The goal for a critical evaluation is to identify additional foundational elements which relate to the product that may increase its value or decrease the risk of product failure.

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“To my parents and siblings, I do not know how to fully express my appreciation,” you drive me crazy and keep me sane (Makowski, 2013, viii).

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> *But you say, “I don’t know where to look; I don’t know what to look for.” And there’s the crux. Is it worth giving up what I have to look for something better? I don’t know-is it? Who can make that decision but you? But even by DECIDING TO LOOK, you go a long way toward making the choice* (Thompson & Brinkley, 1997, 119).

This dissertation has been an exercise in deciding to look.

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Introduction

1.1 Overview

The purpose of this dissertation is to apply a series of processes, to explore a framework that this dissertation calls A First Principles Approach to Product Development in Entrepreneurship. The framework is intended to bridge the gaps between entrepreneurship, engineering design, and industrial design. A first principles approach is intended to be applied to the entirety of the product development lifecycle. The goal is to improve safety for bicycle riders. This research project identifies, applies, and assesses product development processes and techniques, with the goal of improving safety by developing better personal protective equipment (PPE). The first principles approach described in this dissertation investigates the foundational elements of product development in entrepreneurship. The first principles approach is intended for startups developing physical, capital-intensive products, where the key stakeholder who is describing the problem is also close to the purchasing decision, which will be described further in this dissertation. A more comprehensive understanding of product development's foundational elements is achieved by conducting Customer Discovery interviews; systematically analyzing the interviews; combining technologies, and assessing the advantages and disadvantages of relevant design and manufacturing processes; and finally by critically evaluating Customer Discovery and applying the Abstraction Ladder to explore areas for future work in injury biomechanics, psychology, mechanical engineering, and industrial design.

1.2 Motivation

The purpose of this section is to describe the motivation for exploring what this dissertation calls A First Principles Approach to Product Development in Entrepreneurship. The motivation started with my experience in motorcycle apparel design and continued after reading about challenges with football and bicycle helmets. Some of the challenges with motorcycle, football, and bicycle protective equipment are due to Reasoning from Analogy, which will be described later in this chapter. In response to challenges of Reasoning from Analogy, alternative approaches to product development should be explored. So, the need for Reasoning from First Principles in relation to product development is described.

1.2.1 Personal Experience in Motorcycle Apparel Design

In 2014, I started my first technical apparel design job, working for one of the top motorcycle apparel companies in the world. The company designs and develops protective jackets, pants, and helmets for extreme end users. These riders push the limits of their craft and traverse the world, testing what their minds, bodies, machines, and equipment are capable of. To add to the level of risk, this form of two-wheeled thrill seeking often happens alone and in remote locations, where access to medical attention is not readily available. So, when the limits are pushed over the edge, usually resulting in a motorcycle crash, the outcome has the potential to be catastrophic to the rider. The activity's relationship to inherent risk highlights the importance of safety countermeasures.

Due to the critical nature of that protective gear, I started asking questions like: “What happens in an accident?” and “Based on what happens, how do we design and develop apparel?”

I assumed that those who were designing and developing PPE were knowledgeable about the underlying problems to the solutions they were creating.

I was wrong.

Answers I received were a variant of “motorcycle accidents are too complicated to understand, so we don’t know.” As a result, both the company and strategic partners only designed protective gear to industry standards, with no further exploration of relevant impact scenarios and injury biomechanics. Surprisingly, putting few to no resources for understanding impact scenarios, as well as injury biomechanics is not new, or exclusive to the motorcycle apparel industry (Chow et al., 1995). Rather, putting few resources towards understanding impact scenarios and injury biomechanics has historically been the industry approach and is representative of the PPE industry as a whole.

1.2.2 Parallels in PPE Development in Both Football and Bicycle

Professional football exemplifies the highest profile case of industry inattention to the development of standards. Until recently, football helmets were designed to prevent skull fracture, with no emphasis on preventing rotational acceleration and concussion (Rowson & Duma, 2013). Sadly, in 2011, the height of this controversy culminated with the suicides of two football players who were suffering from degenerative brain disease as a result of repeated head impacts (Schwarz, 2011). A result of national concern has been a more intensive evaluation of both the impacts that can cause concussion, as well as football helmet performance (Crisco et al., 2011; Rowson et al., 2013).

In the sport of cycling, although the overall effects have not been as extensive, the professional bicycling world was demoralized by the suicide of Kelly Catlin, potentially linking back to a head injury she suffered the previous year (Boren, 2019). Helmet use has been demonstrated to minimize the risk of severe head injury (Olivier & Radun, 2017); however, lower energy impacts, which are associated with concussion and are more common than high energy impacts, are not represented in current industry standards (Bland, McNally, et al., 2018). The PPE industry has been slow to respond to update standards, so universities have become involved. In 2018, Virginia Tech developed a more rigorous testing method that focused on lower-level impacts and rotational acceleration, the forces widely believed to cause concussion (Bland, Zuby, et al., 2018). These examples in motorcycling, football, and bicycling highlight the severe disconnect between impact scenarios, injury biomechanics, standards, and solutions for PPE.

1.2.3 Reasons for Transitioning from Motorcycle PPE to Bicycle PPE

Although the motivation behind this research began with motorcycle riders, the research questions for my dissertation began with a customer segment around bicyclists with various levels of experience. The reason for this change in customer segment is that bicycling is a more abundant and accessible activity than motorcycling, which made it easier to find and interview participants for Customer Discovery. In the United States, bicycling is more abundant, as there are 32 million bicyclists who ride at least 104 days out of the year compared to the 8 million registered on-road motorcycles (PeopleforBikes, 2015; Teoh, 2019). Bicycling is also more accessible in regards to the cost, as well as the ages that can participate. An introductory bicycle costs between $500-1000, whereas an introductory motorcycle costs between $5000-

$10,000 (Gulley, 2017; Stokes, 2018). In addition, riders from as young as one year old to adults can participate in cycling, whereas a motorcycle rider cannot get their license until they are at least sixteen years of age.

Other considerations were that the research team has familiarity with bicycling and it is a sport that involves a higher risk of injury compared to most activities of daily living (Carmont, 2008; Gottschalk & Andrish, 2011). Compared to a motorcycle helmet, a bicycle helmet can be quite simple. A bicycle helmet often has no chin bar, no visor, no excessive cheek padding, or venting. The bicycle helmet's simplicity can result in a smaller barrier to entry for product development. In fact, most bicycle helmets often have just four basic parts: the impact-mitigating liner, comfort padding, a nylon strap, and a buckle.

1.2.4 Identifying Reasoning from Analogy

Athletic pursuits have progressed faster than the infrastructure surrounding product development for PPE. Unfortunately, when companies only design to the industry standard, with no further exploration of the underlying impact scenarios and injury biomechanics, it can disregard new factors that materialize. A strategy that disregards new factors that materialize can put an end user at a greater risk of injury than they would be if those factors were considered.

The approach of developing to the standard or focusing on general comparisons between two entities, which could be concepts, ideas, or products, instead of developing based upon the underlying problem, is known as "Reasoning by Analogy" (Linsey et al., 2007, 3; Viswanathan & Linsey, 2013). This dissertation will delve into an alternative approach that looks at the foundational elements of a problem, which this dissertation calls "Reasoning from First Principles." Both Reasoning from Analogy and Reasoning from First Principles are generic terms commonly used in the areas of logic (Macagno, 2014; Reiter, 1987) philosophy (Back, 2016; Ribeiro, 2014) and physics (Mirarchi, 1977; Nyden, 2013). The application of Reasoning from First Principles in product development begins with demonstrating problem/solution fit, which means to find "a problem worth solving using a combination of qualitative customer observation and interviewing techniques" (Giardino et al., 2014; Still, 2017, 33). Then from the foundational element of problem/solution fit and navigating additional product development steps, other foundational elements in helmet design, such as impacts and injuries can be explored.

1.3 From Reasoning from Analogy to Reasoning from First Principles

The purpose of this section is to describe challenges with Reasoning from Analogy in relation to product development. In addition, the purpose of this section is to describe the transition from Reasoning from Analogy to Reasoning from First Principles.

1.3.1 Issues with Reasoning from Analogy

For impact protection specifically, Reasoning from Analogy can take place when a standard is implemented. The standard is the problem to be solved, and the helmet is the potential solution (Viswanathan & Linsey, 2013). Comparisons made from the standards can shift the focus away from criteria that are relevant to end users because the standard abstracts away from the complexity of possible impacts and injury biomechanics. Following a guideline with little to no understanding of how or why it was developed can lead to designs that only fit within those parameters. Unfortunately, an approach that focuses on a standard can lead to design fixation, which can narrow the solution space in which designers are able to generate original ideas, limiting creativity (Viswanathan & Linsey, 2013).

1.3.2 The Need for Reasoning from First Principles

Within a historical context, there is no doubt that Reasoning from Analogy, requiring companies to design to an industry standard, has created greater levels of consumer protection (Robertson, 1996). However, it has also created significant design limitations. While athletic pursuits continue to push the limits of the human experience, the infrastructure surrounding the design space is not progressing at the same rate. Thus, an alternative paradigm for product development needs to be explored, where one must understand the phenomena specific to that problem at a foundational level, framing the problem through context and meaning, in a way that values the end user (Friedman et al., 2002). Understanding a problem at a foundational level is a systematic process of challenging assumptions by asking “How?” and “Why?” questions, known as Reasoning from First Principles (Irwin, 1988). However, Reasoning from First Principles, within the application of product development, specifically PPE, is less well researched than product development approaches based upon Reasoning from Analogy and warrants further investigation.

1.3.3 Conclusion

In conclusion, personal experience in the motorcycle apparel industry, as well as head injuries from top athletes in both football and cycling, have illuminated problems with PPE, as well as disparities with how those products are developed. These examples specifically show a problem with outdated safety standards; however, they also demonstrate the broader need to evolve and advance product development methodologies in a way that addresses those challenges. For this dissertation, I explore the application of Reasoning from First Principles, a systematic process challenging assumptions by asking “How?” and “Why?” questions, beginning with finding problem/solution fit, by conducting Customer Discovery.

It is anticipated that applying this process to the entirety of the product development lifecycle will improve safety for the end user. The application of first principles will illuminate what can be applied universally to product development, and what is largely contextual in this specific application. For this exploration, the following research questions were developed. The research questions are answered through the following contributions.

1.4 Research Questions and Contributions

The two primary contributions from this dissertation are: 1.) the creation of the framework that this dissertation calls A First Principles Approach to Product Development in Entrepreneurship and begins to bridge the gaps between entrepreneurship, engineering design, and industrial design, as well as 2.) the application of the methods within that framework, as a case study, where the application of those methods was grounded in qualitative research.

Research Question 1: When using first principles in product development, in what ways can Customer Discovery serve as the foundation to finding a Severe Problem and direct the process for improved safety for bike riders?

- The contribution from this research question is the execution of Customer Discovery in a way that is grounded in qualitative research. The execution of Customer Discovery began with the deconstruction of an initial idea, formation of hypotheses, and creation of interview questions. The semi-structured way in which the interview questions were formed and organized is also a contribution. The questions start with the broader goal of why the participant participated in the activity and then narrowed the questions to test specific hypotheses. A total of 166 problem interviews were conducted and a Severe Problem that can drive product development was found. The interviews were coded, analyzed, and co-triangulated to identify actionable results. Finally, a contribution of this chapter is the operational definitions for different severities of problems.

Research Question 2: Once a singular Severe Problem has been found, which involves a significant behavior change that can direct the solution space, how can the solution space be navigated from that Severe Problem to improve product development?

- The contribution from this research question is the inclusion of brainstorming sessions, between the problem interviews and solution interviews, to find the best solution category for commercialization. In addition, the contribution from this research question is the design and implementation of a brainstorming session specific to the Severe Problem identified in the problem interviews, with participants who experienced that Severe Problem. The contribution also includes the design and implementation of the solution interviews. The brainstorming sessions and solution interviews were coded and analyzed, resulting in a detailed knowledge of the risk associated with a solution that solves the participant's pain point, as well as a business model focused on their needs.

Research Question 3.1: Once problem/solution fit has been found, how can initial product development begin, developing a workflow to streamline the process and provide a seamless experience for the end user from a first principles point of view?

- The contribution from this research question is the addition of a product development process, applied to the product brief. Companies do not always design and develop products to the problem, so it is important to link the creation of the final product to the problem that is driving product development. The product development process includes a roadmap for determining where to begin development. In addition, the contribution from this research question includes the application of the product development process, to develop the beginnings of a workflow, where there is some supporting evidence that the workflow will improve bicycle helmet fit. The workflow includes a recombination of technologies. The recombination of technologies will result in new methods of product development for personal protective equipment. Finally, by ideating, prototyping, testing, and iterating, there is supporting evidence that both the workflow and final product can withstand some technical and regulatory challenges.

Research Question 3.2: With problem/solution fit identified, how can one pause Customer Discovery, and begin to critically think about the broader context of problem/solution fit in order to improve product development?

- The primary contribution from this research question is an improved product development process. The product development process is improved by pausing Customer Discovery and including a step for critically evaluating the Severe Problem and the product development process. The improved process includes the application of the Abstraction Ladder in order to critically think about the problem driving product development in order to direct development and improve the MVP. In addition, the improved process includes a critical evaluation of Customer Discovery to make sure it is the most appropriate process for reducing the risk associated with launching a new venture. Lastly, the contribution from this research question is the demonstration of a feasibility analysis, so the feasibility analysis can serve as a reference point for the new venture team and key stakeholders.

Research Question 4: Once a solution to the Severe Problem has been found, how does one reason back from the solution to better understand both the Severe Problem and solution more comprehensively, and at a foundational level to improve product development?

- The contribution from this research question is a product development process that includes a step for critically evaluating the environmental factors and foundational elements that shape problem/solution fit. Environmental factors can include other relevant product development methodologies for directing future product development. In addition, for this specific dissertation, foundational elements that directly relate to problem/solution fit can include an initial assessment of injury biomechanics, psychology, engineering, and industrial design. Due to the critical nature of PPE, understanding the foundational elements across each discipline should provide improved safety for the rider, by improving performance of the design, as well as reduce potential for product failure. Entrepreneurs, product developers, and researchers can apply the Abstraction Ladder to understand other relevant subjects that shape their own products or services, or other ways to improve product development.

Chapter 2 Background

As described in the previous chapter, my personal experience in the motorcycle apparel industry, as well as the general literature on head injuries in football and cycling, demonstrate the need for better helmet safety standards and product development methods in entrepreneurship. This chapter describes failure rates in existing companies and new ventures and explains the motivation for developing A First Principles Approach to Product Development in Entrepreneurship, in an effort to reduce new venture failure.

Section 2.1 highlights various failure rates for product development in established companies, for researchers, and new ventures. Section 2.2 describes the need for a research focused approach to product development methodologies, specifically referring to Customer Discovery. Then, section 2.3 incorporates Customer Discovery with first principles. Section 2.4 describes the methods and techniques used for exploring A First Principles Approach to Product Development in Entrepreneurship. Section 2.5 illustrates the interdisciplinary nature of the research described in this dissertation, as well as the various colleges, departments, and key personnel needed to complete the research.

2.1 Success and Failure Rates for Product Development

Depending on the context, the failure rate for product development is anywhere between 30 to 75% (Karakaya & Kobu, 1994; Nobel, 2011). The high failure rates serve as motivation to learn about and apply product development methods that can reduce the risk of product failure and increase the chances of success for a new venture. Due to the vast discrepancy of product development failure rates, additional context is needed to determine the specifics of those failures, so the approaches that led to those results can be avoided in future product development.

2.1.1 Understanding Failure Rates for Product Development

The larger context of product development success and failure can add clarity to the benefits of A First Principles Approach to Product Development in Entrepreneurship. Additional context adds clarity by comparing what has not worked in the past to a new approach that addresses previous shortcomings. Whether the new product idea is incubated within a billion-dollar company or simply driven by an individual, developing a successful product is difficult and failure is always a possibility. Even understanding what defines success or failure can be challenging. The reason it can be challenging is the research is not always consistent. In research, there are many different methods used, as well as “discrepancies in the definition of new product-related concepts, such as the meaning of new product success or failure” (Karakaya & Kobu, 1994, 50).

Additional challenges with defining product success or failure go beyond the definition of product-related concepts. Variations in nomenclature are exacerbated further when referencing where in the product development process a failure occurs. It is difficult to determine if authors were referring to the initial idea failure rates, ideas that begin the product development process, or products that are actually launched as commercial products (Castellion & Markham, 2012).

For established companies, one study determined New Product Failure Rate (NPFR) through a statistical analysis of questionnaires, which targeted directors of new product development. The study measured failure based on competitive activities, poor product performance, poor marketing, pricing, product obsolescence, access to distribution channels, and customer switching costs (Karakaya & Kobu, 1994). The study found product failure was, at best, as low as 30% in the medical industry and 40% in the food processing industry (Karakaya & Kobu, 1994). In comparison, Cierpicki et al. defined product failure as “how the firm itself perceives its product to have performed relative to their expectations that determine success” (Cierpicki et al., 2000, 777). The literature review concluded that “the new product failure rate is between 35% and 45% of fully commercialized products launched in developed western economies” (Cierpicki et al., 2000, 778). In an effort to debunk myths that product failure rates are as high as 90%, Castellion and Markham conducted a literature review that found that failure rates are closer to 40% (Castellion & Markham, 2012). The failure rate they found is when failure is defined as “the percent of new products actually introduced to the market and then fail to meet commercial objectives of the business unit that launched the product” (Castellion & Markham, 2012, 976).

However, “regardless of the exact percentage, current rhetoric implies that new product investments are extremely risky. New products can, and still do, fail,” and developing new products that fail, should probably be avoided when possible (Victory et al., 2021, 18). For an established company if the product fails, company structure and a diversified portfolio helps manage risk, so the company does not fail with the product.

2.1.2 Popularized Failure Rates for Startups

For an individual with an idea or a new venture team (NVT) the difficulty of developing a new product is even greater, when compared to an existing company. The reason is, if the product fails, most likely the new venture will fail as well. A popularized startup failure rate is 75%, which is in Steve Blank’s ubiquitously cited Harvard Business Review article, “Why the Lean Start-Up Changes Everything” (Blank, 2013). Unfortunately, in the article, Blank does not define startup failure, rather he generically references research done by Harvard Business School’s Shikhar Ghosh (Blank, 2013). Furthermore, the 75% failure rate Blank cites is defined as “failing to see the projected return on investment” (Nobel, 2011). The definition that Blank used for failure generally means, poor product performance, which is not failure in the binary sense, meaning yes it did fail or no it did not fail. Rather poor product performance can exist in a grey area. Finally, the failure rate Blank references is not direct research, but rather a quote from Ghosh. It is unclear if Ghosh is referring to observations from experience or directly referencing research related to startup failure rates (Blank, 2013). The quote Blank references further defines variations of startup failures saying, “if failure means liquidating all assets, with investors losing most or all the money they put into the company, then the failure rate for start-ups is 30 to 40 percent” (Nobel, 2011).

2.1.3 Failure Rates for Startups Defined by Research

Defining start-up failure as liquidating all assets, with investors losing most or all of the money they put into the company, very closely reflects Brian Headd’s research done in 2003. Brian Headd is an economist at the U.S. Small Business Administration. His research found that after four years, 33% of new ventures closed and were unsuccessful, 17% of new ventures closed and were successful, and 50% of new ventures survived (Headd, 2003). Although return on investment and falling short of projections are important considerations for any new venture, the result of catastrophic failure through the liquidation of assets and complete loss of capital is the scenario new ventures should actively avoid. It is anticipated that having a deeper understanding of the context, distribution, and criterion surrounding both successes and failure could add additional insight.

2.1.4 Failure Rates for Startups Commercializing Research

In response to the poor performance and failure rate of new ventures, the application of "…the lean startup and customer discovery models...have become ubiquitous in startup culture, and have also become go-to methods for state- and nationally-funded entrepreneurship programs" (Batova et al., 2016, 1). The most prominent nationally funded entrepreneurship program in academia is the National Science Foundation's I-Corps. I-Corps boasts that from 2011 to 2017, 973 teams participated and produced over 320 companies, which would translate to a failure rate of 67% (Nnakwe et al., 2018). This failure rate is considerably higher than both Headd's research and Ghosh's observation, who both described new venture failure rates around 30-40%.

It should be noted that there are two considerable limitations with the execution of I-Corps. The first limitation is research teams rely on assumptions due to lack of experience in entrepreneurship. The researchers participating in I-Corps are not necessarily "entrepreneurs," but rather researchers and academics exploring entrepreneurship for the first time. They have spent considerable time developing a core technology and identified its potential for commercialization (Leatherbee & Katila, 2020). "Getting out of the building," making cold calls, and engaging with end users is not something they are necessarily accustomed to (Nnakwe et al., 2018). So, they rely on assumptions about customers, resulting in little iteration (Leatherbee & Katila, 2020).

A result of research teams relying on assumptions is the second limitation, that they are not solution neutral. In response to the sunk costs from developing their core technology, Customer Discovery is spent trying to commercialize that core technology. The general concept of sticking to an original idea, despite finding potentially other better ideas, is similar to the concepts of inventor's bias and loss aversion (Morgan & Sisak, 2016; Susskind, 2014). Not being solution neutral can be a stumbling block, as it leads to design fixation, resists pivoting, and stifles the team's ability to "discover the highest quality solutions" (Viswanathan & Linsey, 2013, 121002-11). Thus, Customer Discovery in I-Corps is not a complete deconstruction of an idea or solution into a product, market, and customer risk hypotheses, a strategy which will be described later in section 4.2.1. Due to the limitations of I-Corps, it is not surprising that new venture failure rates are considerably higher than those described by Headd or Ghosh.

2.2 The Need for a Research Focused Approach to Customer Discovery

In Customer Discovery, the first part of discovery involves finding the best problem/solution fit, through "getting out of the building" and talking with customers. "The aim is to test the riskiest hypotheses of the problem" (Giardino et al., 2014, 30). Testing the riskiest hypotheses of the problem is exceptionally important, as it is the foundation for all future iterations leading to product development. First and foremost, discovery helps the NVT challenge assumptions and "dislodge an entrenched vision of the business idea, as needed, and find a new plan" (Leatherbee & Katila, 2020, 572). Second, "it also motivates the formulation of new ideas, with their corresponding hypotheses-to-be-tested" (Leatherbee & Katila, 2020, 572). Finally, discovery "motivates convergence on a business idea" (Leatherbee & Katila, 2020, 572).

For teams participating in I-Corps, there is no clearly defined or consistent framework for developing questions or testing hypotheses (Giardino et al., 2014; Leatherbee & Katila, 2020). One study found that I-Corps bootcamps "provided remarkably little training about how to conduct effective interviews apart from "listen" and "don't talk about the product" (Batova et al., 2016, 3). Not surprisingly, this sentiment reflected my own experience participating in the I-

Corps National Program in 2022. The challenge of no clearly defined framework is also true for new venture teams outside of I-Corps. Startup literature lacks an “explicit grounding in previous scholarly tradition” (Bortolini et al., 2018, 2). The application of the technique is not grounded in research, so it has been determined that “rigorous analysis of the academic antecedents of LS (Lean Startup) may provide important insights about its implementation challenges, as well as its merits and shortcomings” (Bortolini et al., 2018, 2).

Although the NSF I-Corps program can be a great start for trying to bridge the gap between researchers developing a technology and business development, there are still limitations as described in the paragraph before. When a researcher is developing a technology, they may be using an engineering framework (Pahl & Beitz, 1996). An engineering framework may begin with a market, need, or problem, then follows a series of steps that can include product planning and task setting; design and development; production, assembly, and testing; marketing, consulting, and sales; use, consumption, and maintenance; energy recovery; recycling; and finally, disposal and environmental concerns (Pahl & Beitz, 1996).

However, in an academic setting a researcher does not necessarily begin with a market need or a consumer problem when developing a technology in the lab. A First Principles Approach to Product Development in Entrepreneurship bridges the gap between business, engineering design, and industrial design by providing a framework that can help researchers identify a consumer problem relevant to the technology they are working on. Bridging the gap between business, engineering design, and industrial design can help reduce the risk of failure when trying to commercialize a product or service, which may be based on the technology being developed in a lab. In order to address the limitations described in this section, Chapter 3 of this dissertation describes the application of qualitative research methods to Customer Discovery. Then, Chapters 4 – 8 apply the first principles approach described in this dissertation, in a way that is grounded in research, for a more systematic approach to Customer Discovery, when compared to programs such as I-Corps.

2.3 Advancing Customer Discovery by Incorporating First Principles

There is a distinct need for exploring the foundational elements of product development in entrepreneurship, which, as stated earlier, this dissertation is calling Reasoning from First Principles, in a way that is grounded in research. The need for exploring the foundational elements is similar to that which was identified previously for PPE. For Customer Discovery, as referred to in section 4.1.2, the problem interviews are the first step to developing questions and testing hypotheses, the primary tools for discovering the foundational elements of product development in entrepreneurship (Maurya, 2012). Through the problem interviews, the goal is to ask “Why?” and “How?” until assumptions cannot be deduced any further (Irwin, 1988). From those foundational assumptions, additional principles may follow that reflect how expert designers view those principles in relation to other stakeholders (Waguepack & Babb, 2017). Asking these questions is a continual process.

The problem interviews challenge and support assumptions by exploring pain points experienced by end users, then converging on a singular Severe Problem, a term defined and explained later in this dissertation in section 4.1.5. The process continues by incorporating a brainstorming session, which can begin with making sure the problem is understood and soliciting additional feedback. The brainstorming sessions are the initial steps for diverging from the initial idea and exploring the solution space with end users who are experiencing the problem (Frich et al., 2021; Maurya, 2012; Ozyaprak, 2016). The final goal for Customer Discovery is to find problem/solution fit, an initial indicator of viability for a new venture (Blank & Dorf, 2012).

It is only until there are strong indicators of viability for a new venture that the NVT can begin to critically think about the broader context of both the problem and solution. Specific to this dissertation, after finding problem/solution fit, I began to critically think about both the problem and solution by applying the Abstraction Ladder in Chapters 7 & 8. The reason is that, for product development outside of an established infrastructure, if the product fails, usually the new company can fail as well. *So, regardless of expert insights, impact scenarios, injury biomechanics, and psychology, if the product and company fail there is no mechanism for them to have any meaningful contribution to the end user.*

Then, in parallel with critical thinking, the NVT can begin to “build the right product features that solve real customers' needs, also known as the product/market fit. If the product/market fit is not achieved, then a problem/solution fit must be reiterated, an operation known as pivoting. Ultimately, in order to grow, companies have to test their business models, investing capital and executing tactics for acquiring and converting more customers of their potential market” (Giardino et al., 2014, 30).

2.4 The Application of First Principles to Customer Discovery

This dissertation is a case study for exploring A First Principles Approach to Product Development in Entrepreneurship, through the application of methodologies and techniques from product development. A result of the case study is a more comprehensive understanding of the advantages and disadvantages for each technique. The case study described in this dissertation shows how they work in the context of bicycle helmet design. In addition, a focus of this dissertation is identifying what methodologies and techniques are universally applicable to product development, and which ones are not.

The primary method used was the Customer Discovery Process along with the Lean Canvas (Blank & Dorf, 2012; Maurya, 2012). This process incorporates problem interviews, brainstorming sessions, and solution interviews. In addition, during the brainstorming sessions, the SCAMPER technique was used for brainstorming product ideas.

There are a variety of contexts for exploring a concept or an idea at a foundational level. As foundational components of the process are defined, for example problem/solution fit, techniques like the Abstraction Ladder can be used for a further exploration of first principles (LUMA Institute, 2012). It should be noted that this is a framework and not a step-by-step process. A framework is not necessarily linear, and steps can overlap, happen concurrently, and out of order. The concept of a framework for product development in action is shown in Figure 2.1 (Moggridge, 2007). In Figure 2.1 the black arrows show a cyclical process, and the green arrows show a process that is complex and less orderly (Moggridge, 2007).

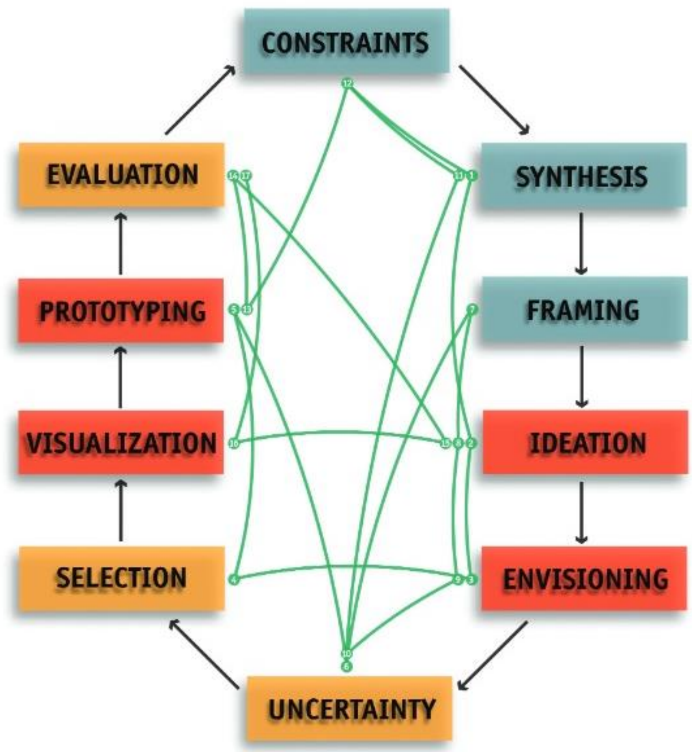


Figure 2.1 Conceptualization of a product development framework from the book Designing Interactions, by Bill Moggridge, used with permission from the MIT Press

The framework that is the topic of this dissertation is shown below in Figure 2.2, and encompasses elements of flowcharts from entrepreneurship, engineering design, and industrial design. In Figure 2.2 the left column of the figure shows the qualitative research methods that were used, as well as where they were used in the process. The middle column of the figure, in the light green section, the figure shows the various Customer Discovery and entrepreneurial processes used to go from an initial idea to the initial elements of a product brief. Then in the middle column, in the light purple section, the figure shows the engineering design and industrial design processes used to go from an initial product brief to product development. It should be noted that in between the light green section and the light purple section, there is overlap between the entrepreneurial, engineering design, and industrial design processes. The overlap between processes demonstrates how this dissertation has begun to bridge the gaps between entrepreneurship, engineering design, and industrial design.

Traditionally in an established company, the aspects of business, engineering design, and industrial design, are separate processes and carried out by personnel from separate departments within that company. However, within the context of a new venture, it is anticipated that the members of the NVT, who are conducting interviews and trying to launch the new venture will also be involved in product development, and critically evaluating key aspects of the new venture, so combining the processes is especially relevant. Next, the light red section on the right side and bottom of the figure shows the methods used for critical evaluation. Finally, the right column of the figure shows the Framework Key.

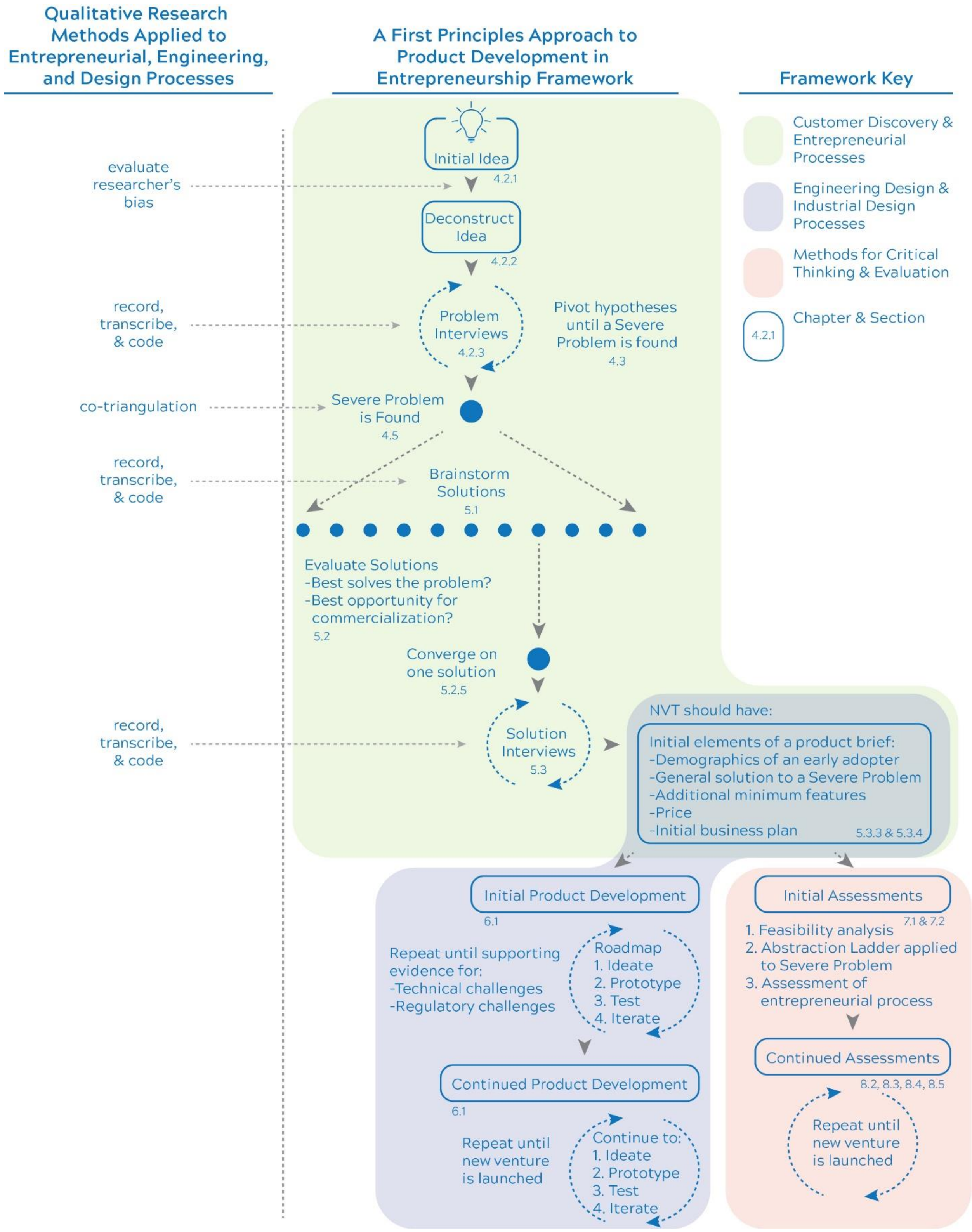


Figure 2.2 A First Principles Approach to Product Development in Entrepreneurship Framework that bridges the gap between entrepreneurial, engineering design, and industrial design flowcharts, where the figure highlights which qualitative research methods were used and when in the process

It should be noted that texts such as *Engineering Design*, by Pahl and Beitz, do include approaches and examples for finding different levels of abstraction for design requirements, solution elements, external influences, and function structures, where the level of abstraction is bound by various constraints (Pahl & Beitz, 1996). Exploring different levels of abstraction in this context seems to share similarities to the Abstraction Ladder, which will be described further in Chapter 7. However, due to the traditional separation of business and engineering disciplines in established companies, it may be unlikely that an engineer's exploration of relevant levels of abstraction would include a review of other criteria that relates to launching a new venture (in this case a feasibility analysis), as well as a review of the entrepreneurial process (in this case Customer Discovery).

2.4.1 Who A First Principles Approach is For

The first principles approach described in this dissertation can be more appropriate for new ventures as opposed to existing firms. The first principles approach can be more appropriate for new ventures when compared to existing firms due to the risk associated with launching a new venture, as 33 – 75% of new ventures fail, as described in section 2.1. Existing firms generally have a diversified product portfolio, which can help manage risk when developing new products. If one product fails, there may be other products that perform well, which can help reduce the negative effects of a product's poor performance.

In addition, a first principles approach can be appropriate for new ventures that have capital intensive products. The reason a first principles approach can be appropriate for new ventures that will most likely have capital intensive products is because the rationale provided from Customer Discovery, the feasibility analysis, and application of the Abstraction Ladder can serve as supporting evidence for new venture success when trying to secure funding from grants, loans, investors, pitch competitions, et cetera.

A first principles approach can also be helpful when the customer segment that an NVT is exploring has the following characteristics: accessibility, the market is large, and there is some autonomy to make a purchasing decision. The reason a first principles approach can be helpful when the customer segment is accessible is because Customer Discovery generally focuses on interviews with potential early adopters. If the NVT is unable to access the customer segment and interview them, the NVT will most likely have trouble learning from that customer segment in order to challenge and support hypotheses. A first principles approach can also be helpful when the customer segment is large, also referring to the total and target markets. The reason a large market can be helpful is because if the NVT begins Customer Discovery with a group of potential early adopters within a larger customer segment and realize that particular group of early adopters does not appear to be viable, then there may be other groups of potential early adopters to pivot to.

A first principles approach can also be appropriate for NVT's who are focusing on a group of potential early adopters who have some autonomy for making a purchasing decision. The reason a first principles approach can be appropriate for NVT's focusing on markets where there is some autonomy for making a purchasing decision is because if an NVT finds a group of potential early adopters with a Severe Problem, there is an assumption that those potential early adopters may be eager to buy a solution that solves their problem. Some appropriate industries that an NVT may focus on are industries that are not heavily regulated, industries that have smaller firms, or industries that have a consumer facing component. For products, services or industries where the purchasing and acquisition of new products and services is more complex or bureaucratic, such as those that segmented by end users, economic buyers, decision makers, influencers, recommenders, and saboteurs, applying the Business Model Canvas may be more appropriate as the person who is describing the Severe Problem may have very little control in being able to buy or implement a solution (Blank & Dorf, 2012).

However, despite segmenting potential industries, markets, and customer segments that a first principles approach may be appropriate for, the most important criteria for an NVT is a drive to continue even amidst challenges. Many entrepreneurs may give up before they find a Severe Problem, a solution that has potential for commercialization, or moving a product past technical and regulatory challenges, even if they have good ideas. Regardless, the point remains the same, whether an NVT needs to pivot a particular hypothesis, solution or both, the ability to continue in the face of delays, roadblocks, and failures is paramount, and can be the difference between success and failure.

2.5 An Interdisciplinary Approach to Research

As entrepreneurship can be an interdisciplinary endeavor, research on the subject can also be interdisciplinary. At Virginia Tech, an interdisciplinary approach specific to the research described in this dissertation includes the following: the Pamplin College of Business for challenging and supporting assumptions, as well as business modeling; the College of Engineering for exploring injury biomechanics and relevant manufacturing processes; and the College of Architecture, Arts, and Design for the end product’s overall design.

2.5.1 The Need for Interdisciplinarity

The Interdisciplinary Ph.D. (IPhD) program at Virginia Tech expects that the research will include members from at least two different disciplinary fields (*Graduate School*, 2023). The primary contribution of this research is the application of a product development process, specifically applying A First Principles Approach to Product Development in Entrepreneurship to the entirety of the product development life cycle. The goal has been to improve safety for the end user. The result has been a more personalized, tailored, and human centered design approach to impact protection, with the aim of launching a new venture from the research. This proposed approach explores if and how the application of first principles can be incorporated for improved safety.

My work was interdisciplinary because it was a project that required balance between the design constraints and processes of several different disciplines. The interdisciplinary work needed to be done at Virginia Tech because it depended on the current research of those disciplines, as will be described in the remainder of this section. Finding balance was the core of interdisciplinarity and was essential for providing value to the end user. The background and experience of each advisor working with me was critical to the dissertation’s success. Co-Chair, and previously Deputy Executive Director for the Institute of Creativity, Arts, and Technology, Dr. Thomas Martin has served as critical support for navigating the interdisciplinary process, through his experience with interdisciplinary work.

2.5.2 Pamplin College of Business

The process began with the Pamplin College of Business with Co-Chair, Prof. Andy Schaudt. First and foremost, we collected primary qualitative data which challenged and supported assumptions around the proposed customer segment and product solution, finding problem/solution fit. Finding problem/solution fit involved asking open-ended questions around the athlete’s personal relationship with the sport, experience crashing, PPE they use, preferences in regards to helmets, and general consumer purchasing habits. Collecting primary data was exceptionally important because it generated relevant data specific to the research study. Finding problem/solution fit served as an indicator for new venture viability. In addition, Dr. Martin's experience with the National Science Foundation I-Corps program brought experience to the Customer Discovery Process and commercializing research.

2.5.3 College of Engineering, Department of Biomedical Engineering and Mechanics

Next, it was important to develop a solution that will not only solve a problem that a customer has described or pass a certain safety standard, but the solution must also prevent and mitigate injury. Thus, it was critical to work with Dr. Steven Rowson and The Helmet Lab. Here we developed a strategy for component testing, as well as how to develop a helmet to the Consumer Product Safety Standard, 16 CFR part 1203 (CPSC, 1998). Then, we asked questions about impact scenarios, biomechanics of brain injury, injury tolerances, prevention, and mitigation strategies, relevant to end users, which will be described further in Chapter 8.

2.5.4 College of Engineering, Department of Mechanical Engineering

Product development continued through collaboration with Dr. Christopher Williams and the DREAMS Lab. Here we developed a workflow around scanning, rendering, and printing structures (mesostructures). Product development has leveraged nTopology for lattice design, Powder Bed Fusion for producing structures, and nylon-based materials (PA11 and PA12). Dr. Williams also brought valuable expertise through his experience with NSF's I-Corps Program.

2.5.5 College of Architecture, Arts, and Design

After the workflow was developed, the product still has to look cool and the end user has to be excited to engage with it. An initial design strategy has begun with Prof. Brook Kennedy and the Industrial Design Program. Here, we could improve the workflow, as well as matters of function like venting, breathability, ergonomics, and versatility. In addition, we can focus on the overall design of the helmet, which includes aesthetic applications. Prof. Kennedy also brought valuable expertise through his experience commercializing products.

2.5.6 Personal Experience

There can be a long road between finding problem/solution fit, finishing the first working prototype, and launching a new venture. My professional experience developing limb armor for a motorcycle apparel company serves as a valuable asset for navigating that process. My professional experience included conducting market research and competitor product analysis, evaluating energy absorbing materials for injury prevention and mitigation. My professional experience also included extensive knowledge on crash profiles, international standards, and test methods, to build a brand's impact protection strategy as the industry leader. My experience culminated with the development of D3o Aero Pro: the lightest, most flexible, breathable, and best vented limb armor on the planet, passing all EN-1621 conditioning (Klim, 2018). However, both success and proficiencies in product development do not guarantee success in launching a new venture.

In addition, having an interdisciplinary degree provides credibility throughout multiple technical disciplines. For PPE specifically, credibility is exceptionally important because it is the tool that will hopefully prevent and mitigate injury in the event of a crash. An interdisciplinary degree provides a holistic understanding for A First Principles Approach to Product Development in Entrepreneurship in the development of safety equipment.

2.6 Chapter Summary and Next Steps

In conclusion, deficiencies in both the PPE Industry and product development demonstrate the need to identify, apply, and evaluate product development methodologies that explore the foundational elements of product development. The framework, A First Principles Approach to Product Development in Entrepreneurship, was created to explore the foundational elements of product development and bridge the gaps between entrepreneurship, engineering design, and industrial design. The first principles approach is intended for entrepreneurs, product developers, and researchers developing physical, capital-intensive products, where the key stakeholder who is describing the problem is also close to the purchasing decision. Exploring a first principles approach was conducted in a way that was grounded in qualitative research, as variations in product development methodologies and nomenclature make it difficult to know which are most appropriate. Due to the scale and scope of exploring the foundational elements of product development for bicycle helmets an interdisciplinary approach was required. The next chapter explores the qualitative research methods needed for applying a first principles approach.

Chapter 3 The Application of Qualitative Research Methods

The previous chapter examined failure rates in entrepreneurship, and explained how a first principles approach could be applied to entrepreneurship in an effort to reduce new venture failure. This chapter introduces qualitative research, which qualitative research methods are most appropriate for Customer Discovery, and how those research methods were applied.

Section 3.1 provides an overview of the chapter. Then section 3.2 highlights approaches to qualitative research, as well as qualitative research characteristics that are relevant to this study. Next section 3.3 specifies that this dissertation is a case study of the Customer Discovery Process, which applies grounded theory to Customer Discovery. Section 3.4 demonstrates how the interviews were transcribed, coded, analyzed, and co-triangulated. Section 3.5 summarizes the chapter.

3.1 Overview

Shortcomings in both the personal protective equipment (PPE) industry and product development in entrepreneurship highlight the need to understand the foundational elements of each, in a way that is grounded in research. This study addresses those shortcomings and improves safety for the rider, by applying a first principles approach to the entirety of the product development life cycle. The contribution of this research is an established framework and the implementation of a product development process, with Customer Discovery as the initial step to A First Principles Approach to Product Development in Entrepreneurship. This framework explores if and how the application of first principles can be incorporated for improved safety, as well as other product categories.

When the exact information needed to drive new product development does not exist the process begins with primary research (Lowe & Zemliansky, 2011). For primary research, qualitative data is collected by conducting Customer Discovery, which involves interviewing both end users and customers (Bjork et al., 2013). Customer Discovery is a systematic process to establish rationale for product development. There are many activities and segments of people that use helmets, even within bicycling. Customer Discovery is the catalyst for down selection, identifying what customer pain point to solve, who to solve it for, and how to solve it. The process can rely on a series of problem interviews, brainstorming sessions, and solution interviews (Blank & Dorf, 2012; Maurya, 2012; Ozyaprak, 2016). Collecting primary, qualitative data through each set of interviews is exceptionally important because it generates relevant information specific to the research study.

The purpose of this chapter is to describe that there is a need for a case study of Customer Discovery. In addition, the purpose of this chapter is to describe how and why approaches in qualitative research were applied to Customer Discovery. By describing a need for a case study, as well as how and why qualitative research methods were applied, this chapter demonstrates that the most relevant qualitative research methods were applied in order to foster an environment for accurate results.

3.2 Approach to Qualitative Research

Section 2.2 described how state and nationally funded programs, as well as new venture teams outside of such programs, have no clearly defined or consistent framework for developing questions or testing hypotheses during Customer Discovery (Giardino et al., 2014; Leatherbee & Katila, 2020). In response to this challenge, I conducted a case study by applying Customer Discovery in a way that is grounded in qualitative research. Conducting such a case study requires examining the most relevant literature that defines qualitative research. This section describes the application of qualitative research methods to Customer Discovery, which demonstrates that qualitative research is a fundamental component of the research described in this dissertation. Specifically, I examine the role of the researcher, characteristics of qualitative research, the rationale for developing a case study, and how it was executed, so that future entrepreneurs, product developers, and researchers may reference, apply and build upon the methodologies and findings.

When conducting a case study, it can be difficult to compare a first principles approach to other existing entrepreneurial texts. On the one hand, there is no shortage of product development or entrepreneurial texts. In a way, all I have done is reorganized and applied methodologies that are readily available and already exist. On the other hand, as described in section 1.2, there are limitations with the motorcycle apparel industry, football, and cycling, as companies are not designing to the problem. Those limitations are most likely relevant in other industries as well.

Determining whether or not a first principles approach has improved the new venture team's (NVT) likelihood for success compared to other approaches does not seem to be binary, meaning yes it has improved the likelihood for success or no it has not. The evaluation of improvement can be subjective. It is also difficult, if not impossible, to conduct a controlled scientific experiment where the NVT's approach is the only variable. In addition, the success or failure of a new venture can be directly tied to the team's effort and ability to problem solve challenges along the way. For this dissertation, when applying a first principles approach and describing the advantages and disadvantages when compared to other entrepreneurial texts, there is an underlying assumption that there would be an equal amount of effort and problem-solving ability from the NVT that is applying it had the NVT taken a different approach.

3.2.1 Overview of Qualitative Research

In contrast to quantitative research, qualitative research has no firm structure, where procedures change and evolve regularly (Creswell, 2007). Despite the lack of a firm structure, qualitative research, "generally falls within the process of scientific research" (Creswell, 2007, 41). The fluidity of qualitative research presents a challenge when instructing others on designing a study, as well as knowing when the study is completed (Creswell, 2007). Although books on the subject vary, the book *Qualitative Inquiry and Research Design* by John W. Creswell heavily influenced this qualitative research study. Creswell described that the general approach is to create "options for qualitative researchers…weighing the options… and then letting readers choose for themselves" (Creswell, 2007, 41). In qualitative research, all researchers generally start with an issue, study literature associated with that issue, ask questions, collect, and analyze data, and write a final report (Creswell, 2007).

3.2.2 Role of the Researcher in Qualitative Research

The factors that influence a researcher's decisions for designing new studies are how they have conducted previous studies, as well as how they collect and interpret data (Denzin & Lincoln, 2011). The interpretive approach to qualitative research has much to offer, however it should focus on the phenomena of social worlds as opposed to the researcher and self-referential work (Creswell, 2007). In response to potential bias from the researcher, the research process begins with philosophical assumptions from the researcher, acting as the basis for research. The possibility for bias is especially true for the researchers themselves, as they bring their own, "worldviews, paradigms, or sets of beliefs to the research project" (Creswell, 2007, 15). The researcher's world views either implicitly or explicitly influence the design, conduct, and analysis of the study (Creswell, 2007). In response, good research requires that, at a minimum, these assumptions are pointed out (Creswell, 2007).

3.2.3 Reflection on Researcher's Assumptions

Product development is the immediate paradigm through which I view the creation of this study, as my background is in motorcycle and snowmobile apparel design, as previously described in section 1.2. An inherent goal of my doctoral studies is to find a problem that has the potential to direct product development. The practice of finding a problem is also referred to as problem setting (Schon, 2016). The goal is not to conduct over 170 interviews and conclude that there were no problems severe enough to direct product development. My goal is to transition from Customer Discovery to product development. That goal stems from my perception that finding problem/solution fit is the catalyst for entrepreneurship, and entrepreneurship has the ability to be more than simply an exchange of goods and services, but rather a vehicle for positive change in the world.

Another consideration for how I approached the study is, my previous experience was in high-end apparel for an extreme group of end users. Similarly, I have an expectation that the final solution may be a high-end product. In addition, I have a bias towards extreme groups of end users. My bias is shown through the groups I interviewed such as pro and semipro athletes, children getting on a balance bike for the first time, or other segments of riders. Furthermore, as a former student athlete, Returned Peace Corps Volunteer, and mountain biker, the groups of participants I started with and pivoted to are largely a reflection of my own personal interests. Regardless of the specific demographics, I am interested in thrill and adventure seekers, outdoor activities, and people of all ages pushing their physical limits. My desire to begin Customer Discovery with Pro and Semipro Men is the result of my professional experience and personal interests, as I transition from the motorcycle and snowmobile industry to the bicycle industry.

Other than the traditional relationship between participant and researcher, no power imbalance was expected. A juxtaposition of such a power imbalance could be, the potential cultural and socioeconomic disconnect between an American researcher studying disenfranchised communities in Southeast Asia. For my study, A First Principles Approach to Product Development in Entrepreneurship, I am researching demographics primarily in the U.S, with some international participation.

I am also a part of the national and cultural majority and that affects the lens through which I view and conduct this body of research. Furthermore, the research is directly influenced by my co-chairs and advisors. The final conclusion of the research is an interpretation from a study I designed, conducted, and analyzed. Lastly, this reflection of my assumptions specific to the research is dependent on my ability and willingness to identify and describe the most relevant assumptions.

3.2.4 Common Characteristics of Qualitative Research

According to Creswell, in qualitative research, there are nine common characteristics (Creswell, 2007):

- Natural setting
- Researcher as key instrument
- Multiple sources of data

- Inductive data analysis
- Participants' meanings
- Emergent design
- Theoretical lens
- Interpretive inquiry
- Holistic account

This study, A First Principles Approach to Product Development in Entrepreneurship, utilizes a few common characteristics of qualitative research, as they are most closely aligned with Customer Discovery. *Researcher as a key instrument* identifies me, the researcher, as a crucial part of the process, conducting and collecting the interviews themselves, without relying on methods developed by other researchers (Creswell, 2007). I designed the set of questions for each user demographic in relation to product, market, and customer risk hypotheses, so identifying my role as a crucial part of the process is especially relevant. I also transcribed and coded each interview specific to the research questions being asked. The next characteristic is *Participants' meanings*, focusing on how the participant views the problem or issue, as opposed to the researcher's meaning that they want from the collected data (Creswell, 2007). By conducting open-ended interviews, I was able to focus on participants' meanings, as it gave them the opportunity to answer each question as they saw fit. The third characteristic is *Emergent Design*, meaning that phases of the process may shift, not limited to questions asked or participant demographics (Creswell, 2007). *Emergent design* is present through the research as I pivoted from various product, market, and customer risk hypotheses, as well as updated the questions for each demographic. Finally, *Interpretive inquiry* is present in this body of research, as it relies on multiple interpretations of the data, in an effort to circumvent the researcher's inherent bias (Creswell, 2007). For this study, *Interpretive inquiry* begins with the researcher's interpretation of the data and continues through co-triangulation, so "multiple views of the problem can emerge" (Creswell, 2007, 39).

3.2.5 The Need for Qualitative Research

Section 3.2.3 described some of the broad assumptions and world views associated with the research, as these assumptions help shape the study. The next steps are reviewing the literature relevant to the area of investigation and identifying an issue or problem that is not accounted for in the most relevant literature (Creswell, 2007). An issue or problem "may be one in the 'real world' or it may be a deficiency in the literature or past investigations of a topic" (Creswell, 2007, 42).

Sections 1.2 and 2.1 reviewed the literature relevant to the area of investigation, as well as identified a variety of deficiencies in the literature. Deficiencies in the literature described the disconnect between impact scenarios, injury biomechanics, standards, and solutions for PPE through motorcycling, football, and bicycling industries. Deficiencies in the literature were also described in the popularized failure rates for startups, failure rates for startups defined by research, and failure rates for startups commercializing research. Although there are discrepancies between product development failure rates, the point remains the same, the goal is to reduce catastrophic failure, meaning the liquidation of assets and complete loss of capital. As a result, the deficiencies in both the PPE industry and product development demonstrate the need to conduct qualitative research to better understand their foundational elements.

The deficiencies in both the PPE industry and product development in entrepreneurship previously described are good reasons to explore the issues further, as opposed to simply relying on previous literature. Qualitative research is a tool for exploring the issue or population with measurable variables (Creswell, 2007). Qualitative research also facilitates a detailed and intricate understanding of the issue (Creswell, 2007). Understanding an issue is based on engaging with people directly, being open to unexpected answers, and new directions (Creswell, 2007).

3.3 Qualitative Research Design and Implementation

This section describes how and why I designed the qualitative research study contained in this dissertation. Specifically, this section highlights that the research conducted in this dissertation is a case study of Customer Discovery as a foundational element of entrepreneurship. In addition, this section applies the qualitative research approach grounded theory to the Customer Discovery Process. From grounded theory, I applied relevant interviewing methods and strategies to further demonstrate the process is grounded in research.

3.3.1 Designing a Qualitative Research Study

There are five different general approaches to qualitative research: narrative, phenomenology, grounded theory, ethnography, and case studies (Creswell, 2007). The qualitative study composed and applied largely depends on the approach the researcher chooses, as research questions from grounded theory would be different from those framed by an ethnographic study (Creswell, 2007). Regardless, qualitative research follows a basic process of introduction, research questions, methods of data collection, and analysis (Creswell, 2007).

The goal of this study is to apply and evaluate a series of product development methodologies, exploring the foundational elements of product development in entrepreneurship. As a result, I decided to conduct a case study, specifically an intrinsic case study, where the “focus is on the case itself (e.g., evaluating a program)” (Creswell, 2007, 74). This dissertation is an intrinsic case study, focusing on the design and application of a product development methodology, ultimately evaluating the process. The Customer Discovery Process (CDP) is the designed and applied product development methodology. The CDP is based on interviews with potential early adopters and key partners (Blank & Dorf, 2012). Therefore, the primary method of data collection is recording the participant’s responses. Participant observations about the interviews (the follow up portion of each interview), as well as direct observations from the interviews were additional methods of data collection.

When designing a case study, one of the considerations is that many cases may be appropriate for the study (Creswell, 2007). So, it must be determined to study a singular case or multiple cases (Creswell, 2007). There is no set number for a multiple case study, but I considered the product development methodologies Jobs to Be Done and Design Thinking as well (Plattner et al., 2011; Ulwick, 2016). The reason for conducting a singular case study and not including these additional methodologies is that their inclusion would have diluted both the overall analysis and depth of the study. However, I have experience with both Jobs to Be Done through the NSF I-Corps Regional Short Course, as well as Design Thinking through the University Innovation Fellows Program. So, even though an in-depth multiple case study is not appropriate, I am able to make educated comparisons of the methodologies in section 8.2, based on my experience and familiarity with the literature.

Important features that mark this case study are as follows. The singular “case” for this study was the design and application of the Customer Discovery Process, specifically exploring PPE for cyclists. This “case” is a bounded system, bounded by time (eighteen months for data collection), participants (potential early adopters and personnel within the bike industry) and data collection method (interviews), all disclosed in an approved IRB protocol. To demonstrate different ways to design and apply the methodology, I used multiple variations of product, market, and customer risk hypotheses. To highlight the need for this case study, in sections 1.2

and 2.1, I described deficiencies with the PPE industry and product development in entrepreneurship, providing context and “illustrating the complexity of the issue” (Creswell, 2007, 93).

Finally, the purpose of this case study is to implement a series of product development techniques, starting with Customer Discovery, creating a product development framework for entrepreneurs. I have called the framework created from this dissertation, A First Principles Approach to Product Development in Entrepreneurship, implementing it with individuals that use bicycle helmets and bike industry personnel. The foundational goal of this research is to find a Severe Problem that has the potential to drive product development for a new venture. The secondary goal is to continue development throughout the entirety of the product development lifecycle.

3.3.2 Implementation of the Case Study

As a product development methodology, Customer Discovery inherently relies on open-ended questions and semi-structured interviews (Blank & Dorf, 2012; Maurya, 2012). Using open-ended questions for data collection is similar to the qualitative research approach grounded theory (Creswell, 2007). In an effort to ensure I conducted Customer Discovery with a research focused approach, I incorporated additional grounded theory methods when conducting the interviews and analyzing the data. A method I incorporated during the interview and coding process was journaling (memoing), a process of writing ideas during the interviewing and coding process that may relate to the evolving theories emerging from the data (Creswell, 2007).

For a grounded theory study, 20 to 30 interviews are typically conducted or, “until the new information obtained does not further provide insight into the category” (Creswell, 2007, 160). Within this study, for each set of hypotheses, the least number of interviews I conducted was four and the most was thirty-one. The number of participants, accessibility to the participants, and expectation that there was more data to be collected dictated the variability for the number of interviews.

I conducted the problem interviews and solution interviews over the phone and web conferencing platforms, as participants were located throughout the continental United States, and a smaller sub section of participants were located internationally. All of the problem and solution interviews were one-on-one. For one-on-one interviews, the research needs participants who are open to speaking and sharing ideas (Creswell, 2007). All of the interviews were done remotely; therefore, the participant could pick a setting that was comfortable for themselves. Participants who were shy or less articulate presented a challenge in data collection. During the interviews, I listened under the assumption that participants were telling the truth to the best of their ability. Prior to conducting interviews with participants, I conducted a small pilot study with friends and family to refine the questions, practice my interviewing skills, the recording process, and finally ask for feedback (Creswell, 2007).

I adjusted each set of questions to a specific group of participants, or based on that particular pivot, e.g., the pivot from pro riders to masters riders. As I interviewed participants, I found that the way I was asking a certain question was leading to answers that were beyond the scope of inquiry, so I adjusted the questions accordingly. For example, the interviews originally started with the question, “How many helmets do you own?” However, the answers included every helmet in their garage, which they were no longer using, or were damaged. An answer this comprehensive was not useful, as I was only interested in helmets they were using regularly. So, I adjusted the question to read, “How many helmets do you own that you could potentially use for a ride that day?” In addition, as I progressed through the interview process, I got better at asking open-ended follow-up questions. For example, when a participant mentioned MIPS, I’d follow up with “Why MIPS?”.

I conducted two brainstorming sessions over the web conferencing platform Zoom and used the collaborative web platform Miro. One of the advantages with focus groups is that similar groups of end users, who are cooperative, can lead to collaborative and synergistic exchanges (Creswell, 2007). In comparison, a participant who is being interviewed individually may be hesitant to share their experiences (Creswell, 2007). One logistical challenge with focus groups is finding a time the whole group can participate (Creswell, 2007). It is also a challenge "to encourage all participants to talk and to monitor individuals who may dominate the conversation" (Creswell, 2007, 133).

3.4 Qualitative Research Analysis

This section describes how I analyzed the interviews and reached various conclusions. The analysis process begins with how I transcribed the interviews. Next, I categorized themes from the interviews. Finally, two other qualitative researchers and myself co-triangulated the interviews, meaning, I coordinated an external review of the interviews to see if the researchers came to similar or opposing conclusions.

3.4.1 Transcription Process

I recorded all of the interviews, as it can be a challenge to ask questions and write answers at the same time, resulting in incomplete notes (Creswell, 2007). The recorded interviews were then transcribed. I broke the transcription process down into three steps, 1.) the automated transcription, 2.) listening to the recording, while reading the automated transcription and making edits, 3.) proofreading the final transcription.

The first step in the process involved having the interviews transcribed using an automated transcription service such as Temi or Transcribeme!. Virginia Tech's Institute of Creativity, Arts, and Technology funded the majority of the transcription services. After I received the automated transcriptions, the second step was to listen to each recording, make sure the transcription matched what the participant said and edit accordingly. The reasons for the transcription not matching what the participant said was often due to a bad recording, noise in the background, thick accent, or the participant not speaking loudly or clearly enough. If there was a section in the recording that was inaudible, I listened to it three times, to see if I could understand it. If I still could not understand it, I'd write [inaudible], along with the closest phrase I could come up with and a question mark. For example:

ID_1208: 00:25:56 You know there's a lot of kids [inaudible][that should?] wear knee pads.

As I listened and edited the transcriptions, I took notes on the participant's answers. The third step involved proofreading the final transcription. At my discretion, I proofread each interview for clarity and grammar. I listened to each section of the recording that was inaudible another three times and determined if what was being said could be understood by myself, the researcher.

Other considerations for transcribing were, the interviews were transcribed to reflect the participants voice, as well as for readability. Not all, but many of the, "ums," "uhs," "ahs," "you knows," and "kind ofs"' were removed from the text. The editing process required deliberation from myself as the researcher. The overall arching goal was to maintain the spirit of what the participant was trying to describe or communicate.

For example, the original text read:

Unusual if you're suffering from, um, you know, you can, what do you call it? If you have symptoms of a concussion.

It was then edited to:
Unusual if you're suffering from, um, what do you call it? If you have symptoms of a concussion.

Finally, during the transcription process, I deidentified the interviews to the best of my ability. In addition, I removed all participant’s and children’s names, replacing the child’s name with son, daughter, oldest son/daughter, youngest son/daughter, or child.

3.4.2 Coding Overview

I then coded and analyzed the transcribed interviews. Analyzing the interviews involves identifying specific excerpts of text to create general themes or perspectives, organizing, and categorizing them (Creswell, 2007). The process involves navigating multiple layers of abstraction, beginning with the raw data from the interviews and forming broader groups and categories (Creswell, 2007). The analysis is not necessarily linear, steps can overlap, and happen concurrently (Creswell, 2007). Generally speaking, as researchers, “we present our data, partly on participants' perspectives and partly based on our own interpretation, never clearly escaping our own personal stamp on a study” (Creswell, 2007, 43).

For analysis, I also incorporated procedures from grounded theory, such as the process of coding interviews. The coding process is simply a method for categorizing ideas or happenings the participant describes in the interviews and identifying the relationships between categories (Creswell, 2007). The coding process relies on an overlapping and interconnected framework of procedures that begins with “developing categories of information (open coding), interconnecting the categories (axial coding), building a “story” that connects the categories (selective coding), and ending with a discursive set of theoretical propositions (Strauss & Corbin, 1990)” (Creswell, 2007, 161).

The coding process started with a combination of both open coding and template coding. Open coding is a process used to highlight themes from the transcripts resisting any preconceived notions from the researchers, then simplify the group of categories to a smaller set of themes that describe the phenomena being explored (Blair, 2015; Creswell, 2007). For this study I also incorporated template codes as they use predefined categories for highlighting themes from the transcripts (Blair, 2015).

The coding process incorporated template coding, which included using product, market, and customer risk hypotheses as categories. For example, for the product risk hypothesis, I knew I was looking for a problem around “safety” or “fit”. So, I would highlight excerpts of the text that were relevant to that category.

The reason the coding process incorporated open coding was, the word “problem” can be an ambiguous, contextual, and application specific word. Other than a problem with “safety” or “fit” I did not know exactly what type of problem I was looking for. Operationally defined terms such as Severe Problem and Major Problem only emerged as I read through the interviews and identified recurring themes. Another example of open coding occurred when participants described Minor Issues that could be categorized in multiple ways. For example, when a Masters Rider described:

ID_712 (10:29): I was getting a lot of sweat in my eyes. Um, and I think initially it didn't have much of the absorbing band across the way your forehead goes. Um, so I, it did bug me quite a lot actually. And then, I guess that's another modification and I just put another Velcro soft strip and I've fixed that problem, but it was quite annoying.

Sweat drip in the eyes lies at the intersection of many Minor Issues and could be coded in a variety of different ways, for example: Visibility, Safety, Breathability, Venting, Temperature Management, Sweat Management, or Sweat Absorption, to name a few. There could also be a variety of hierarchies within those codes.

Another challenge with open coding semi-structured interviews was when a participant described a scenario or a situation. For example, when a Downhill Rider described:

Interviewer: Why do you ride, what does it mean to you?
ID_1004: 00:01:02.28 Fun and excitement.
Interviewer: OK do you have any stories that kind of embody that feeling of what you enjoy, what's so exciting about it to you?
ID_1004: 00:01:26.40 ... this past summer, just being out with the guys. We're at the World Cup race, watching all the World Cup racers practice and race was pretty incredible. And every day we'd hit the trails ourselves as a group of typically 8 to 15 people and I mean, to be honest, I'm one of the faster guys, so it's really fun to be at, sort of toward the head of the line and just hammering away.

This section could have simply been coded as Fun and Excitement, but those codes have no depth compared to the story he tells shortly afterwards. However, now that he told the story, the goal or Job to Be Done could be coded in a variety of ways, for example: Social Interaction, Competitiveness, Physical Fitness, and Technicality of the Sport.

One of the challenges with coding is the origin of the code or category name (Creswell, 2007). Codes come from a variety of sources, whether they are *in vivo* codes referring to the exact words used by the participant, they come from industry nomenclature, or they are a term the researcher creates to describe the information (Creswell, 2007). Coding is an imperfect, iterative, human process, as the terms are updated and grouped. For myself, coding a description consistently for different demographics of riders was a challenge. For example, Minor Issues with sweat drip could be coded as, Sweat Management for Masters Riders, Sweat Absorption for Downhill Riders, and Thermal Comfort for Pro and Semipro Women.

The challenge with consistently categorizing and classifying descriptions highlights the need for axial coding. Axial coding is the process of "'winnowing' the data," standardizing labels, grouping categories, organizing hierarchies, and discarding information that is not relevant (Creswell, 2007, 152). An equally important part of axial coding is, as the codes are being organized, the researcher identifies a code or category to focus on (Creswell, 2007). The one category of focus is known as the core or central phenomenon (Creswell, 2007). The central phenomenon is "typically one that is extensively discussed by the participants or one of particular conceptual interest because it seems central to the process being studied" (Creswell, 2007, 160). For this study, the central phenomenon was influenced by the pre identified categories, product, market, and customer risk hypotheses. The central phenomenon was identified as the Severe Problem of helmet fit for US Bike Parents as described in section 4.5. The additional codes or categories are then organized around that central phenomenon. The researcher can continue to collect data or reexamine the dataset for additional context in regard to the central phenomenon (Creswell, 2007).

The interviews lead to a variety of unexpected categories, as the questions were open-ended. The unexpected categories include but are not limited to conversations on pricing or recommendations to make a cooler looking construction helmet. I coded one unexpected theme that frequently came up as "Quotes That Warm My Heart," an example of this category was when a father, participant ID_1212 described his daughter's introduction to biking as:

ID_1212: 00:07:14.69 And she just took off immediately. So, I'm sure me and my son we'll be chasing right behind her forever.

The coding process ends with selective coding, meaning a comprehensive and complete body of text describing a series of theoretical propositions or “the researcher may write a ‘story line’ that connects the categories” (Creswell, 2007, 67). The developed theory can take various forms, such as a narrative statement, visual picture, or a series of propositions (Creswell, 2007). For this dissertation, selective coding resulted in a body of text of problem interview learnings, based on Ash Maurya’s book, *Running Lean* (Maurya, 2012).

3.4.3 Co-triangulation Overview

Finally, due to the subjective nature of coding for the individual researcher, I coordinated the interviews to be co-triangulated. Co-triangulation is an external check of the coding process, which involves additional researchers reading and coding the transcribed interviews, presenting their own interpretations of the data (Creswell, 2007). In practice, I collaborated with Dr. Nathaniel Porter, Virginia Tech Social Science Data Consultant. Together we developed a strategy for the co-triangulation process, as well as intercoder agreements. Intercoder agreements are a set of guidelines to determine what exactly the additional researchers are agreeing on, as they read through the transcribed interviews (Creswell, 2007).

Through a Virginia Tech Proof of Concept Funding grant, I hired two researchers Carey Stewart and Logan Layne. Dr. Porter, Mrs. Stewart, Mr. Layne, and I read through the intercoder agreements together to make sure there was a collective understanding for co-triangulation. Then, I would send Mrs. Stewart and Mr. Layne three interviews at a time for them to code. After they coded the interviews, the three of us would meet over Zoom where they would describe their reasoning for coding a particular section of the text. Next, each of us would state whether or not we agreed with that particular code and the reasoning that supported it. We agreed upon the vast majority of the codes, although there were a few codes where we did not reach a consensus. However, for the codes where we did not reach consensus, it did not affect the findings of this dissertation.

3.5 Chapter Summary and Next Steps

This chapter presented an overview of qualitative research. The overview included describing the need for the research, highlighting the researcher's role, and the various characteristics of qualitative research. For the specific research in this dissertation, the application of a case study was described, as well as how and why research methods were applied. The methods applied include interview strategies from grounded theory.

After describing an overview of the qualitative research specific to this dissertation, an analysis of the interviews was described, giving specific detail to transcribing, coding, and co-triangulation processes. The goal of this chapter was to demonstrate that the research conducted and described in this dissertation is in fact relevant research that contributes to the greater body of knowledge which relates to launching a new venture. In addition, the application and results of the research contained in this dissertation will help guide entrepreneurs, product developers, and researchers to launch their own new ventures. The next chapter applies the qualitative research and product development methodologies described in this chapter, starting with deconstructing an initial idea as the first step for reducing the risk of failure in a new venture.

Chapter 4 Using Customer Discovery to Find Different Severities of Problems

The previous chapter described an overview of qualitative research methods, highlighting which ones are most relevant to Customer Discovery, demonstrating that the activities described in this dissertation are grounded in research. The purpose of this chapter is to begin applying those research methods, starting with deconstructing an initial idea as the first step for reducing the risk of failure in a new venture.

Section 4.1 recounts a brief history of entrepreneurship and the creation of business models, leading up to the Lean Canvas. Section 4.2 instructs how to deconstruct an initial idea, form hypotheses, fill out the Lean Canvas, create interview questions, interview potential early adopters, and summarize findings. Section 4.3 describes the process of pivoting.

Once a viable group of early adopters was found, Section 4.4 advises how to code the interviews for a more comprehensive understanding of that target market. Section 4.5 details a comprehensive problem interview learning specific to US Bike Parents. Section 4.6 elaborates on the other components of an opportunity worth pursing, specifically referring to observing trends and finding a gap in the marketplace. Then section 4.7 describes the process and application of co-triangulation in order to reduce bias when reviewing the interviews. Section 4.8 presents a discussion on the different types of problems sought in Customer Discovery, how Customer Discovery can direct the development of safety counter measures, approaches to interviewing, and co-triangulation. Section 4.9 reiterates the contribution of this chapter. Finally, section 4.10 summarizes the chapter.

Research Question 1: When using first principles in product development, in what ways can Customer Discovery serve as the foundation to finding a Severe Problem and direct the process for improved safety for bike riders?

The contribution from this research question is the execution of Customer Discovery in a way that is grounded in qualitative research. The execution of Customer Discovery began with the deconstruction of an initial idea, formation of hypotheses, and creation of interview questions. The semi-structured way in which the interview questions were formed and organized is also a contribution. The questions start with the broader goal of why the participant participated in the activity and then narrowed the questions to test specific hypotheses. A total of 166 problem interviews were conducted and a Severe Problem that can drive product development was found. The interviews were coded, analyzed, and co-triangulated to identify actionable results. Finally, a contribution of this chapter is the operational definitions for different severities of problems.

4.1 Business Modeling and Customer Discovery Overview

The purpose of this section is to demonstrate that the product development methodologies used in this dissertation are directly tied to the historical context of business and entrepreneurship. In addition, it serves as an overview of the methodologies used, specifically the Lean Canvas, Customer Discovery (CD), and the problem interviews. Other aspects of this section include additional context for CD, specifically describing the length of time that CD will be conducted and why, as well as the nuances of CD in an academic setting. Finally, due to the ambiguous nature of the term “problem” I operationally define different severities of problems.

4.1.1 The Emergence and Iterations of the Business Model Canvas

In response to the rise and fall of e-businesses and the dot com bubble of the 1990’s, authors and academics proposed new business modeling approaches for creating and managing companies (Osterwalder, 2004). In 2004, Alexander Osterwalder’s research on business models led to the creation of the Business Model Scorecard (Osterwalder, 2004). Through Osterwalder and Pigneur’s book, *Business Model Generation*, they developed a more user-friendly version of the Business Model Scorecard, the Business Model Canvas (Osterwalder & Pigneur, 2010). The Business Model Canvas (BMC) has become a popular business modeling tool in both the entrepreneurship and business communities (Pellegrini, 2021). The BMC is a tool “to help someone think about a business more comprehensively and effectively” (Pellegrini, 2021, 224). The BMC has building blocks that direct the user to think about and write down essential components of their business, as shown in Figure 4.1 (Pellegrini, 2021).

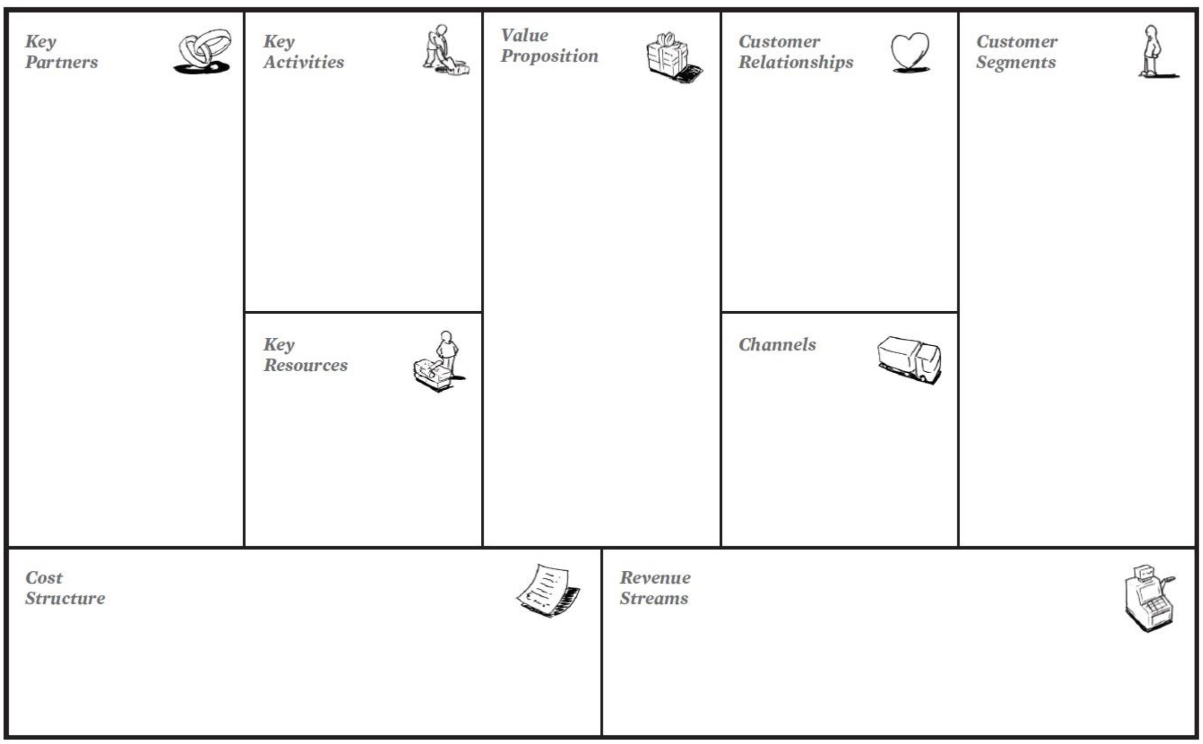


Figure 4.1 The Business Model Canvas (Clark et al., 2010, 44), used with permission from John Wiley and Sons

Developed in 2010, and updated in 2012, one of the most popular iterations of the Business Model Canvas is Ash Maurya’s Lean Canvas (LC) as shown in Figure 4.2 (Maurya, 2012; Pellegrini, 2021). In relation to the problem interviews, the most important differences between the canvases are Maurya replaces *Key Partners* with *Problem*, listing problems the customer is experiencing, then adds *Existing Alternatives* under *Problem*. He also replaces *Key Activities* with *Solution*, referring to features that may be a part of a final solution. Finally, he adds *Early Adopter*, under *Customer Segments.* Another difference is the BMC is not as explicit in presenting an order in which to fill out the canvas, in comparison the LC directs the reader to first fill out the *Problem, Existing Alternatives and Customer Segments*. Despite the nuanced differences between the BMC and LC, the goal of the tools is to help entrepreneurs reflect, “clarify and record their ideas for starting a business” (Pellegrini, 2021, 226).

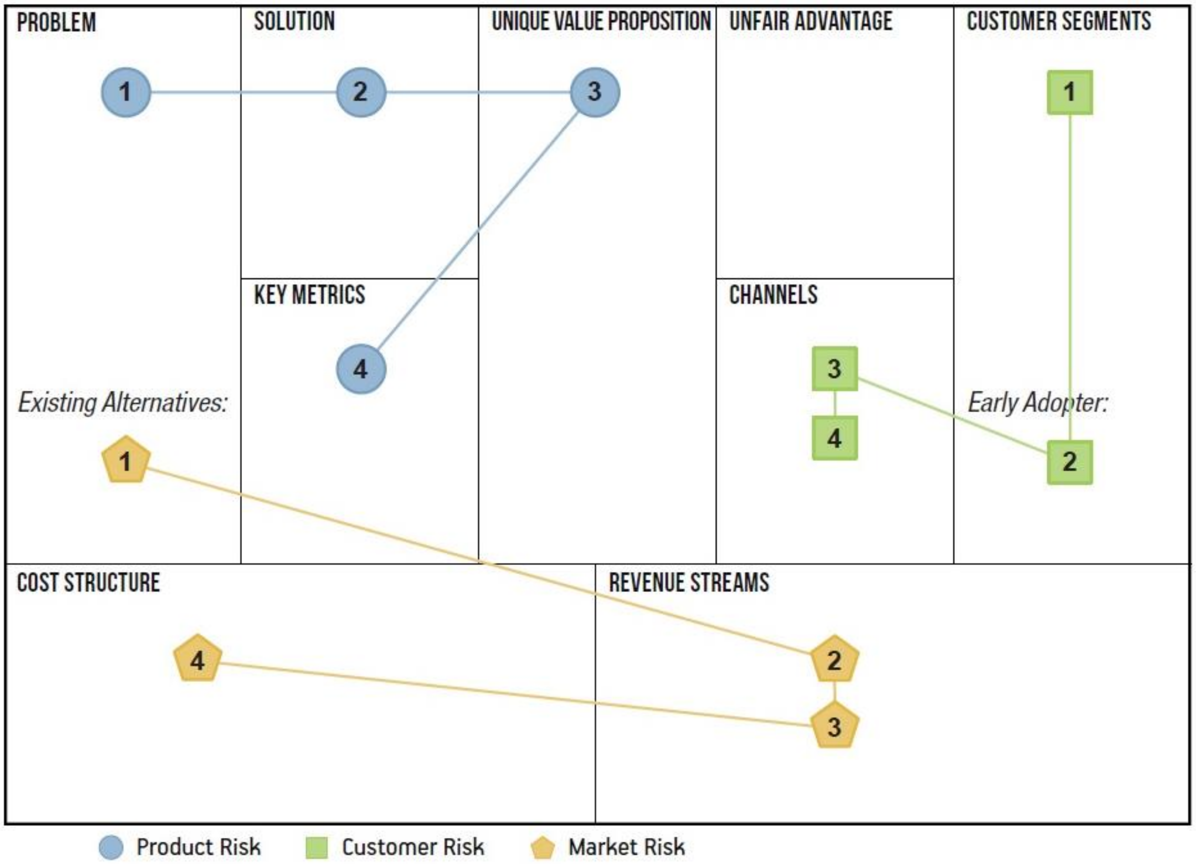


Figure 4.2 Lean Canvas (Maurya, 2012, 67), from Running Lean, 2nd Edition, by Ash Maurya. Copyright © 2012 Ash Maurya. Published by O'Reilly Media, Inc. Used with permission

The problem interviews are the method by which a new venture team (NVT) collects responses from key stakeholders in order to challenge and support some initial hypotheses. According to Maurya, the NVT should begin with a set of three risk hypotheses:

Product risk: What are you solving? (Problem)
How do customers rank the top three problems?
Market risk: Who is the competition? (Existing Alternatives)
How do customers solve these problems today?
Customer risk: Who has the pain? (Customer Segments)
Is this a viable customer segment?
(Maurya, 2012, 81)

Maurya describes that the NVT is done with problem interviews when they can identify these exit criteria:

- A must-have problem
- How customers solve this problem today
- The demographics of an early adopter

(Maurya, 2012, 91)

4.1.2 Problem Interview and Customer Discovery Overview

The problem interviews inherently focus on product risk (problem) or the *Problem* section of the LC, as the building block of the canvas and the foundational element for this specific type of entrepreneurship. The goal is to find a problem that a potential early adopter is experiencing and has the potential to drive product development. Finding a problem is the first part of problem/solution fit (Maurya, 2012). I advanced Maurya's interpretation of the *Problem* section by operationally defining three severities of problems: Severe Problems, Major Problems, and Minor Issues, as described later in section 4.1.5.

Focusing on product, market, and customer risk hypotheses demonstrates an NVT does not need to fill out the entire canvas before developing hypotheses, interview questions, conducting interviews, and pivoting. For this dissertation, I used the LC for documenting hypotheses, represented by the yellow sticky notes in Figure 4.3. In addition, I used the LC for pivoting between hypotheses, represented by the green sticky note, as shown in Figure 4.3. To support and challenge the initial hypotheses, my co-chairs and I developed open-ended questions intended to further explore problems that I perceived the participant was experiencing.

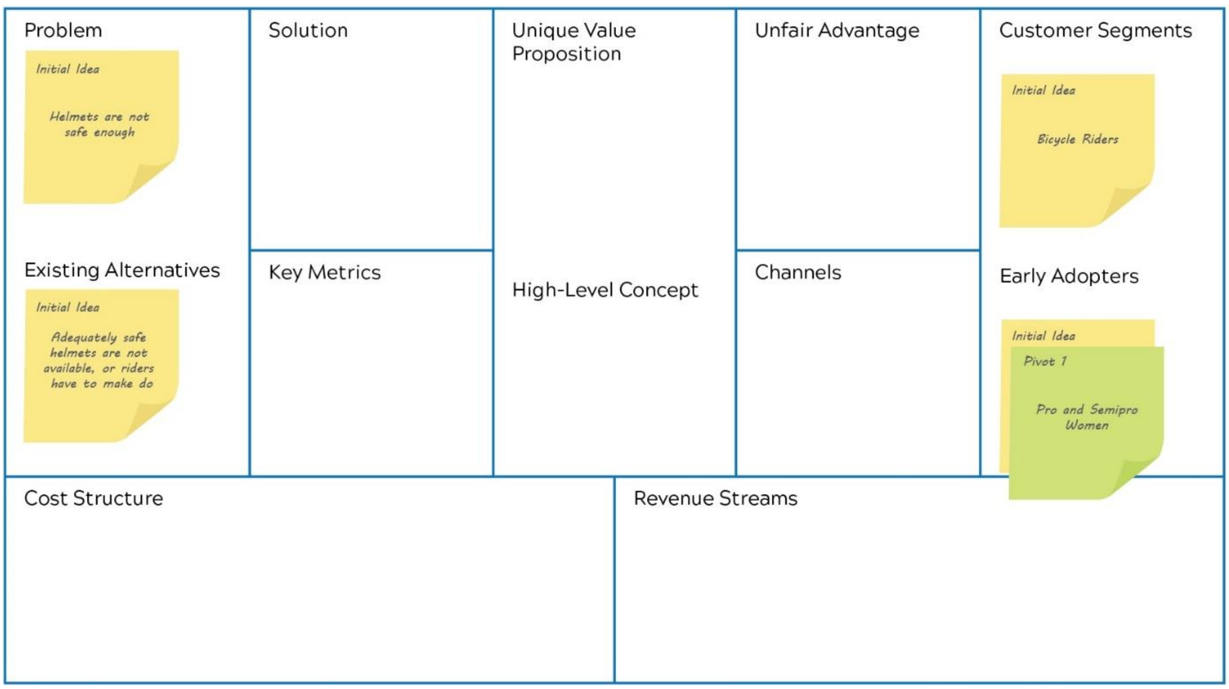


Figure 4.3 Application of the Lean Canvas for this dissertation , this figure is based on the Lean Canvas (Maurya, 2012)

Once the problem interviews have been completed, the NVT should conduct brainstorming sessions before filling out any other portions of the LC, as the NVT is still solution neutral. The goal of brainstorming is to confirm the problem is understood, identify any missing contextual considerations, and brainstorm potential solutions with the people who experience the pain point the most.

From the brainstorming sessions, a variety of potential solutions may be generated. The NVT can then go through the entirety of the solution landscape asking the questions, "Which solution solves the problem the best?" and "What is the best opportunity for commercialization?" The original idea or solution that started the journey of CD may not be the best opportunity for launching a new venture, as described later in section 5.2. The solution interviews are the final step of CD, although the reader should bear in mind that CD can be a continual and iterative process. The NVT might discover information during the solution interviews that motivates them to return to earlier steps of CD. The goal of the solution interviews is to identify if the solution solves the problem, learn about any additional product considerations, and determine an initial strategy for pricing (Maurya, 2012).

4.1.3 Determining the Duration of the Problem Interviews

The duration of Customer Discovery (CD), especially the problem interviews, is largely resource dependent. Some of the most important resources are the NVT's proximity to groups of potential participants, time, and money. Through conference papers and journal articles, one of the most well documented executions of CD is the National Science Foundation's I-Corps Program and the research teams that participate in it. The program typically lasts between six to eight weeks, each team is awarded $50,000 and is expected to complete at least 100 interviews (Batova et al., 2016; Oh et al., 2019; Sakhalkar et al., 2020). However, there is nothing inherent about 6 weeks or 100 interviews that will determine if an NVT will find a customer pain point that can drive product development. The time allowed for CD, funding and number of interviews, determines the number of pivots the team is able to do in an effort to find a customer pain point. Examples and strategies for pivoting will be discussed further in section 4.3.

CD outside of an academic setting lasts on average five to seven months (Marmer et al., 2011). However, it should be noted that the start-ups sampled were specifically internet start-ups out of Silicon Valley. Also, for solo founders, the process takes 3.6 times longer compared to teams of two or three (Marmer et al., 2011). Finally, without the constraints of time, money, and number of interviews, CD is largely considered to be an ongoing process. It is ongoing until problem/solution fit is found, or the NVT has answered the question, "Does it seem viable?" with "yes" or "no" (Blank, 2013). Then depending on the answer, the NVT needs to determine what the next steps are (Blank, 2013).

4.1.4 Constraints of Customer Discovery in an Academic Setting

For the specific application of CD conducted in the context of my PhD program, where the application of CD was the research, my co-chairs and I decided that CD will be conducted until we reach one of three criteria. The first of these criteria was that a Severe Problem has been found that results in a significant behavior change by the potential early adopter, the second was until we reached 150 problem interviews, and the third was a time limit of a year and half before serious reassessment of the hypotheses was needed. An NVT conducting CD outside of academia would not be subject to these specific constraints, which is a limitation of the generalizability of the research described in this dissertation. However, there is an expectation that NVTs will face limitations of time and resources particular to their CD effort.

Ultimately, CD starting with the problem interviews is about challenging and supporting assumptions through primary data. There is a lot of uncertainty in the process and there are no guarantees that the next pivot will be successful, or how many pivots it will take until a Severe Problem is found. Some teams never find a Severe Problem that can drive product development. However, not finding a Severe Problem is preferable to the alternative of expending resources on product development for a product that customers will not want.

4.1.5 Operationally Defining a Problem

As described in section 4.1.2, for the problem interviews, in order to systematically and consistently identify a problem the participant was describing, the definition of a problem was divided into three different categories: Severe Problems, Major Problems, and Minor Issues, which are defined in the following paragraphs.

Severe Problems: an event or circumstance that was deemed negatively by the participant being interviewed, where the result was a significant behavior change compared to the established norm. In addition, there was considerable amounts of frustration expressed. For example, participant ID_1202 described their experience as:

> *My choice of helmet was specific to the size of the kid's head at that time. So in other words it's very hard to find helmets for my little kid that fit them properly, getting them on a bike, getting in the seat of a bike so young, does that make sense? I had to do a lot of research for each of their first helmets. I had to do a lot of work, I couldn't get anything locally that fit them in order to get a helmet that was small that it'd work….*
>
> *I did do a lot of online research. Since I was building bikes, I had a network of shops who were almost always a brick and mortar shop, but had a healthy online business, but focused on idiosyncrasies and weird stuff, weird parts and restoration and that sort of thing... And through that network I had three or four different places that I would use regularly to find replacement parts or just purpose built need stuff for my [inaudible]. And it was through that, I was able to ultimately find access to a bike seat and a bike helmet that I liked for my kids for their first venture out...*
>
> *But he (one of the shops) had found access to some stuff that were brought over, so that first helmet that I used on my kids was not a domestic inspected helmet, but it was something that I ordered, tested it myself, looked at it and then decided it was good to go and put it on my kids, cause it was a good helmet.*

Major Problems: an event similar to a Severe Problem, with a significant behavior change and considerable amounts of frustration expressed, however there was some outlier which disqualifies them from having a Severe Problem. An outlier could be they found an adequate solution on the second or third try. For example, participant ID_1250 described their experience as:

> *My smallest guy, my three-year-old, he's a small three. Like, he is on the lower percentile of the average of sizes of kids. So, when kids go for wellness checkups, the pediatrician will say, "Your child is currently on..." whatever percentile. And my kid is just barely even on the chart. My three-year-old is like a year behind in just physical size because he's tiny. So, his helmet in particular, it's really hard to find a helmet to properly fit a toddler for it to be tight-fitting, but not too tight, but also adjustable. And currently right now, the helmet is on the smallest adjustable size and it is still loose. Not really loose, and we have to make sure he puts it on a certain way so that the way we have it adjusted is actually the back part…. where the neck connects with their head. But yeah, it tends to fold under and we have to adjust it small enough, because that's where most adjustments are in helmets. Yeah, I'd say concerns with loose-fitting helmets, specifically with toddlers.*

In this example, when the participant said that the helmet was "not really loose, and we have to make sure he puts it on in a certain way," that was the outlier which disqualifies them from having a Severe Problem, as the participants have found an adequate solution to living with the frustrations.

Minor Issues: an event or circumstance that was deemed negatively, however there was no resulting behavior change or frustration expressed. For example, participant ID_1235 described their experience as:

> *So we got it, it does not fit him very well. It's constantly kind of riding back on his head and coming loose.*

An important consideration is that despite defining Severe Problems, Major Problems, and Minor Issues, there is still subjectivity in how I review each participant's response. To reduce my inherent biases, the transcribed interviews were co-triangulated in section 4.7.

4.2 From Idea to Forming Hypotheses, Creating Questions, and Conducting Interviews

The purpose of this section is to demonstrate to entrepreneurs, product developers, and researchers how to apply the various methodologies described in this dissertation to their own idea. I begin by deconstructing an idea into product, market, and customer risk hypotheses. Next, the section describes how I solicited participants and came up with interview questions, where I anticipated the participants' responses would challenge and support the hypotheses. After conducting the interviews, I organized relevant answers from the interviews using Ash Maurya's, problem interview learning template (Maurya, 2012). Based on the responses from the interviews, no Severe Problem was found, so we pivoted.

4.2.1 Deconstructing an Initial Idea and Forming Hypotheses

To begin, I started with an initial product idea for a safer helmet through 3D printed structures for pro and semipro cross country male mountain bikers. For brevity's sake, I will refer to pro and semipro cross country male mountain bikers as "Pro and Semipro Men." The reason for selecting this initial idea was that issues with injury have been identified in mountain biking and mountain biking can be a sport that involves a risk of injury for concussion, compared to most activities of daily living (Carmont, 2008; Gottschalk & Andrish, 2011). Furthermore, that risk of injury does not decline with experience and there can be equal prevalence in injuries for elite and amateur athletes (Stoop et al., 2019). I initially anticipated that elite athletes would be more willing to purchase a helmet, as it is an essential piece of equipment for them, or they would be in a better position financially to purchase a high-end solution with more safety features.

Additional considerations for trying to make a safer helmet were limitations with helmet design, as studies have shown that the areas impacted most are often not represented in the CPSC-specified testable area (Bland, Zuby, et al., 2018). Also, helmets have been found to perform inconsistently between standard and real-world conditions (Bland, McNally, et al., 2018). Unfortunately, deficiencies in helmet design can affect its safety and can put the rider at risk. Finally, at the time of this initial idea, in the Fall of 2018, helmets that incorporated structure based thermoplastic liners, such as Koroyd and Wavecel, were considered to be some of the safest helmets on the market (Bland, Zuby, et al., 2018; Fox, 2018; Phillips, 2019). Figure 4.4 shows the deconstruction of the initial idea into product, market, and customer risk hypotheses.

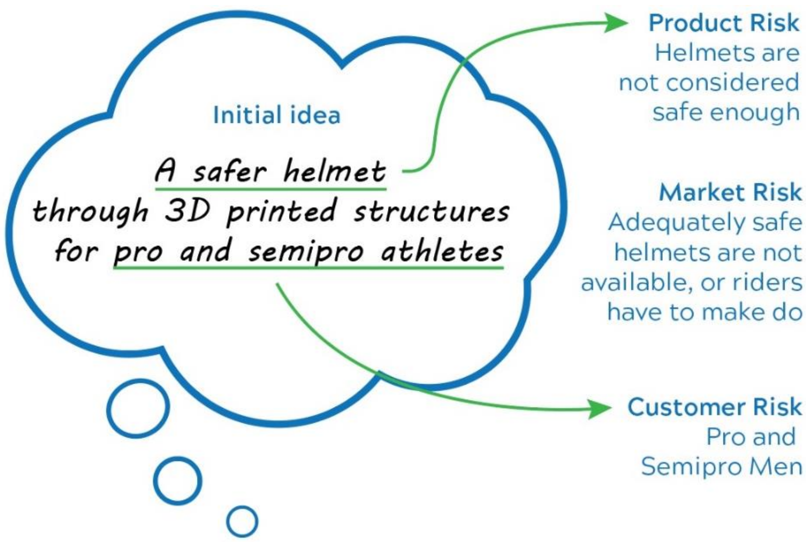


Figure 4.4 Deconstruction of the initial idea into a product, market, and customer risk hypotheses

4.2.2 Initial Hypotheses

For the problem interviews, we developed three hypotheses to identify and explore the pain points potential early adopters were experiencing in relation to risks associated with product development.

Product risk hypothesis: Safety is a primary concern for the majority of users.

- Product risk focuses on the Severe Problem trying to be solved. We chose safety as the product risk, as it has been identified that most companies design PPE to the industry safety standard, as opposed to designing to real world scenarios that the end user experiences.

Market risk hypothesis: There are not enough helmet styles available that include adequate safety features for users who require a high level of safety for their individual sport.

- Market risk focuses on how customers currently solve product needs. We chose to focus on available safety features in currently available mountain biking helmets.

Customer risk hypothesis: Pro and Semipro Men are a group of potential early adopters.

- Customer risk focuses on identifying a viable customer segment. We chose this user group as they have the highest level of experience and expertise regarding bicycling and safety. In addition, they also represent the user group that will be impacted by future development of safety equipment for mountain biking.

For this first set of problem interviews, our goal was to find out if safety is a Severe Problem, or if current safety features and product offerings fulfill the needs of Pro and Semipro Men. Our analysis of the responses heard during the problem interviews provided an initial assessment of the problems and product needs of Pro and Semipro Men, and whether there was an initial indicator for viability. For example, if a consistent problem is found, that can serve as an initial indicator that a new venture may be viable. Or conversely, if no consistent problem is found, that would serve as an initial indicator that a new venture may not be viable.

4.2.3 Interview Process

In the Fall of 2018, participants were identified through the US Cycling National Racing Results web page, with a total of 55 identified end users (USA Cycling, 2018). Next, individuals were contacted through the social media platforms Instagram and Facebook. After making initial contact, I followed up with additional study information and set up a time to conduct the interview if the individual was interested. A total of 31 athletes responded and 16 interviews were completed. The shortest interview was 10 minutes, and the longest interview was 29 minutes, the average interview length was 18 minutes.

The interviews were conducted over the phone and recorded with a digital recorder. Recording the interviews over the phone allowed me to fully engage in the interview to appropriately ask follow up questions, without having to focus on writing down every response. Some real time observations were written down during the interview to capture immediate feedback. Each interview was transcribed. During the transcription process I identified problems that were expressed by the participant, which challenged and supported the risk hypotheses, as well as found new and unexpected themes expressed by participants. The interviews were coded and co-triangulated for a more in-depth analysis of the data.

The problem interview questions were developed to challenge and support the initial hypotheses, as well as determine problems the participants could identify and express. Interview questions focused on the athlete's personal relationship with the sport, experience crashing, personal protective equipment they use, helmet preferences, and general consumer purchasing habits, as shown in Figure 4.5. I asked open-ended questions, which allowed participants to answer freely and served to prevent me from leading participants to answers that only support the initial hypotheses. The interview questions were developed to understand the broader goal of why they participated in the activity and then narrow the questions to challenge and support the hypotheses described in section 4.2.2. Organizing the questions in this way helps determine how top of mind various problems were in relation to the goal of the rider, compared to specific questions about their helmet. It should be noted that this system is not perfect as participants sometimes forget details or remember pain points at different times during the interview.

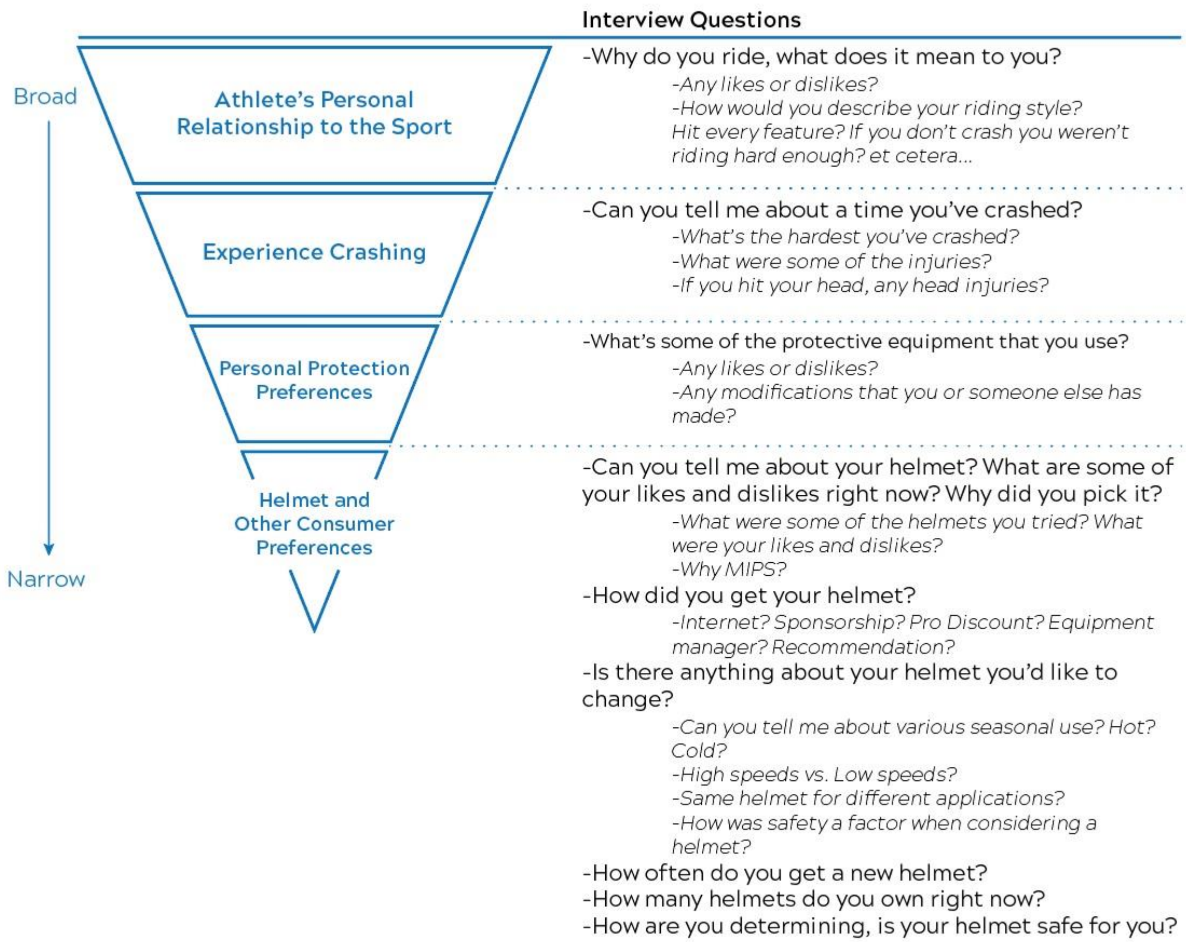


Figure 4.5 Problem interview questions

4.2.4 Initial Findings

For this initial set of interviews, I originally did not go through a formal coding process. Rather, based on answers from the participants, I went through the transcribed interviews and found relevant phrases that fit themes specific to the risk hypotheses, themes for scaling customer acquisition, as well as identified new themes that were not expected. It was not until I had pivoted nine times to a group I call US Bike Parents, that the themes of Severe Problems, Major Problems, and Minor Issues began to emerge and could be operationally defined.

After I had completed the 166 problem interviews, and 14 pivots, with the operationally defined terms, I went back and formally coded Pro and Semipro Men, as well as the rest of the subsequent groups. Even a formal coding process, with operationally defined terms, requires some subjective judgment by me, the researcher, as answers from the open-ended questions allow for variation between participants and require some interpretation. For an NVT, recording, transcribing, and coding each group of interviews is probably excessive, but was an important step for a qualitative research focused approach to Customer Discovery.

4.2.5 Pro and Semipro Men, Initial Problem Interview Learning

As described in section 4.2.1, I started Customer Discovery with Pro and Semipro Men. The rationale for beginning with this group of potential early adopters was that there were similar rates of injury for elite and amateur athletes and limitations with helmet design (Bland, Zuby, et al., 2018; Stoop et al., 2019). With these considerations in mind, I anticipated that elite athletes would be more willing to purchase a high-end solution with additional safety features. The completed sections of the Lean Canvas are shown in Figure 4.6.

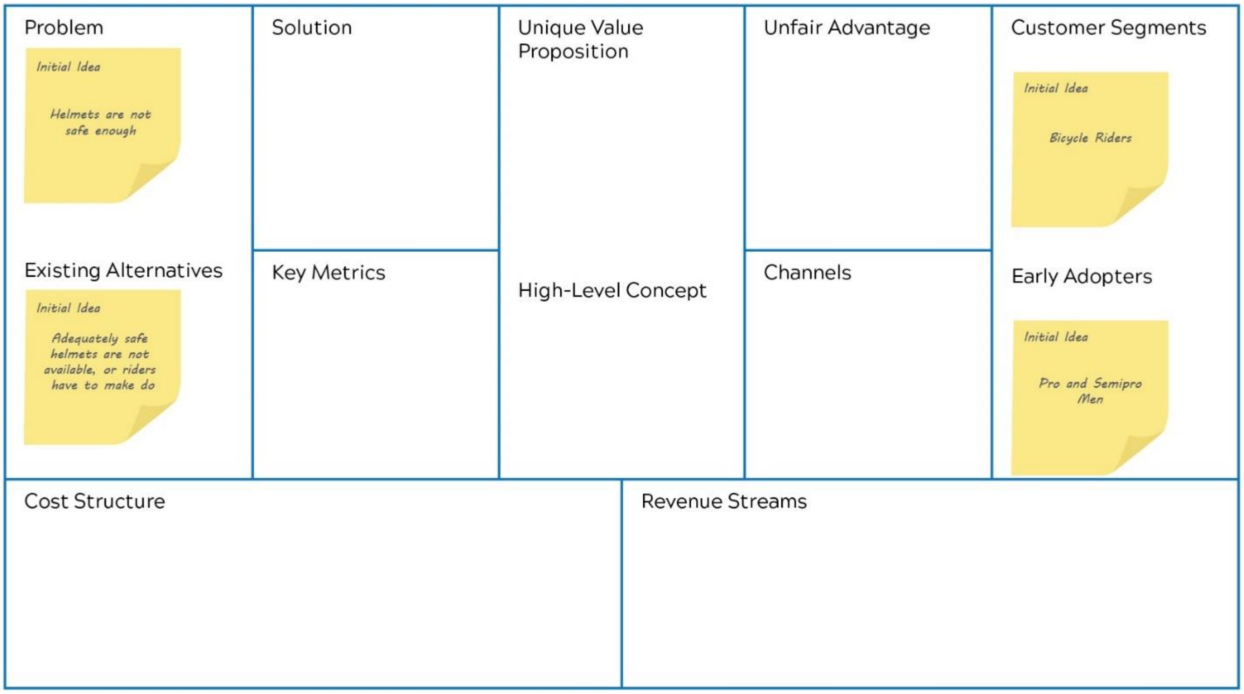


Figure 4.6 First sections of the Lean Canvas filled out, this figure is based on the Lean Canvas (Maurya, 2012)

As stated in section 4.2.2, for this first set of problem interviews, the goal was to determine if safety was a Severe Problem (product risk), or if current safety features and product offerings (market risk) fulfilled the needs of Pro and Semipro Men (customer risk). These risks are organized using Maurya's problem interview learning template from *Running Lean*, where the primary goals were to determine if a problem has been found, as well as whether or not we should pivot:

Product risk: What are you solving? (Problem)

Hypothesis
Helmet safety is a primary concern for the majority of potential early adopters.

Insights
For Pro and Semipro Men, I found no Severe Problems. I found one Major Problem with bicycle helmet safety, where one of the athletes, even though he received free helmets through a product sponsorship, purchased a different trail helmet with more coverage, as he perceived that it was safer.

Unexpected Themes
I found that a high number of riders experienced some form of head injury and that they do care about technologies that will help keep them safe. This insight would lead me to believe that safety was somewhat of a concern for riders. When riders were asked how they determined that their helmet is safe for them, the primary response was the use of

MIPS or similar technologies. The second leading response was that the helmet passes a safety standard.

An additional Major Problem that a rider experienced included developing tinnitus due to excessive wind noise. Another Major Problem a rider described was not wearing a full-face helmet, elbow, and knee pads because they were hot and restrictive, which would cause him to lose focus on the ride. In regards to biking in general, a Major Problem was traffic as one rider had multiple friends who had been hit by cars.

Market risk: Who is the competition? (Existing Alternatives)

Hypothesis

There are not enough helmet styles with adequate safety features for users who require a high level of safety for their individual sport.

Insights

The primary focus for the market risk hypothesis was to determine how riders who had a Severe or Major Problem solved the problem with helmet safety. There was only one Major Problem in regards to safety. In addition, I found very few riders had strong dislikes with their current helmet. Sporadic issues were identified surrounding buckles, sweat drip, equipment being hot, preference for more safety features, straps, and bulkiness. The initial findings show that the helmet industry has matured, with very streamlined product offerings, where most end users within this market segment are happy with what is currently available.

Customer risk: Who has the pain? (Customer Segment)

Hypothesis

Pro and Semipro Men are potential early adopters.

Insights

For customer risk, I found that most riders received their helmets for free through product sponsorship. Although Pro and Semipro Men may be the appropriate end user, they are not the appropriate customer. The findings identified one interesting outlier, as one of the athletes purchased a trail helmet because it had more coverage than the helmet he received for free, which he perceived as being safer than the free helmet.

Summary of Problem Interviews with Pro and Semipro Men:

After conducting sixteen interviews, only one rider described a Major Problem with bicycle helmet safety. For Pro and Semipro Men, we could not identify a problem that had the potential to drive product development. So, we completed our first pivot to a customer segment where we anticipated safety would be a greater concern. The customer segment we pivoted to was Pro and Semipro <u>Women</u>. We anticipated safety would be a greater concern for women because bicycle helmets are not always designed to real world scenarios and studies have shown women can have lower injury tolerances than men (Kieffer et al., 2021; Rowson et al., 2016). The next section describes an overview of the problem interview pivots, as well as reasons for pivoting.

4.3 Pivoting Overview

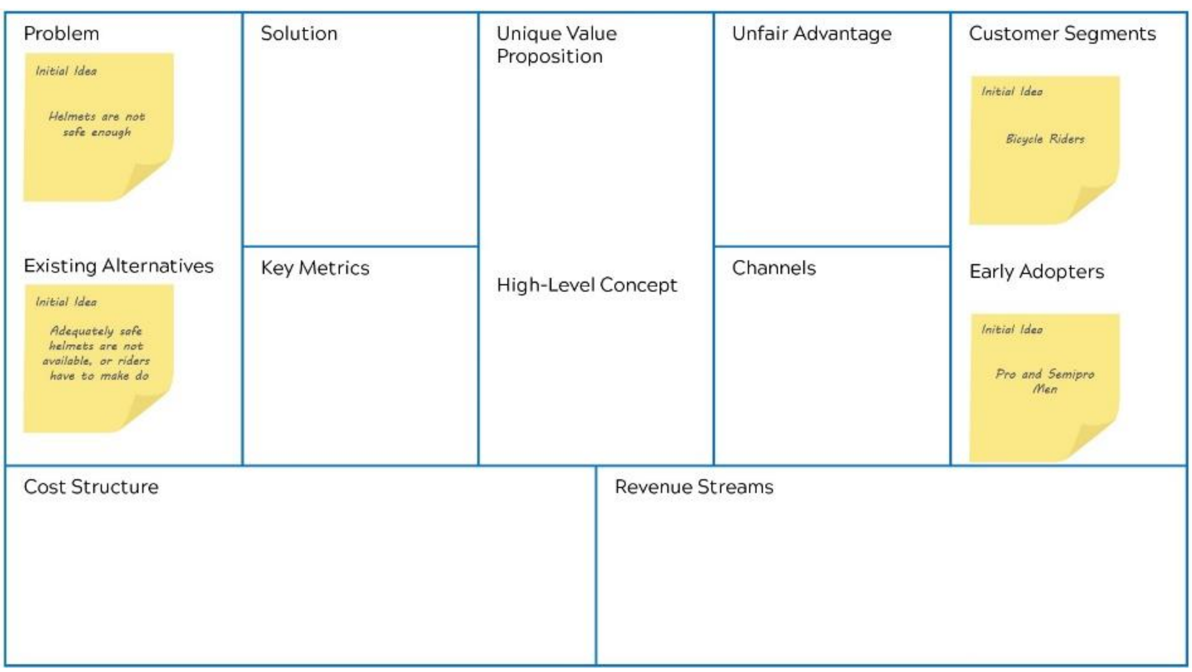
The purpose of this section is to give an overview of pivoting in response to what the NVT has learned through CD. The overview starts with Pro and Semipro Men, then describes the first pivot to Pro and Semipro Women, as well as subsequent pivots to what is considered to be the most viable customer segment, US Bike Parents. Next, reasons for pivoting are provided. US Bike Parents are specifically highlighted, as they have described Severe Problems with helmet fit. US Bike Parent's Severe Problem of helmet fit appears to be a problem that can drive product development, so it is anticipated that they are a viable customer segment.

With a potentially viable customer segment identified the section transitions to coding, as well as a brief overview of the coding process. As described in section 4.2.4, after each problem interview, I did not immediately transcribe and code each set of interviews. Rather, I took some notes during the interview, as themes began to emerge around whether or not there was a problem that could potentially drive product development. Lastly, this section describes differences between creating a problem interview learning for Pro and Semipro Men, a customer segment I pivoted away from, compared to creating a problem interview learning for US Bike Parents, a potentially viable customer segment.

4.3.1 Pivots

As mentioned in section 4.2.1, an initial idea for a safer, 3D printed bike helmet for Pro and Semipro Men was described. Then that initial idea was deconstructed into product, market, and customer risk hypotheses. The hypotheses were then added with yellow sticky notes to the Lean Canvas as shown in Figure 4.7 a).

After conducting sixteen interviews, only one athlete described a Major Problem with his helmet not having enough coverage area. So, I determined there was no Severe Problem that had the potential to drive product development. In response I pivoted to Pro and Semipro <u>Women</u>. The pivot is shown below in Figure 4.7 b) as the Lean Canvas is updated with the green sticky note referring to Pro and Semipro Women.



a)

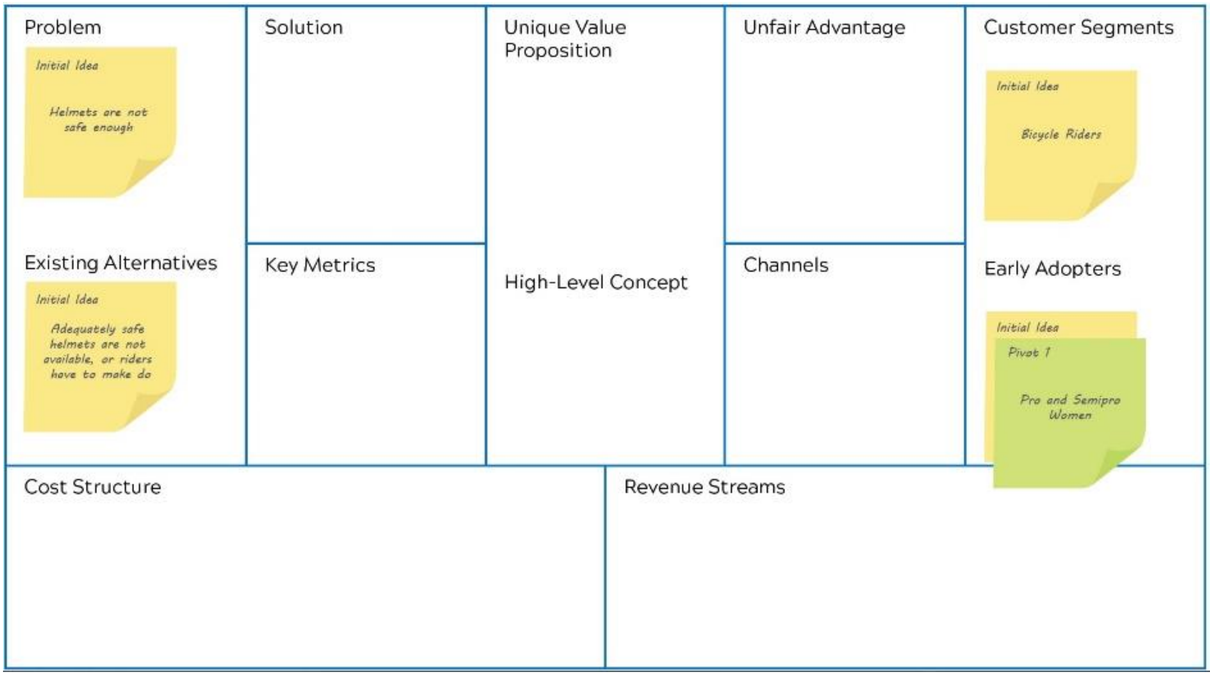
b) 

Figure 4.7 a) The first iteration of the Lean Canvas with Pro and Semipro Men, b) The first pivot to Pro and Semipro Women, represented with the green sticky note, these figures are based on the Lean Canvas (Maurya, 2012)

From the seven interviews with Pro and Semipro Women, no Severe Problems with safety were found and athletes were happy with current product offerings, so we pivoted to Team Directors.

Figure 4.8 shows an overview of each pivot and corresponding risk hypotheses. In Figure 4.8, the initial set of interviews was done with Pro and Semipro Men, which is shown in the top left corner of the first row and first column. I then pivoted the customer risk hypothesis to Pro and Semipro Women, which is shown directly right of Pro and Semipro Men. I determined Pro and Semipro Women were also not a viable group of potential early adopters, so we continued pivoting the customer risk hypothesis by interviewing a Team Director, as well as various demographics of parents, NICA Directors, masters mountain bikers, downhill riders, and bike company personnel. In Figure 4.8, the asterisk in the first column of the fourth row, highlights the group of potential early adopters US Bike Parents. The reason this group is highlighted is because they represent the group of potential early adopters with the greatest number of Severe and Major Problems. The presence of the Severe and Major Problems serves as an initial indicator for problem/solution fit. Because this group represents the most viable customer segment, I comprehensively coded the interviews from US Bike Parents.

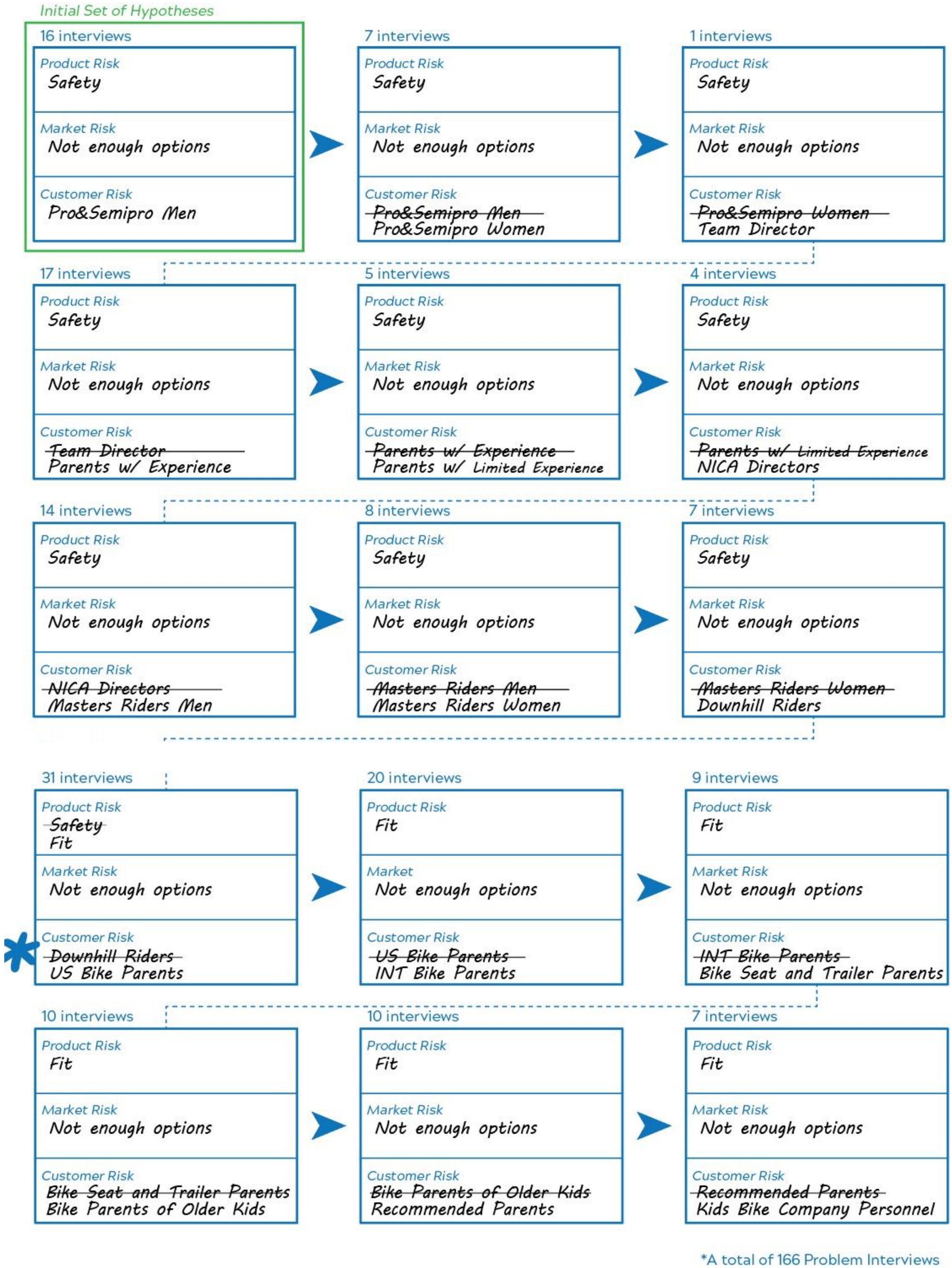


Figure 4.8 Overview of pivots

4.3.2 Reasons for Pivoting

As described earlier in section 4.3.1, pivots are a technique for adjusting a singular hypothesis when there are no indicators of viability from the current set of hypotheses. From the initial set of interviews with Pro and Semipro Men, only one Major Problem was found. The Major Problem was the behavior change from the rider who received free helmets through a product sponsorship, yet purchased a different helmet which had more coverage. So, I determined that this was not a strong enough indicator for viability. Consequently, I pivoted and changed one of the initial three hypotheses based on the product, market, and customer risks.

It should be noted that pivoting is an exploratory process and does not guarantee success for finding a Severe Problem that can drive new product development (Bandera & Thomas, 2019). As mentioned in section 3.3.2, for a grounded theory study 20 to 30 interviews are typically conducted or until it is not expected new information will provide additional insights. For this dissertation, depending on the size and access to potential early adopters, the goal was to interview at least 10-20 participants before deciding to pivot. One potential group of customers, which I called "Parents with Limited Bicycling Experience," were potential early adopters that did not cleanly fit into this strategy. For Parents with Limited Bicycling Experience, I was only able to interview five parents. The reason for the low number of interviews was that there was no clear or direct way to reach participants, as I was reaching out to friends and family. Also, when I asked, "Is there anyone else you'd recommend?" no participants offered any recommendations, as bicycling was not a part of their lifestyle. Ultimately, after five interviews, I pivoted.

Another important consideration for pivoting is beginning with a heuristic known in the business community called, "First Who, Then What" (Collins, 2011). A successful pivot begins by having the right people in the room that will foster a positive environment for trying out new ideas and introducing new assumptions to explore. For my research the right people involved my co-chairs and myself during our bi-weekly meetings. For each pivot, we only changed one assumption, meaning, if our assumptions were product risk: Safety; market risk: Not enough options; customer risk: Pro and Semipro Men, we then only pivoted the customer risk to Pro and Semipro Women. A visual representation of the pivots is shown below in Figure 4.9. As we pivoted, we tried to focus on changing only one hypothesis at a time.

Figure 4.9 Visualization of pivots

Once I found an initial indicator of viability, which is the Severe Problem of bicycle helmet fit for US Bike Parents, we continued to explore ways to segment those early adopters even further. The segmented groups of early adopters are shown in Figure 4.8, after the asterisk highlighting US Bike Parents. After conducting the additional problem interviews, I was not finding the same consistency of Severe Problems or gaining new insights. What I knew about the Severe Problem of helmet fit had become saturated, so we paused Customer Discovery and I began coding and analyzing the interviews (Creswell, 2007).

The summary of the coding and analysis is the problem interview learnings. As stated previously in section 4.2.5, the first problem interview learning was demonstrated with Pro and Semipro Men. For the problem interview learning with Pro and Semipro Men, I strictly followed Maurya's problem interview learning template. In addition, I strictly followed Maurya's problem interview exit criteria. The goal for following Maurya's template was to identify themes relating to the problem interview exit criteria which included: "A must-have problem, how customers solve this problem today, the demographics of an early adopter" (Maurya, 2012, 91). The goal for following Maurya's problem interview learning template and exit criteria, was simply to determine whether or not we should pivot.

The problem interview learnings for US Bike Parents also included themes relating to the problem interview exit criteria. However, because US Bike Parents were identified as the most viable group of early adopters, the interviews were coded and analyzed further for relevant information that added context to the problem, existing alternatives, and the customer segment. Additional problem interview exit criteria, as well as coding relating to product, market and customer risk hypotheses is described in the next section 4.4.

4.4 Problem Interview Exit Criteria and Coding

The purpose of this section is to explain the process of coding interviews and describe when and how it was applied to this specific dissertation. Coding is a qualitative research method for determining what one knows by systematically categorizing themes found in the interviews (Creswell, 2007). The reason for coding is, by applying a systematic process, it can reduce subjectivity and bias as I reviewed the interviews. In addition, applying a systematic process to categorizing the interviews can add clarity for knowing when to transition from the problem interviews to the brainstorming sessions.

As described in section 4.2.4, after each problem interview, I did not immediately transcribe and code each set of interviews. Rather, I only took some notes during the interview, as themes began to emerge around whether or not there was a problem that could potentially drive product development. During the frenzy of Customer Discovery, the initial notes from the interviews were enough for my co-chairs and I to have a conversation about what we were learning from the participants and whether or not we should pivot.

It was only until I had completed the majority of the problem interviews that I began transcribing and coding them. The benefit of delaying the transcribing and coding process was that it allowed me to focus on conducting interviews and pivoting in order to find a group of potential early adopters with a problem that can drive product development. The benefit of transcribing and coding the interviews is it is an opportunity to find additional customer insights that were not found during the initial interview. Then, if the new venture finds problem/solution fit and launches a new venture, the interviews with other groups of potential early adopters may be the customer segments that help the new venture transition from early adopters to the early majority. When transitioning to the early majority, the new venture team should not have to do as much Customer Discovery or recollect data.

4.4.1 Product Risk (Problem) Hypothesis Coding

As described in section 4.2.2, the product risk hypothesis focuses on a problem. The first principles approach to product development begins with finding "a problem worth solving using a combination of qualitative customer observation and interviewing techniques" (Still, 2017, 33). So, the central question being identified, categorized, and answered is, what is "a problem worth solving?" (Still, 2017, 33), as described in section 1.2.4.

Finding a problem is a task that requires discernment from myself, the researcher. The reason for this is that the word, “problem” can be ambiguous, contextual, and application specific. During the interview process, I knew I was looking for a problem, however, I did not fully understand what that really meant. I knew that I, the interviewer, should not intentionally or unintentionally lead a participant to describing a problem that simply confirms my initial hypotheses. During an interview, the negative association of leading a person to a particular answer is also known as “leading the witness” (Cole et al., 1997, 378). Also, the problem should be one the participant can clearly identify and articulate and that has the potential to drive product development. So, for the problem interviews, when a theme around a problem began to emerge from participants’ answers, I operationally defined that specific problem to systematically and consistently identify a problem the participant was describing, as described in section 4.1.5.

After speaking with pro and semipro athletes, masters riders, downhill riders, and various demographics of parents, conducting 79 problem interviews, the participants described concerns with safety, challenges with buckles, complaints with helmets being too hot, annoyances with hair getting caught, and irritation with traffic. Some of those seemed to have the potential for directing product development. However, after speaking with the second parent of US Bike Parents, participant ID_1202 described the Severe Problem that is quoted in section 4.1.5*,* expressing frustration at the amount of effort spent trying to find a helmet that fit their child. It was then that this Severe Problem with helmet fit began to emerge throughout the responses of US Bike Parents. So, I operationally defined a Severe Problem in section 4.1.5. A summary of each Severe Problem is described in Appendix A.

As these themes emerged from the interviews, I continued operationally defining and rank ordering types of problems. The next theme that emerged from the interviews was Major Problems. Major Problems were similar to Severe Problems, however during the interview, there was often a disqualifier from the problem truly being a Severe Problem. Major Problems were operationally defined in section 4.1.5, where an example of a Major Problem is also quoted in that section. A summary of each Major Problem can be read in Appendix B.

Operationally defining and rank ordering types of problems helps identify the problem that will drive product development, which is the foundational element in entrepreneurship described in this dissertation. In addition, operationally defining and rank ordering the types of problems helps identify the market size within the technology adoption curve (Rogers et al., 2014; Sahin, 2006). Participants who experienced Severe Problems can be representative of early adopters. Participants who experienced Major Problems can be representative of the early majority.

4.4.2 Market Risk (Existing Alternatives) Hypothesis Coding

As described in section 4.2.2, the market risk hypothesis focuses on how customers currently solve product needs. The market risk hypothesis was primarily answered through the question, “Can you tell me about your helmet?” as well as the follow up question, “Any likes or dislikes?” For the majority of participants I spoke with, helmets on the market solved their current product needs.

Participants who described “dislikes" of products already on the market or aspects within biking, were operationally defined as Minor Issues in section 4.1.5, where an example of a Minor Issue is also quoted in that section. Minor Issues were a component of how the potential early adopter currently solved their product needs and were not problems to the same degree as Severe Problems or Major Problems. It is not anticipated that Minor Issues will drive product development. Nevertheless, Minor Issues are important for identifying pain points that are a part of the overall user experience, prioritizing features and benefits, as well as the additional development of other products beyond the minimum viable product.

When participants responded with “likes” of products already on the market or aspects within biking, the series of answers led to another category called General Preferences. For example, participant ID_1208 described their experience as:

> *It's also got the ratcheting lock mechanism in the back so they can tighten it securely to their head, in addition to the chin strap. So they get a really great fit and the helmet doesn't move around on their head either when they're riding or if they were to crash and bang on the ground.*

General Preferences were operationally defined as: features and benefits the participant described that either they or their child like and was available on the market.

Identifying General Preferences can add value to the overall design and development of a solution, as various features and benefits are incorporated. However, no single preference was considered a large enough driver for product development in entrepreneurship, as they already exist in various forms and are readily available to customers. One of the challenges with coding both Minor Issues and General Preferences was there can be overlap between the two categories. For example, if a participant said they do not like being hot, were they really saying they like airflow? Or, if a participant said they like a lot of vents, were they really saying they do not like being hot? These were important considerations for operationally defining terms, however, neither Minor Issues nor General Preferences are the primary drivers of product development in entrepreneurship. In addition, the ambiguity of language and meaning is why qualitative research requires discernment from the researcher, as well as the checks and balances of co-triangulation.

It should be noted that simply asking, “Can you tell me about your helmet?” and following up with, “Any likes or dislikes?” was not comprehensive for all the ways in which potential early adopters were currently solving their product needs. There were answers where there was no current helmet on the market that participants liked or solved their product needs. For example, other ways in which parents solved their needs were delaying the time in which their child was allowed on the bike; letting their child use a helmet that did not fit and would flop around since it was “better than nothing;” or implementing more creative strategies like using a towel to fill the extra space in the helmet so it would fit better.

4.4.3 Customer Risk (Customer Segment) Hypothesis Coding

As described in section 4.2.2, the customer risk hypothesis focuses on identifying a viable customer segment, specifically early adopters. The first consideration for determining if a customer segment was viable relates back to product risk, highlighting the number of potential early adopters experiencing the problem and the severity of the problem. For example, for Pro and Semipro Men, only 1 of the 16 riders had a Major Problem with helmet safety. It was anticipated that a viable customer segment will be one with a concentrated number of Severe Problems. If the NVT can then solve that problem, that customer segment was anticipated to be early adopters of the solution. It should be noted that there is no universally applicable number of Severe Problems or early adopters that can determine a viable customer segment. Ultimately, the number should be large enough to represent a target market that can support the launch of a new venture. Variables for determining that number can include but are not limited to the severity of the problem, the willingness of participants to switch products, as well as the cost and price of the final product or service.

The second consideration was additional contextual demographic information that can challenge or support that the group was a viable customer segment. Contextual demographic information can include the differences between the customer and the end users. In addition, contextual information can include ways to connect and communicate with early adopters, such as avenues for building customer relationships and potential sales channels. Reaching out to each individual early adopter is often unsustainable for a new venture. Therefore, identifying channels for connecting and communicating in ways that can scale and reach a broader audience was an important consideration for determining a viable customer segment.

The third consideration was contextual information to help the NVT understand how the rider's problem relates to the broader goal of why they engage in cycling. The industry nomenclature is known as Jobs to Be Done or Customer Jobs, meaning, "the process that people are trying to execute" or "what was the 'job' the customer was trying to get done" (Ulwick, 2016, 16, 18). The concept of Jobs to Be Done can be summarized as:

> *You probably know the famous saying by Harvard marketing professor Theodore Levitt: "People don't want to buy a quarter-inch drill. They want a quarter-inch hole." But in fact, people rarely want a hole in the wall either; they want a comfortable living room. To achieve this goal, they need to do a series of activities, such as agreeing on a painting with their partner, buying that painting, drilling a hole in the wall, and screwing in a hook to hang up the painting. Focusing only on the drill or the painting or the hook would miss the main point of why people use these items* (Stickdorn et al., 2018).

In layman's terms, all we were trying to find out was what were the person's overall goals they were trying to achieve. People do not ride bikes to wear helmets, people ride bikes for physical fitness, to be outside, transportation, personal development, et cetera. Severe Problems specific to bike helmets were a byproduct of the participant's desire to ride their bike. The next section describes the problem interview learning for US Bike Parents, with additional context relevant to the product, market, and customer risk hypotheses.

4.5 US Bike Parents, Coding and Analysis

In section 4.2.5, when creating the problem interview learning for Pro and Semipro Men the primary goal was to determine whether or not to pivot. Having found a potentially viable customer segment, US Bike Parents, the purpose of this section is to create a comprehensive problem interview learning with the additional context described in section 4.4. The problem interview learning in this section serves as a reference point for the NVT as they conclude Customer Discovery and look to transition to the brainstorming sessions.

4.5.1 Comprehensive Problem Interview Learning

The problem interview learning with additional context relevant to the product, market, and customer risk hypotheses begins with US Bike Parents. The reason for beginning with US Bike parents was because they had the most Severe and Major Problems, serving as a potential indicator for problem/solution fit. In the previous section 4.3.1, Figure 4.8 started with Pro and Semipro Men and showed the 79 interviews and 9 pivots up to US Bike Parents, where US Bike Parents are highlighted with an asterisk. For all the interviews between those two groups there was one Severe Problem and six Major Problems with bicycle helmet fit. These findings around helmet fit led us to believe we should explore new groups of potential early adopters where helmet fit was a problem.

So, my co-chairs and I brainstormed as a group. We knew there were high-end bike brands for adults but wondered if there was something similar for kids. After searching various blogs and websites I found five US kids specific high-end bike companies Guardian, Pello, Prevelo, Woom, and Cleary Bikes. Parents who bought a bike from one of these brands for their kids are referred to as US Bike Parents. I conducted thirty-one interviews with US Bike Parents. The shortest interview was 18 minutes, the longest interview was 49 minutes, and the average interview length was 34 minutes. The pivoting journey to US Bike Parents applied to the Lean

Canvas is shown in Figure 4.10. For the problem interview learning, similar to Pro and Semipro Men, I followed Maurya's template from *Running Lean* to assess the product, market, and customer risks*:*

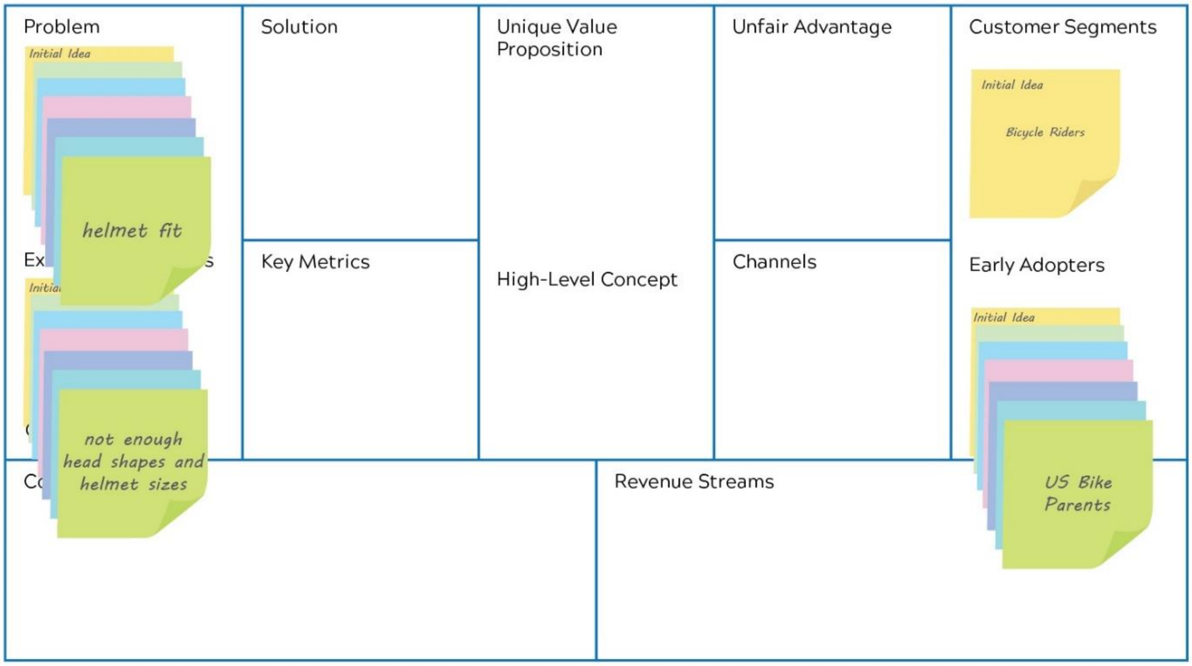


Figure 4.10 Visualization of all the pivots to US Bike Parents, this figure is based on the Lean Canvas (Maurya, 2012)

Product risk: What are you solving? (Problem)

Hypothesis
Helmet fit is a primary concern for the majority of potential early adopters.

Insights
As stated in section 4.4.1, for this demographic of potential early adopters, some of the parents described the challenge of finding a properly fitting helmet for their child. For US Bike Parents, the distribution of Severe Problems, Major Problems, and Minor Issues is shown in Figure 4.11.

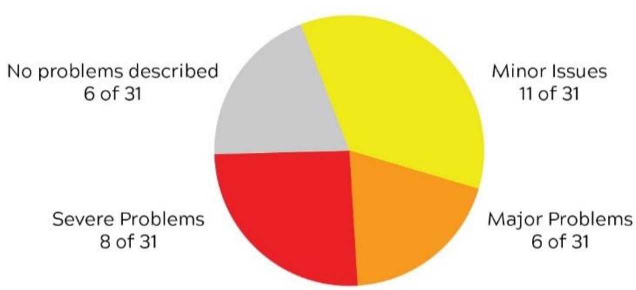


Figure 4.11 Pie chart depicting the distribution and severities of problems for US Bike Parents

When a participant described problems during an interview, there was a difference between the participant remembering a problem they experienced in the past vs. a problem they were experiencing in real time. For US Bike Parents, I was able to find both Severe and Major Problems with helmet fit, however, every time a participant described the problem it was always a problem they experienced in the past and had since solved. For this Customer Discovery exploration, I was unable to find a participant that was experiencing a Severe or Major Problem of helmet fit at the time of the interview. It is possible to conclude that the helmet industry has matured for this demographic. Some parents described challenges with helmet fit in real time, but they were only Minor Issues.

From the interviews with US Bike Parents, a theme that emerged was how the problem of helmet fit affected the children's riding experience. If the helmet was uncomfortable, did not fit, or was deemed "unsafe" by the parents, the child's introduction to biking could be delayed, or worse, the child may choose not to bike. Participant ID_1232 described the importance of helmet fit in relation to the child's enjoyment of biking as:

ID_1232: 00:22:04.22 We'd gone through a few helmets that we'd just, the kids they're not comfortable in and again it's like the kids are not comfortable and they're whining and complaining, it doesn't come back as like, "oh, I just need a new helmet," it comes back as, "I don't like biking."

Unexpected Themes

During the interviews, other pain points took the form of an extensive product search, product modifications, were the result of an injury from improper riding gear or traffic, or involved scenarios that were described with considerable frustration. The pain points that were described have similarities to the way in which the Severe Problem of helmet fit was operationally defined. For example, one participant described a pain point that was similar to a Severe Problem, where they detailed an extensive search for a smaller helmet that would not butt up against the top part of a rear mounted kid's bike seat in an uncomfortable manner. The challenge of finding a smaller helmet that would not push the kid's head forward against the bike seat was one individual scenario. That scenario was not a recurring or emerging theme, so it was not operationally defined.

Market risk: Who is the competition? (Existing Alternatives)

Hypothesis

There are an inadequate number of helmet head shapes and sizes for parents who want a quality biking experience for their children.

Insights

As described in section 4.4.2, the market risk hypothesis focuses on how customers currently solve product needs. The primary focus for the market risk hypothesis was how parents who had a Severe or Major Problem solved the problem with helmet fit, as they were experiencing that problem. The distribution of existing alternatives is shown in Figure 4.12. The figure shows, for parents who experienced the Severe Problem of helmet fit, the primary way they temporarily solved the problem was to keep searching for additional helmets from month to month. For parents who experienced a Major Problem with helmet fit, two of the most common ways for temporarily solving the problem were making do with an ill-fitting helmet and finding a proper fitting helmet on the second or third shopping trip.

Figure 4.12 Temporary ways participants solved Severe and Major Problems with helmet fit

As stated in section 4.4.2, the secondary consideration was how Minor Issues were a component of how the parents currently solved their product needs. The most common Minor Issues were chin straps, venting and breathability, accommodating hairstyles, difficult buckles, helmet aesthetics, scratchy straps, helmet weight, coverage area, and removable jaw pieces.

In relation to other PPE, there were Minor Issues with full face helmets, elbow and knee pads, sizing options, and durability issues with kids' gear. For biking in general, Minor Issues included concerns for kids riding in and around traffic. Additional Minor Issues included challenges with bike culture and kids biking in non-ideal conditions.

General Preferences

As stated in section 4.4.2, identifying General Preferences can influence the design and development for the final solution. No single preference is expected to drive product development in entrepreneurship, as they already exist in various forms and are readily available to consumers. General Preferences from the interviews included the aesthetic of the helmet, safety, comfort, and feature integration.

General Preferences share similarities to Minor Issues and, while neither are expected to drive product development, both can lead to improving user experience with the final product. In addition, for both Minor Issues and General Preferences there may be multiple competing preferences. Competing preferences should be treated with discernment from a product development team. A common theme was that kids' helmets have improved dramatically since the parents were children, as participant ID_1239 described:

> *ID_1239 (16:18): No, we haven't modified the helmet at all, you know, we're actually pretty impressed with how much children's helmets have improved since we were children, in the terms of their build, their adjustability and the fit, in particular they have the ratchet mechanism on the back that you could adjust to a child's head size, which didn't exist while we were kids.*

Customer risk: Who has the pain? (Customer Segment)

Hypothesis

US Bike Parents, referring to parents who bought a bike from a US kids specific bike company are potential early adopters.

Insights

As described in section 4.4.3, the customer risk hypothesis focuses on identifying a viable customer segment. The first consideration included determining the number of potential early adopters experiencing the problem and the severity of the problem. Based on the previous section in this problem interview learning, 8 of the 31 US Bike Parents who described a Severe Problem of helmet fit were anticipated to be early adopters of a solution that is yet to be defined. After the brainstorming sessions, and solution interviews have been completed, there will be a final assessment of the early adopters.

The second consideration was contextual information challenging and supporting the viability of the customer segment. From the interviews, it is expected that the potential early adopters will be a combination of 1.) the customers, referring to the US Bike Parents whose child had the Severe Problem of helmet fit, as well as 2.) the end users, referring to parents' children between the ages of 9 months and 3 and a half years old.

Additional contextual information can include ways to connect and communicate with early adopters, such as avenues for building customer relationships and potential sales channels. In regards to building customer relationships, specifically referencing the solicitation methods for this study, I connected with US Bike Parents through the social media platform Instagram. I messaged 129 parents, 62 parents responded, and from those responses I conducted 31 interviews. Compared to the other demographics solicited for this study, Instagram was a successful method for connecting with potential early adopters.

In regards to potential sales channels, almost half of parents bought their children's helmets at bike shops, although some mentioned the challenge of bike shops not being close. Parents also purchased helmets from online distributors such as REI, Backcountry, Chain Reaction Cycles, Sports Check, or Amazon. Another popular option was purchasing helmets from sporting goods stores. Additional considerations could include direct to consumer sales channels.

Finally, the third consideration for the customer segment was understanding how the problem relates to the broader goal of why they engage in cycling. From the interview responses, the parents generally described the broader goal of cycling as: an outdoor, family activity that provides fun and enjoyment, that will serve the family throughout their life and compliment other activities, while promoting physical fitness and personal development. Unfortunately, the problem of helmet fit was not simply a barrier to biking, but rather a barrier to the broader goal that the parents described in the interviews. Participant ID_1242 described the friction between injury and the goal of getting on bikes as:

> *ID_1242 (03:11): …and dislikes for me as a mom, would just be that there's a lot of opportunity for injury. The three-year-old actually got stitches in her chin two weeks ago, cause she crashed into a concrete curb and landed on the other side, rushed her to the emergency room to get that done…. Uh, so the injury part of it is just not so great. Um, but the benefits definitely outweigh that with how much fun it is and how it gives us all an opportunity to do something together. It gives us physical exercise, it gets us outside. It's just fun and at every skill level and at every age.*

Solving the Severe Problem of bicycle helmet fit may create a path for a more seamless introduction to biking, similar to the way the balance bike created a path for a more seamless introduction to biking by circumventing training wheels.

4.5.2 Summary of Problem Interview Learning for US Bike Parents

I conducted 31 problem interviews with US Bike Parents. For product risk, I found that 8 of the parents experienced a Severe Problem of helmet fit for their child. This finding would lead me to believe that helmet fit was a concern for this demographic of parents and that they are potential early adopters of a solution that would solve that problem.

For market risk, the parents who experienced the Severe Problem of helmet fit adapted by continually looking for better fitting helmets that did not work, delaying their child's introduction to biking, using a helmet from another activity, or using an ill-fitting helmet as they kept looking for other options. In addition, as parents described "likes" and "dislikes" with helmets, other Minor Issues and General Preferences surfaced that will direct product solutions.

For customer risk, for these parents, just under a third of their children experienced the Severe Problem of bicycle helmet fit. In addition, when segmenting specific potential early adopters, for US Bike Parents there is a distinction between the customers, who are the parents, and the end users, who are the children. Additional contextual considerations include Instagram as a potential channel for building customer relationships, as well as bicycle retailers and online distributors as potential sales channels. Finally, the problem of helmet fit serves as a barrier to the parent's broader goal of having their kids participate in a fun, outdoor, lifetime, family activity that promotes fitness and personal development, as well as compliments other activities.

4.5.3 Summary of Pivots After US Bike Parents

After conducting interviews with US Bike Parents, I considered them to be the most promising group of potential early adopters. However, none of the participants I spoke with were experiencing the problem at the time of the interview, it was always a problem they had experienced in the past. So, I continued exploring variations of this demographic to see if I could find parents who were experiencing the Severe Problem at the moment of the interview and could potentially be a more promising group of early adopters. Figure 4.13 shown below, is a subsection of Figure 4.8, which showed an overview of all the pivots. Figure 4.13 shows the pivots after US Bike Parents which includes: International Bike Parents, Bike Seat and Trailer Parents, Bike Parents of Older Kids, and Recommended Parents. Although I found other Severe Problems, no other customer segment had the number or concentration of Severe Problems as US Bike Parents.

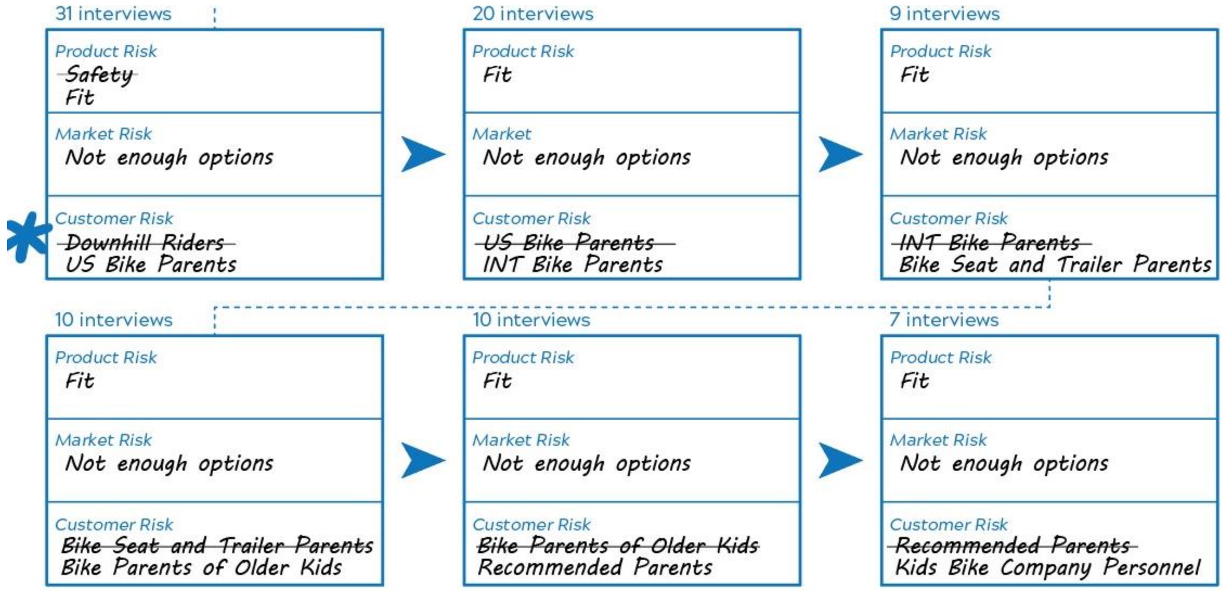


Figure 4.13 Overview of pivots after US Bike Parents

In order to gain additional perspectives about US Bike Parents, I also reached out to US kid specific bicycle industry personnel. The goal for reaching out to US kid specific bicycle industry personnel was to see if there was any overlap in observation, gaps we were not seeing, as well as new insights for future product development around personal protective equipment. Also, US kids specific bicycle retailers could serve as a potential sales channel. So, the interviews with industry personnel served to find various pain points that affect how they interact with brands and bring on new products.

Ultimately, 166 problem interviews were conducted. For the problem interviews, I have focused on finding a Severe Problem worth solving, however there are additional components to identifying an opportunity worth pursuing. The other two components for identifying if an opportunity is worth pursuing are observing trends and finding a gap in the marketplace (Barringer & Ireland, 2016). The most attractive opportunities for a new venture take advantage of all three sets of circumstances. An overview of observing trends and finding a gap in the marketplace is described in the next section 4.6.

4.6 Identifying if an Opportunity Is Worth Pursuing

As stated in the previous section 4.5.3, the components for identifying if an opportunity is worth pursuing are 1.) finding a problem, 2.) observing trends and 3.) finding a gap in the marketplace (Barringer & Ireland, 2016). The most attractive opportunities for entrepreneurship have all three. By conducting Customer Discovery, I found a Severe Problem described by potential early adopters. This means that for US Bike Parents, 8 of the 31 parents interviewed, had a difficulty with helmet fit so severe, they went to multiple bike shops, returned multiple helmets and/or disregarded a buying option because “it won’t work,” with severe amounts of frustration expressed. The resulting behavior was considered to be a significant behavior change and therefore denoted as a Severe Problem, which is a strong indicator for problem/solution fit.

4.6.1 Observing Trends

In 2018, the global kids bicycle market was estimated to be 4.1 billion USD (*Kids Bicycle Market Size, Share & Trends*, 2017). The growth in this industry is attributed to parents, teachers, schools, clubs, and residential societies (*Kids Bicycle Market Size, Share & Trends*, 2017). Bicycling has been promoted as a daily activity to be used for sports and fitness, fun with friends and family, as well as a mode of transportation (*Kids Bicycle Market Size, Share & Trends*, 2017). Furthermore, the removal of China's one child policy should also support growth as it has the largest market share for the children's bicycle market (Children's Bicycle Market by Type and Geography - Forecast and Analysis, 2022). There has been some decline in kids owning and accessing bikes, as parents are concerned about kids riding on busy roads and maintaining the bike (*Kids Bicycle Market Size, Trends & Forecast, 2023-2033*, 2022). The decline in ownership is also attributed to three consistent themes, electronics or video game use, the closure of brick-and-mortar toy stores, and rising costs for kids bikes (Sorenson, 2019).

Over the past five years, the bicycle industry has experienced moderate volatility as costs with aluminum and steel have increased and decreased (Ristoff, 2022). In 2014, industry revenue was at 6.7%, then in 2017, dropped to 2.7% (Ristoff, 2022). In addition, offshore wages are on the rise, as well as tariffs on bicycles and parts (Ristoff, 2022). In response to rising costs, bike manufacturers are slowly bringing some facilities back to the US, after decades of offshoring (Ristoff, 2022).

Despite these drops in revenue, "operators targeting the high-income consumer market have experienced significant growth during the past five years" (Ristoff, 2022, 11). For example, high-end bikes have continued to be a successful product targeted at high-income consumers (Ristoff, 2022). Some of the tradeoffs for such products are they usually have greater profit margins, but also require skilled labor (Ristoff, 2022).

The growing trend in demand for high-end bikes has also been true for the parents who want a high-quality biking experience for their children (*Kids Bicycle Market Size, Trends & Forecast, 2023-2033*, 2022). There is a demographic of parents who are, "focused on providing their children with an impressive introduction of the cycling world, particularly when it is their children's first bike" (*Kids Bicycle Market Size, Trends & Forecast, 2023-2033*, 2022). Then if there is interest from the child, the parents want to make sure the kids are "equipped with safety and comfort" (*Kids Bicycle Market Size, Trends & Forecast, 2023-2033*, 2022).

Other industry reports found a trend in the premiumization of adult bicycles (*Bicycles: United States*, 2019). Then, when the parents decide to buy their young children's bicycle, they "are increasingly opting for models similar in quality to their own" (Bicycles: United States, 2019, 21). It is expected that this trend will continue as disposable personal income continues to rise (*Bicycles: United States*, 2019). In addition, the "high-end models are generally tailored to the specific body proportions and strength of children" (Bicycles: United States, 2019, 21). The most notable brand pursing this trend is Strider Sports International, as well as smaller firms such as Cleary Bikes (*Bicycles: United States*, 2019).

4.6.2 Finding a Gap

Over the last couple of decades, kid specific bike companies continue to emerge, which demonstrates that the industry is growing. Although there were a few kids specific bike companies prior to 2007, the emergence of the children's bicycle and balance bike industry began with Strider Bikes in 2007, as shown in Table 4.1. Then from 2012-2017 the industry surged with the launch of thirteen new, high-end, children's specific bicycle companies. As the industry has continued to grow, two children's specific bike part companies were launched producing another level of high-end aftermarket parts for children's bikes. Below, Table 4.1 shows kids specific bicycle and bicycle part companies that were launched since 2007.

Table 4.1 List of kids specific bicycle and bicycle parts companies

Bike Company	Launch Date	Website
Strider	2007	https://striderbikes.com/story/
Kinderfeet	2012	www.linkedin.com/company/kinderfeets-llc/about/
LilShredder	2012	http://www.bikeroar.com/brands/lil-shredder
Pello	2012	https://www.pellobikes.com/faq
Spawn	2012	https://eurekabike.com/bike-brands/spawn
Frog	2013	https://infographic.frogbikes.com/
Woom	2013	https://woom.com/en_US/pages/our-story
Guardian	2013	https://guardianbikes.com/pages/about-us
Cleary	2014	http://www.bikeroar.com/brands/cleary-bikes
Trailcraft	2014	https://www.coloradoan.com/story/sports/outdoors/2014/11/24/youth-bikes-focus-fort-collins-trailcraft-cycles/70061414/
Prevelo	2016	https://prevelo.com/pages/media-kit
Flow	2016	https://www.pinkbike.com/news/flow-convertible-kids-bike-outdoor-demo-2016.html
Meekboyz	2016	https://meekboyz.com/about-us/
Squish Bikes	2017	https://www.cyclesprog.co.uk/reviews/squish-18-review/
Wild Child Bike Parts	2017	https://wildchildbikes.com/blogs/news/tagged/opening
Eutheia Balance Bike Parts	N/A	https://www.eutheiacycling.com/

Although the children's specific bicycle industry has begun to mature, there is still a gap in the market, as there is no high-end helmet company that solely focuses on kids helmets. The problem with helmet fit for children started over twenty years ago and has become increasingly more apparent as the children's specific bicycle industry has grown (Bromell & Geddis, 2016; Hagel et al., 2010; Rezendes, 2006; Thai, McIntosh, & Pang, 2014). The identification of the gap in the children's bicycle helmet market is supported through Customer Discovery as 8 of the 31 US Bike Parents interviewed described Severe Problems with bicycle helmet fit.

Major firms can provide a large selection of products for many different disciplines of bicycling (*Bicycles: United States*, 2019). In addition, major firms can control market share through, "acquisition of potential competitors, brand loyalty, domination of distribution channels, globalized supply chains, significant investments in design and technology" (Bicycles: United States, 2019, 26). However, in regard to launching a new venture, barriers of entry in the bicycle industry can be low (*Bicycles: United States*, 2019). For smaller companies such as Cleary Bikes, they have found a gap in the market specializing in high-end kids bikes (*Bicycles: United States*, 2019).

4.7 Co-Triangulation

As described in section 3.4.3, determining the key takeaways from the interviews can be subjective. In an effort to reduce subjectivity and bias I collaborated with Virginia Tech's Social Science Data Consultant to create intercoder agreements, as well as a strategy for co-triangulation. In addition, I worked with qualitative researchers Carey Stewart and Logan Layne when co-triangulating the interviews. Together, we co-triangulated the 31 interviews from US Bike Parents. From the co-triangulation process Mrs. Stewart surmised that:

> *A Severe Problem that emerged was the difficulty of being able to find properly fitting bike helmets for individuals with smaller sized heads including children, infants, and toddlers. The same theme was repeated in numerous interview transcripts about the lack of availability of properly fitting bicycle helmets for individuals with smaller sized heads.*

From the co-triangulation process Mr. Layne surmised that:

> *Helmet fit seemed to not only occur most often as a Severe Problem compared to Major Problems and General Preferences, but it also was well defined amongst the participants. The parents said that determining if the helmet fit properly or not is the first thing they check when going to a store. Online shopping was often avoided when ordering helmets because it is nearly impossible to know what their child needed, or it would take multiple back and forth exchanges to find the perfect fit. When the parents would describe their experience of trying on helmets it was mentioned that it is very difficult to find a helmet that was able to fit their child's head.*

Mrs. Stewart's and Mr. Layne's interview summaries and their reviews of the co-triangulation process can be read in Appendix C. Based on the summaries, we reached a consensus that bicycle helmet fit was a Severe Problem for some of the US Bike Parents.

4.8 Discussion

In contrast to the approaches described by Maurya, Blank, Dorf, Osterwalder, and Pigneur, the first principles approach described in this dissertation improves initial product development over existing approaches by using Customer Discovery (CD) for finding a Severe Problem as the basis for driving product development. Of those authors, Osterwalder and Pigneur's book *Business Model Generation* does the least to highlight a problem as the basis for driving product development. Rather they focus on a value proposition as the building block that "describes the bundle of products and services that create value for a specific Customer Segment" (Osterwalder & Pigneur, 2010, 22). The value proposition can include solving "a customer problem" or satisfying "a customer need," however, Osterwalder and Pigneur do not describe any additional context or problem severity a customer may experience (Osterwalder & Pigneur, 2010, 23). In addition, they describe that a value proposition can also include other forms of value such as the iterative improvement of products through newness, performance, or customization (Osterwalder & Pigneur, 2010).

In *Running Lean,* Ash Maurya develops the concept of using problems to drive product development further than Osterwalder and Pigneur. As described in section 4.1.1, Maurya removes Key Partners from the modeling canvas and replaces it with a Problems section. However, although Maurya gives problems a home on the Lean Canvas, he only vaguely defines a problem as a "problem worth solving," or superficially describes a "customer pain level" without further detail (Maurya, 2012, 37, 51).

In *The Startup Owner's Manual,* Blank and Dorf go the furthest in defining problems, as well as using problems as a means for driving product development. In the text, they describe their "problem recognition scale" which includes brief definitions of latent, passive, and active problems, as well as a customer's vision to solve a problem (Blank & Dorf, 2012, 85). Blank and Dorf's "active (or urgent) problem" is the closest to Severe Problems, but their definition of an active problem is difficult to follow when they describe it as, "they recognize a problem or passion and are searching for a solution but haven't done any serious work to solve the problem" (Blank & Dorf, 2012, 85). In their definition of an active problem, they do not describe the severity of the problem, and the definition seems muddled with the inclusion of the word *passion.* In addition, the definition seems contradictory, if a person is actively searching for a solution, wouldn't that be considered as serious work to solve the problem?

Overall, BMC, LC, and CD are tools that can be used to try to reduce the risk of failure for a new venture team. The point is, as described later in section 7.2.2, for products that can be capital intensive or require significant technological development, CD can help reduce the risk of failure by acquiring early adopters as a result of interacting with participants through the problem interviews. Participants with a Severe Problem, meaning the significant behavior change and considerable amounts of frustration expressed during the interview, can be a good indication that those participants may buy the product before most customers. CD can help an NVT acquire and activate potential early adopters, as well as reduce the NVT's initial customer acquisition costs.

It should be noted that not all new ventures will be capital intensive or require significant technological development. As described later in section 6.1.3, creating a new venture could be as simple as building an app for food enthusiasts using a visual programming language, where the capital and technological developments needed are minimal. For products where minimal capital and technological developments are needed, finding a Severe Problem through CD may not be necessary. As described by Osterwalder and Pigneur, using a value proposition as the building blocks for the new venture may be adequate.

CD can serve as a foundation for directing the product development process for improved safety for bicycle riders by identifying problems that are severe enough to indicate that there might be a viable market for a new product. For the problem interviews, I started with broad questions, then narrowed the questions to the specific problem I was trying to learn about. If I did find a Severe Problem that the participant could identify and articulate, as well as a solution to that problem, it is anticipated that participant may adopt a safety counter measure that addresses that Severe Problem.

For example, during the interviews many participants described a desire to have either MIPS or a MIPS like technology for reducing rotational acceleration. The use of rotational acceleration as an engineering metric to reduce head injury has gained exposure through MIPS and the Virginia Tech Helmet ratings (Bliven et al., 2019; *Virginia Tech Bicycle Helmet Ratings*, 2023). However, there could be other engineering metrics, such as impulse for reducing head injury that are not as well known. It is anticipated that participants would be less likely to adopt a technology that reduces impulse, as they would be less aware of the engineering metric, as well as any correlation it may or may not have with head trauma. The point is, CD can serve as a foundation for directing the process for improved safety for bicycle riders by focusing on their Severe Problems with equipment, which can be a strong indicator they would be willing to adopt a safety counter measure that solves that problem.

When conducting interviews, the interviewer should be present during the interview, ask appropriate follow up questions, and limit distractions, such as taking notes. A focus of this dissertation has been highlighting failure rates in entrepreneurship as described in section 2.1. In addition, a focus of this dissertation has been to explore how to reduce the risk of failure by applying qualitative research methods to CD. When applying qualitative research methods to CD, I conducted most of the interviews by myself, as well as recorded, transcribed, and coded every interview, which was a very time intensive process. Then for the NSF I-Corps Program, I-Corps teams were asked to have two team members on each interview. One team member's job was to conduct the interview and the other's job was to take notes. None of the NSF I-Corps interviews were recorded, transcribed, or coded. From my experience, whether applying qualitative research methods as described in this dissertation or the approach from the NSF I-Corps Program one is not necessarily better than the other. The point is, when conducting interviews, the interviewer should be present during the interview, ask appropriate follow up questions, and limit distractions, such as taking notes. Also, it is recommended to document important aspects of the interview for future reference, so the NVT can reduce their own personal bias and collectively make decisions based on evidence from the interviews. So, recording, transcribing, and coding the interviews is probably not necessary for other NVT's.

As described in section 4.7, co-triangulation is a method for reducing personal bias when trying to determine the key take aways from the interviews. However, co-triangulation may also be an unnecessary step for most NVT's, if they are able to coordinate at least two team members per interview. The purpose of including steps such as co-triangulation or having multiple team members on an interview is to reduce personal bias when listening to the interviews, as well as delegate activities related to documenting the interview that may interfere with asking questions and listening.

As described in section 2.1, historically CD has not been grounded in qualitative research methods, so this dissertation serves as an extreme example for applying qualitative research methods to the process. The aspects of qualitative research that were applied were conducting an intrinsic case study, identifying the role of the researcher, applying components of grounded theory, as well as recording, transcribing, coding, and co-triangulating the interviews. For most NVT's this level of depth is probably not necessary. However, as descried later in section 8.2.1, entrepreneurial and product development practitioners such as Tony Ulwick may say the qualitative research methods described in this dissertation do not go far enough and fail to quantify and rank order the qualitative data from the interviews.

4.9 Contribution

One of the contributions of this chapter is the semi-structured way in which the interview questions were formed and organized, starting with the broader goal of why the participant participated in the activity and then narrowing the questions to challenge and support the specific hypotheses. As described in section 2.2, a criticism for conducting interviews is the advice can be vague and there is little to no structure given for interviewing participants to challenge and support hypotheses. However, in contrast to that criticism, Maurya describes a detailed example for how to create a problem interview script. Unfortunately, his problem interview script starts with leading statements and closed-ended questions in the Tell a Story section (Maurya, 2012). He continues to ask leading and closed-ended questions in the Problem Ranking section (Maurya, 2012). Then, Maurya finishes with a few open-ended questions, in order to explore the "customer's worldview" (Maurya, 2012, 87). However, at that point it is too late, the interviewee has already been led to the problems the NVT wants to talk about.

Additional contributions include the 166 problem interviews that were conducted. The interviews were coded, analyzed, and co-triangulated to reduce bias and identify a Severe Problem that can drive product development. The final contribution from this chapter is the operational definitions for different severities of problems, referring to Severe Problems, Major Problems, and Minor Issues. As described in section 4.8, authors of entrepreneurial texts have provided definitions for problems in the past, however there are limitations with each of their definitions.

4.10 Chapter Summary and Next Steps

In summary, the Lean Canvas serves as a tool for supporting the creation of product, market, and customer risk hypotheses. Then CD, specifically the problem interviews, serves as a means for finding a problem that can drive product development. In addition, CD challenged and supported the initial hypotheses documented on the Lean Canvas.

I deconstructed my initial product idea of a safer, 3D printed bicycle helmet for Pro and Semipro Men into product, market, and customer risk hypotheses. Then, I created interview questions, solicited participants, and conducted problem interviews. For Pro and Semipro Men, no Severe Problems were found, so I pivoted the customer risk hypothesis to Pro and Semipro Women. Next, the process of and reasons for pivoting were described. Then, an overview of all the pivots was presented. As I was conducting problem interviews and pivoting between customer segments, the group US Bike Parents was considered to be the most viable customer segment. With a potentially viable customer segment identified, US Bike Parents, the problem interview exit criteria was described and a comprehensive problem interview learning was created.

Identifying an opportunity worth pursuing is more than simply finding a problem that can drive product development but can also include observing trends and finding a gap in the marketplace. Observing trends and finding a gap was described in relation to US Bike Parents. Then, the interviews were co-triangulated to reduce bias from myself, the interviewer. During co-triangulation, we reached consensus that bicycle helmet fit was a Severe Problem for some of the US Bike Parents.

Once a Severe Problem was found, one that resulted in a significant behavior change from the participant, CD continued by conducting brainstorming sessions, where there were two goals. The first goal was to confirm the Severe Problem was understood. The second goal was to explore the solution space with potential early adopters who have experienced it. Confirming the Severe Problem and brainstorming solutions can help to gauge problem/solution fit. The combination of problems interviews and brainstorming sessions, will help answer the question, “Is this an opportunity that should be pursued?” Going through this process will answer my second research question.

Chapter 5 Brainstorming Solutions and Converging on a Singular Product Category

In the previous chapter an initial product idea was deconstructed, problem interviews were conducted, and a Severe Problem was found, all of which were grounded in qualitative research methods. In this chapter brainstorming sessions and solution interviews were conducted, while grounded in qualitative research methods, and a solution category was determined.

Section 5.1 describes an overview of the brainstorming sessions, demonstrating how they were conducted. Section 5.2 provides rationale for assessing the various ideas and demonstrates how to converge on a singular solution category. Then, section 5.3 explains the purpose of the solution interview, how to conduct them, as well as presents a solution interview learning specific to this dissertation. Section 5.4 presents the discussion for the chapter. Section 5.5 reiterates the contributions from this chapter. Finally, section 5.6 summarizes and concludes the chapter.

Research Question 2: Once a singular Severe Problem has been found, which involves a significant behavior change that can direct the solution space, how can the solution space be navigated from that Severe Problem to improve product development?

The contribution from this research question is an improved product development process by including brainstorming sessions, between the problem interviews and solution interviews. The goal is to find the best solution category for commercialization. Many entrepreneurial texts use Customer Discovery (CD) to identify rationale from the interviews that challenges and supports the NVT's initial idea. However, including a step that tries to explore other relevant ideas for commercialization can help dislodge entrenched ideas about the product and help an NVT find an idea that may be better. In addition, the contribution from this research question is the design and implementation of a brainstorming session specific to the Severe Problem identified in the problem interviews, with participants who experienced that Severe Problem. A corresponding set of guidelines for developing sessions for other areas of product development is included. The contribution also includes the design and implementation of the solution interviews. The brainstorming sessions and solution interviews were coded and analyzed, resulting in a detailed knowledge of the risks associated with a solution that solves the participant's pain point, as well as a business model focused on their needs.

5.1 Brainstorming Session Overview

In Chapter 4, a Severe Problem was found through the problem interviews. That problem was the Severe Problem of bicycle helmet fit for US Bike Parents. The purpose of this section is to describe how to confirm the problem has been understood and converge on a singular problem, as well as to diverge from the initial product idea, by brainstorming potential solutions. Confirming the problem and brainstorming solutions were both conducted during the brainstorming sessions. This section describes the general process and guidelines for the brainstorming sessions. Then, the way in which that process was applied to this dissertation is described.

The brainstorming sessions described in this chapter help to address the issue that the initial product idea that started CD may not be the most appropriate solution for solving the Severe Problem found in the problem interviews. It should also be noted that authors such as Maurya, Blank, and Osterwalder generally reference brainstorming throughout CD, however, they do not explicitly outline a brainstorming session in their literature. For the potential new product that is the topic of this dissertation, it would have been easy enough to stay with the initial idea of a 3D printed helmet for solving the problem of helmet fit. However, the goal of CD is not to simply find a problem that will support the initial product idea. Rather, the goal of CD is to de-risk a new venture, which can include diverging from the initial product idea (Frich et al., 2021; Maurya, 2012). My addition of the brainstorming sessions to this stage of CD provides a generally applicable approach to brainstorming, so an NVT can explore alternative solutions as it searches for problem/solution fit.

5.1.1 Brainstorming Session Process

Brainstorming sessions served as a technique that links the Severe Problem to the solution. There had been several weeks in between the problem interviews and the brainstorming sessions, so before the brainstorming activity began, I read a summary of the problem the participant described during their initial problem interview. Next, I would ask if there were any additional insights about the problem that the participant would like to include. Reading the summary helped confirm that I understood what they initially described, to see if there were any new insights they may have remembered, or if they remembered the situation differently than when they first described it. Then I would transition to the brainstorming activity.

The purpose of brainstorming was to diverge from the initial idea and consider all possible solution categories (Frich et al., 2021). The goal was to find problem/solution fit, which is the next level of reasoning for a first principles approach. The brainstorming sessions were used to solicit feedback from end users who have experienced the Severe Problem, collaboratively brainstorming ideas, and identify as many potential solutions as possible.

Brainstorming sessions can be done in person or virtually (Horvát & Uzzi, 2022). In addition, they can be conducted with those who described the problem (Cooper & Dreher, 2010). Sessions ideally would include roughly 2-12 participants (Gallupe et al., 1992). In theory, more brainstorming sessions could produce more ideas. When conducting the brainstorming sessions, a training session is recommended, especially if digital technologies are used. In addition, a practice session for generating ideas is also recommended. When brainstorming, one technique that could be used is the SCAMPER technique, which will be described later in this chapter (Ozyaprak, 2016). Although, there are many brainstorming techniques and variations to those techniques that could also be used (Chulvi et al., 2012). At the end of the sessions, there should be many new ideas for how to potentially solve the problem identified in the problem interviews.

From the sessions, I developed a few guidelines for future entrepreneurs, product developers, and researchers. The guidelines were based on my experience developing, planning, and conducting the interviews. However, some of the guidelines can also be found in other brainstorming literature (Isaksen & Gaulin, 2005).

A set of guidelines for setting up future brainstorming sessions can include:

Setting up the session:

- Remember, the goal of the brainstorming sessions is to come up with new ideas.

- Action words such as Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, or Reverse (SCAMPER) are used to elicit new ways of thinking about the problem, as well as ways to solve it. Other action words can be appropriate.
- Conduct the brainstorming sessions with those who are experiencing the problem, or experienced the problem, as they have the most to gain from solving it. Brainstorming sessions with other key stakeholders can be appropriate.
- A brainstorming session should have at least two participants and a moderator, although more participants are preferred.
- The moderator should set group rules prior to the brainstorming session.
- The brainstorming sessions can be in person or digital, in person would have been preferred.
- Finally, a group brainstorming session should be collaborative, where participants are building off each other's ideas.

Have a practice session:

- Sharing and building upon each other's ideas is not necessarily intuitive, have a practice brainstorming session that is fun and lighthearted.

During the actual session:

- After the practice session and at the beginning of the actual session, include a prompt which describes a problem statement identified from the Severe Problems in the problem interviews.
- At the end of the prompt, be very clear that the goal for the session is to find ways to solve a problem. For my specific scenario, the final question was: How might we improve helmet fit?

After the session:

- Debrief, asking "what worked?" "what did not work? and "why?" as feedback can make future sessions better.

During a brainstorming session, it is expected that ideas will be voiced that do not directly relate to the prompt given. Although it can be helpful to have new ideas for other problems, the goal of the brainstorming session is to generate creative solutions that directly relate to the problem identified during the problem interviews. Specific to the brainstorming sessions described in this dissertation, occasionally the conversation would drift into problems about helmets that did not relate to the problem of helmet fit. As the moderator, it was challenging to know when to let the conversation explore a new direction yet trying to redirect it towards the initial problem identified in the problem interviews. Finally, there are many brainstorming techniques and variations on those techniques (Chulvi et al., 2012). A recommendation is that entrepreneurs, product developers, and researchers explore other techniques and apply the ones that are most appropriate for their purposes.

5.1.2 Application of the Brainstorming Sessions

For this dissertation I designed a brainstorming session, as well as conducted two sessions. I conducted two sessions with parents who had experienced the Severe Problem of helmet fit. From the sessions we came up with a variety of ideas for potentially solving the problem.

For this dissertation, brainstorming sessions only included participants who participated in a problem interview. Specifically, the sessions only included US Bike Parents who had expressed a Severe Problem with helmet fit. However, due to time and resource constraints, only two brainstorming sessions were conducted. For each brainstorming session, there was one participant, as well as one or two co-chairs who acted as participants. The research was done virtually as participants were located across the United States.

I started each session with a brief training session of the virtual collaborative platform being used, which was Miro. Next, I gave participants an opportunity to mention any additional insights that they may have experienced with challenges surrounding helmet fit, that may not have been included in the problem interviews. Then the session incorporated a fun and lighthearted brainstorming practice activity, so they felt comfortable and enabled to participate fully.

For the brainstorming practice activity, I started by reading out loud the following problem statement: *It's a hot summer day, you want to use the hose to cool down in a fun way, using the garden hose and a sprinkler, but the kids are bored with it. How might we substitute, modify, maximize, or adapt it to make it more exciting?* After the problem statement was read, I gave the participants three minutes to try and think of at least five ideas. As shown in Figure 5.1, we had three participants, and each participant was given a column of digital sticky notes on which to write their ideas.

Figure 5.1 Digital sticky notes where the participants would write down ideas for the practice session

Once the three minutes were up, I gave the participants time to read through all the ideas. Then participants would pick their favorite idea and build on that idea through the phrase, “yes and…” Saying “yes and…” is a brainstorming technique for not criticizing an idea, giving it validation, and building on it without judgment (Hatcher et al., 2018). The goal was to collaboratively build on each other's ideas to bring forth something that was better than an idea that any one individual could produce.

After the practice activity, I read a problem statement, which was based on the Severe Problems identified in the problem interviews. The problem statement expressed how parents have described challenges with helmet fit, ultimately delaying their children’s progress with biking. Participants were encouraged to write down ideas they already had, as well as other off the wall ideas. When brainstorming we used the SCAMPER technique for trying to solve the problem of helmet fit (Ozyaprak, 2016). The participants were asked to come up with at least five ideas each. After five minutes had passed, the group took a three-minute break so all the ideas could be looked through and participants picked their favorite idea that was not theirs. Then the group took an additional three minutes to build on each other’s ideas with, “yes and…” Finally, we debriefed, and I asked participants what they thought was successful, what was not, and why.

5.1.3 Analyzing Brainstorming Sessions

Both sessions were recorded and transcribed. The transcripts were then coded. During the coding process, I identified and categorized solutions that were mentioned during the sessions. The coding process for the sessions required less discernment from myself than the problem interviews. When coding the sessions, I was primarily looking for solutions described by the participants. However, for the problem interviews, I was categorizing participant’s responses based on the operationally defined terms of Severe Problems, Major Problems, and Minor Issues.

Each session had its own quirks. General challenges were participants navigating the collaborative brainstorming software (Miro) and clicking through links from the practice session to the actual session. A primary concern throughout the sessions was to ensure participants' identities were not revealed. Some of the strategies I used to ensure this were asking participants to only use their first name, as well as asking them not to reveal any personal information. However, other than my co-chairs and I, we never had more than one participant in a session, so we never ran into the problem of revealing a participant’s personal information to another participant.

5.1.4 Brainstorming Session Summary 1

For our first session, I was the moderator, while participant ID_1301 participated in the brainstorming session, as well as co-chairs Dr. Martin and Prof. Schaudt. The session lasted for a total of 41 minutes. To confirm the problem was understood, I read out a summarized version of the problem the participant described in our first interview. The participant had no new additional insights.

During the session, ideas for solving the problem of bicycle helmet fit included the use of thinner or thicker comfort pads; eliminating or improving the ratcheting mechanism; developing a malleable internal padding that will form to the child’s head; the use of multi-point adjusters similar to ski boots; and a heat molded internal liner similar to mouth guards.

5.1.5 Brainstorming Session Summary 2

For our second session, again I was the moderator, while participant ID_1302 participated in the brainstorming session, as well as co-chair Prof. Schaudt. The session lasted for 50 minutes. To confirm the problem was understood, I read out a summarized version of the problem they described during the problem interview. Again, the participant had no new additional insights.

During the brainstorming session, ideas for solving the problem of bicycle helmet fit included an inflatable bladder that inflates every time, to the shape of the rider's head; fully inflatable head protection; including an additional ratcheting mechanism on the chin strap for adjustment; a signal that lets you know when the helmet is level and fit properly; mailing multiple helmets (nesting them or making them stackable) for the rider to try on, similar to the Warby Parker model; and leveraging 3D tools to assess and measure fit in relation to helmets available on the market.

5.1.6 Summary of Brainstorming Sessions

Overall, the sessions were worthwhile explorations, leveraging expertise from those experiencing the problem. However, I had limited expectations for the brainstorming sessions to yield many insights as participants are not necessarily familiar with developing new technologies or manufacturing processes. The participants had experience with the problem, but they did not necessarily have the technical competence to solve the problem (Taylor, 1982). Future brainstorming sessions could include relevant personnel that have knowledge for improving "the transferability of the findings to real-world applications" (Isaksen & Gaulin, 2005, 322).

During the brainstorming sessions a few challenges arose. One challenge was the participants were not familiar with the various online tools for collaboration. For example, some training was needed for the program Miro and even with training, there were still minor missteps. Another challenge included the practice session had a higher level of freedom and creativity, compared to the actual session. When coming up with ideas for how to make a hose more fun on a hot summer day, the ideas flowed. However, when it came to coming up with ideas for improving helmet fit, participants were more reserved.

A challenge that only presented itself in the first brainstorming session was participants would get distracted, talking about other problems relating to bicycle helmets, such as knowing when a helmet is damaged. Although this is not inherently a problem, it does delay progress for generating more relevant solutions and is not the goal of the brainstorming sessions. The goal of the problem interviews is to explore the problem space and converge on a singular problem that can drive product development. The goal of the brainstorming sessions is to come up with as many ideas as possible to solve that problem. Considerations for future brainstorming sessions could include navigating the balance between sticking with the original plan versus allowing for alternative directions and fostering a collaborative dialogue despite diverging from the initial goal.

It was unclear if any of the brainstorming sessions would come up with the final solution. However, it was anticipated that the brainstorming sessions would challenge the initial product idea, as well as add ideas to the overall solution landscape. The ideas that participants presented may or may not directly relate to the final solution. In addition, the participants' ideas for products, features, and other improvements may contribute to future solutions.

Finally, one solution category that stood out was to offer more kid specific head shape and sizing options. For current companies, offering more kid specific head shape and sizing options, similar to adult helmets would seem like the simplest solution. However, the current kids bicycle helmet market is not attractive enough for helmet companies to offer such options. Based on the assumptions that the simplest solution would be to offer more kids specific head shape and sizing options and that the kids bicycle helmet market is not attractive enough for existing firms, it could be argued that the market is not large enough to support a new custom fit helmet company. Although the market may not seem large enough, a similar analogy could be made to the bicycle industry not offering higher quality kids bikes. However, as described previously in section 4.6.2, since 2012 thirteen new, high end, children's specific bicycle companies launched, solving challenges around kids bikes, despite the existence of many larger existing brands (Bonkoski, 2022; King, 2008; Mayer, 2021).

5.1.7 Grouping and Organizing Potential Solutions Categories

I grouped and categorized ideas generated from the problem interviews, brainstorming sessions, as well as ideas generated by my co-chairs and myself outside of Customer Discovery. In the Fall of 2020, we had a conversation regarding the advantages and disadvantages of each. The goal was to objectively diverge from the initial idea of 3D printed helmets and consider all possible solutions categories.

The solution space consisted of everything from non-consumption, meaning if participants simply stopped biking the challenges surrounding helmet fit would be solved; to developing a force field that was inexpensive, lightweight, and would protect from all injuries, as well as a wide range of alternatives, as shown below in Figure 5.2. A few of the solution categories in between non-consumption and a force field included developing a helmet line with a greater variety of smaller sizes and head shapes with traditional manufacturing methods; inflatable airbag or 3D printed liners to interface with traditional foam helmets; an airbag helmet that stays inflated during use; a fully 3D printed helmet; and finally, an airbag helmet that inflates during a crash.

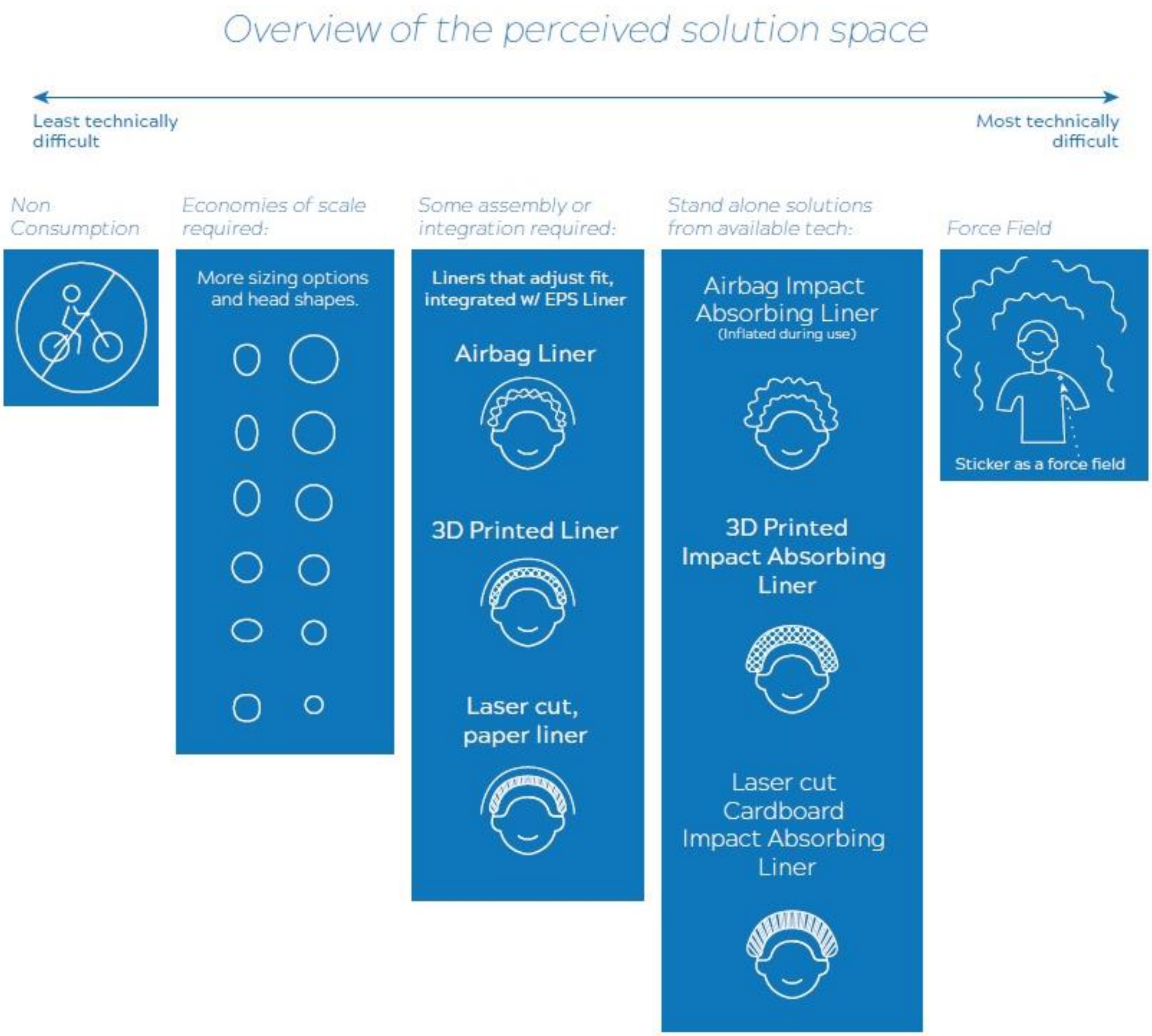


Figure 5.2 Solution landscape overview

5.2 Solution Down Selection

The purpose of this section is to demonstrate the process of solution category down selection, meaning the act of winnowing down potential solutions by critically thinking about the advantages and disadvantages of each. The process for determining the most appropriate solution can be both complex and simple. An example of a complex method for down selection would be to apply a cost-importance analysis, which is a method used in user experience design (Hartson & Pyla, 2012). A cost-importance analysis examines the problems in a particular design, ranks the importance of that problem, describes a solution, estimates a cost for that solution, and gives priority ranking to that group (Hartson & Pyla, 2012). However, determining the most appropriate solution can be as simple as having a conversation between key stakeholders, discussing problems, brainstorming solutions, and agreeing on a final solution (Hartson & Pyla, 2012).

For this dissertation, the process of down selection was filtered through two questions. 1.) “How well does the solution solve the Severe Problem?” and 2.) “What solution has the best opportunity for commercialization?” The goal was to converge on the “best” solution.

When identifying the “best” solution, the term “best” can be vague, and interpretation can be subjective. For this dissertation, the best solution category refers to a solution that solves the problem and seems to have the most potential for commercialization of the alternatives considered. Also, the term “best” specifically refers to the ideas generated within the brainstorming sessions, as there could be better solutions we did not come up with during the sessions. Determining the best solution category required judgement by myself the researcher, and is supported with secondary data in sections 5.2.1, 5.2.2, and 5.2.3.

It should be noted that a solution category is not the same as a minimum viable product (MVP), a common term used in entrepreneurship (Blank & Dorf, 2012). An MVP is “a concise summary of the smallest possible group of features that will work as a stand-alone product while solving at least the ‘core’ problem and demonstrating the product’s value” (Blank & Dorf, 2012, 80). The MVP from this dissertation will be identified from the solution interviews in section 5.3.4. Also, a solution category refers to a generalized solution without specifically describing the features and benefits of that solution.

5.2.1 Down Selection: Does it solve the Severe Problem?

Using the first question as a filter, “How well does it solve the Severe Problem?” eliminated helmet liners as a solution early on. The primary concern was helmet liners do not address the issue that many of the kids' heads are too small for current helmets on the market. As a result, the helmet liner would need to be unrealistically big to interface with a helmet that was also big and not the correct size. An additional concern is that airbag or 3D printed liners might have potential issues with the liner interfacing incorrectly with a third-party helmet, which would negatively affect how well it can solve the Severe Problem. Helmet liners would most likely increase weight and bulk, causing comfort issues.

5.2.2 Down Selection: What solution has the best opportunity for commercialization?

Identifying the best opportunity for commercialization was the next filter for determining the best solution. When asking this question and grouping the solutions, I identified and named a few heuristics for down selection based on the grouped solutions. The first heuristic I identified was to avoid solutions that were dependent on economies of scale, which I call Small Scale Solutions. Historically product development has been dependent on economies of scale, meaning, a new venture would need to make thousands of something to reduce the cost per part (Husan, 1997). From my professional experience, molds can be between $20,000 - $100,000 and require selling thousands of helmets to reduce the cost per part, to make the product economically viable.

For a new venture, there are two challenges with leveraging solutions dependent on economies of scale. The first challenge is a new venture’s focus is on niche or segmented markets, as it allows the new venture to distinguish themselves from major competitors and focus on a core segment of potential early adopters (Blank & Dorf, 2012; Farhana & Swietlicki, 2020). However, focusing on a segmented market of early adopters can reduce the advantages of using economies of scale, because the target market is not large enough to support the cost savings when producing large quantities of products. The second challenge was a capital-intensive solution can create an additional difficulty of raising capital, especially for a product that will become seasonally obsolete (Atherton, 2012). Raising capital usually results in the surrender of partial ownership of the new venture (De Bettignies & Brander, 2007). Therefore, because we are focusing on a segmented market, as well as trying to reduce the exchange of equity for capital, these considerations eliminate developing a helmet line with a greater variety of smaller sizes and head shapes with traditional manufacturing methods.

The second heuristic I identified was to find other companies that are also solving the problem in similar industries and pursue similar solutions, which is a term used in the business community known as second-mover advantage (Kopel & Löffler, 2008). Second-mover advantage starts with a firm identifying companies and technologies that are already solving this pain point for other markets (Kopel & Löffler, 2008). Then the NVT should follow that company's product strategy, with the goal of doing it better, which can include but is not limited to making the product cheaper, scaling faster, or adding more desirable features and benefits (Kopel & Löffler, 2008).

One opportunity for second-mover advantage was to develop an airbag helmet that inflates on impact. Airbag helmets are currently available and could solve the challenges surrounding helmet fit. However, current airbag helmets are much heavier at 800g than traditional helmets, which are between 200-400g (Bussey, 2023; *Tech Specs - Technical Specifications*, 2023). Also, airbag helmets can be more expensive with prices fluctuating between $300-600 than traditional helmets, which usually cost between $100-300 (Alexa, 2019; Broudy, 2017; *Hövding - Official Online Shop*, 2023). The second opportunity for second-mover advantage was to develop a 3D printed helmet, as they are also available and could solve the challenges surrounding helmet fit. Current 3D printed solutions are less heavy at 300g and less expensive around $400, compared to airbag helmets (*HEXR Helmet*, 2023; Locke, 2018).

5.2.3 Down Selection: Current Trends in Product Development

Another consideration for down selection was that I assessed the current climate for product development and how it had been trending. The first industry trend considered was trends to more personalized and customized products (Zheng et al., 2017). Personalized and customized products can leverage end user data, specifically anthropometric data for sizing and could be advantageous when creating a solution around personalized fit.

The second industry trend considered was geopolitical shifts that could affect commercialization. A relevant example of geopolitical shifts would be the Trump Administration's tariffs on imported goods from China, as well as the effects of pandemics to global supply chains (Burkart & Steltenpohl, 2020; Rugaber, 2019). Although there are many advantages to offshoring such as lower costs and more comprehensive supply chains, those advantages may not outweigh the unpredictability of increased tariffs and massive delays in the manufacturing, shipment, and arrival of products. Thus, localized production could be more advantageous compared to solutions that require offshoring.

Finally, minimum viable products are often developed for small niche markets (Blank & Dorf, 2012). Leveraging manufacturing methods, such as additive manufacturing for production, can be advantageous in low volume production for niche markets (Weller et al., 2015). Additive manufacturing can localize production and circumvent traditional barriers of entry, like navigating the nuances of global supply chains and expensive molding costs.

5.2.4 Other Considerations for Down Selection

Using heuristics may not always be the optimal strategy for down selection. In engineering, a popular method for down selection is the Quality Function Deployment (QFD). A QFD translates customer wants and needs into technical design requirements (Park & Kim, 1998). Customer Requirements, Design Requirements, and solutions are given numeric values, weighted, and ranked for further down selection. It should be noted that applying numeric value to the selection process does not necessarily make it objective, even though it gives the appearance of objectivity. Rather, the application of numbers and weighting relies on interpretation from the design team, making it "highly subjective in nature" (Raharjo et al., 2008, 254).

5.2.5 Final Solution Overview

Ultimately, by applying the aforementioned heuristics, of the options that were considered, the additively manufactured helmet appears to provide a better combination of solving the problem and providing opportunities for commercialization than any other options. The helmet will have some form of adjustability, as well as additional room for growth, so it will last the child approximately one and a half years. It should be noted that finding novel solutions is not an easy process. For example, the ratcheting system in the back of helmets is a popular solution that solves the issue of fit for many adults. I do not anticipate I would have thought of that solution on my own or in a brainstorming session. Although the ratcheting system does not solve the issue with fit perfectly, it bridges the gap and can make helmets more tolerable to wear. In addition, during my ME 5644 course, our project team conducted a few customer discovery interviews, where we identified other customer needs and design requirements that may influence future product development. The customer needs, design requirements, and projected costs are shown in Appendix D, which is the final report from our project team of Dominic LoPinto, Noah Haefner, Corbin Hawk, Joshua Hull, and myself.

5.3 Solution Interview Overview

Once there are strong indicators of problem/solution fit, the next phase of Customer Discovery is to conduct solution interviews (Blank & Dorf, 2012; Maurya, 2012). The purpose of this section is to describe the reason for the solution interviews, as well as describe how they were applied within the context of this dissertation. The primary goals of the solution interviews were to identify if the solution solved the Severe Problem, identify any additional features or product considerations, and understand why (Maurya, 2012). The secondary goal of the solution interview was to gauge potential pricing (Maurya, 2012). Indicators for pricing can be anchored to what the customer says they would pay to solve the Severe Problem, what they would pay for the exact solution, as well as pricing benchmarks like what they paid for similar products.

Solution interviews enable a new venture to "test the solution with a 'demo' before building the actual product" (Maurya, 2012, 95). For digital products such as software, building wireframes, mock-ups, and creating videos are recommended strategies for demoing (Maurya, 2012). For physical products, developing sketches, 3D models, and low fidelity prototypes are recommended strategies for demoing (Maurya, 2012). The goal was to use a "demo" as a stand in for the actual product, show it to the potential early adopters, and garner feedback for further refinement (Maurya, 2012).

5.3.1 Solution Interview Questions

This section presents the solution interviews I used for this dissertation, which were based on the solution interview template Maurya presents in *Running Lean.* Following Maurya's template exactly was difficult. One of the challenges with following it were redundancies between the problem interviews and solution interviews Maurya presents. An example of a redundancy was

Maurya collects the same demographic information in both sets of interviews. I had already collected demographic information in the problem interviews, so I did not collect demographic information again for the solution interviews. Another challenge was demoing the solution in the manner that Maurya describes. The solution from this dissertation was a process for improved helmet fit, from technologies that had not yet been developed. In response, I presented a generalized description for a custom fit helmet as the demo for the solution interviews.

The challenges I experienced when trying to follow Maurya's template for the solution interviews highlight the importance of critical thinking and never following any methodology blindly. Entrepreneurs, product developers, and researchers applying the methods from this dissertation should consider the specific context of their solution in order to apply product development methodologies appropriately. It is recommended to compare the solution interview in this dissertation to other entrepreneurial resources for navigating the appropriate application.

The solution interviews were structured as follows:

Welcome:
For the welcome, I started with:

> *First of all, I really appreciate your willingness to participate, it has been a learning experience.*

Tell a Story:
Next, I described a summary of the problem they originally described in the problem interview saying:

> *During our initial interview, you described the challenge of finding a proper fitting helmet for your child, when they first started riding. Generally speaking, this meant you started looking for a helmet for your child when they were one to one and a half years old. You did online research with measurements, but couldn't find anything. You then went to various sporting goods and biking stores. However, nothing was small enough or fit them properly, so it was loose and hanging off the back of their head.*

Initial Test Pricing:
In an effort for the pricing to be solution neutral, before even describing the theoretical product, I asked:

> *At the height of the pain point, what would you have paid to solve your problem?*

If the participant struggled to provide an answer, I included additional prompts such as:

> *At the time would you have spent twice as much? Or 10% more, et cetera?*

Demo:
As described earlier, demoing the exact product was challenging for my specific circumstances. Once the participant described a price, I would follow up with a general description of the solution saying:

> *What if I could solve that problem with a custom fit bike helmet, with no additional problems, no strap issues and will accommodate 1.5 years of growth. Any other features you'd recommend? Why is that? Based on the prototype, are there any additional considerations we should look at?*

Test Pricing:
Then I would follow up with:

> *Based on the proposed solution, what would you pay for that solution?*

Additional Test Pricing:
As it will be described later in section 5.3.5, Maurya described challenges with directly asking prospective customers what they would pay for a product or service (Maurya, 2012). In

response to this challenge, I included additional questions that focused on the prices they have already paid for similar products, which included:

> *What's your personal helmet? How much did you pay for your personal helmet? How much did you pay for your personal bike? How many bikes? What's the average overall? What's the most expensive?*

Document Results
In *Running Lean*, Maurya suggests taking five minutes to write notes following the interview (Maurya, 2012). For my particular situation, Customer Discovery was conducted in the context of research, so every interview was recorded and transcribed, with some notes taken during the interview.

5.3.2 Solution Interview Learning

The solution interviews were conducted with six US Bike Parents, as well as four company personnel at kid specific bike companies. In the section below, I followed Maurya's template for a solution interview learning in *Running Lean*.

After conducting six solution interviews with US Bike Parents, I learned:

Customer risk: Who has the pain? (Early Adopters)

Hypothesis
Solution interviews will support that US Bike Parents are potential early adopters.

Insights
Based on the previous problem interviews, I identified that parents who purchased a bike from a US kids specific bike company experienced the Severe Problem of bicycle helmet fit. From the additional solution interviews, there were no new insights for segmenting the market further.

Product risk: How will you solve these problems? (Solution)

Hypothesis
Solution interviews will support the minimum feature set.

Insights
The general description of a custom fit helmet, as a solution, was well received by parents. Additional features they described were having a rotational acceleration technology, such as MIPS, a ratcheting mechanism for adjustment, a magnetic buckle, mountain bike style coverage, and a visor. One participant also mentioned the preference of having a removable jaw piece. One of the benefits of using a process such as additive manufacturing, circumventing overseas production, and injection molded solutions is that it circumvents the need for minimum quantity orders that drive specific features sets for a product.

Market risk: What is the pricing model? (Revenue Streams)

Hypothesis
Interviews will find that participants would pay $90.

Insights
Two of the six parents said they would pay just under $100. Two of the six parents said they would pay about $150, and two of the parents said they would be happy to pay at least $200 for such a helmet.

5.3.3 Solution Interview Exit Criteria

In *Running Lean*, Maurya describes that an NVT is done with solution interviews when they have identified the following:

- Can identify the demographics of an early adopter
- Have a must-have problem
- Can define the minimum features needed to solve this problem
- Have a price the customer is willing to pay
- Can build a business around it (using a back-of-the-envelope calculation)

(Maurya, 2012, 108)

5.3.4 Final Product Brief for the Minimum Viable Product

Based on the problem interviews, US Bike Parents (early adopter) described a Severe Problem of helmet fit (must-have problem). Based on the brainstorming sessions, and solution interviews, a final product description is a custom fit additively manufactured helmet and liner. The helmet will have some form of adjustability, as well as additional room for growth, so it will last the child approximately one and a half years. The features and benefits should include a rotational acceleration technology, such as MIPS, a ratcheting mechanism for adjustment, a magnetic buckle, mountain bike style coverage, and a visor (minimum features needed to solve the problem). The target cost is under $100 and target retail is $150 (price customer will pay). Finally, the target volume will be based upon the target market, which will be addressed in the market feasibility portion of section 7.1.3. Determining the cost to build, retail price, and the size of the target market should determine if a business can be built around the product.

5.3.5 Solution Interview Considerations

For this dissertation, I tried to follow Maurya's solution interview template as closely as possible. However, for my particular solution, there were a few challenges with following his process exactly. One of the challenges was, the solution of improved fit was a difficult concept to physically demo. Another challenge was, many of the parents we talked to also ride bikes, wear helmets, and have a perspective on what fits and what does not. A rider's perspective of what fits and what does not lies between a rider's subjective perception of fit and a more objective evaluation of fit (Ellena et al., 2016). For this dissertation, I had not yet developed a perspective for quantifying improved helmet fit, which made it difficult to create a demo and quantify the improvement. As a result, it was challenging to demo the product in a way that fit Maurya's description for demoing a product described in section 5.3.

During the solution interviews, another challenge was testing the price in the same way that Maurya explains in *Running Lean*. When describing solution interview pricing strategies, Maurya recounts an interview he conducted where he asked the prospective customer what they would pay for a particular product. The prospective customer answered that they would pay $15-20 a month (Maurya, 2012). After hearing the low figure given by the prospective customer, Maurya explains that he would like to charge $100 a month and describes his rationale. His rationale for charging a higher price was, “$100/month is less than two developer hours a month” (Maurya, 2012, 99). In this particular example, Maurya anchors his price to what his prospective customer would normally pay its developers to complete similar work.

For my particular problem/solution fit, it was difficult to draw helpful tips from Maurya’s example. In relation to improved helmet fit, strategies for anchoring the price could have included the amount of time parents spend adjusting their child’s helmet, compared to what they would make hourly; the amount of time spent looking for a helmet, compared to what they would make hourly; the estimated monetary value of their child not receiving a head injury; or the estimated monetary value of the extra time they get to spend riding with their child. Another consideration for anchoring the price could be applying similar pricing differences between lower-end kids’ bikes compared to higher-end kids’ bikes.

In response to the nuances of my particular solution, first I directly asked prospective customers what they would pay to solve the problem of helmet fit, without describing a solution. For follow up questions, I asked them what they would pay for the solution I described; and finally I asked about pricing benchmarks for similar products they have purchased, such as their personal helmets and bikes. It should be noted that Maurya vehemently disagrees with directly asking prospective customers about what they would be willing to pay. In *Running Lean*, Maurya paints with an exceptionally large brush as he states, “there is no reasonable economic justification for a customer to offer anything but a low-ball figure…you often can (and should) convince a customer to pay a ‘fair’ price for your product that is usually higher than what both you and the customer think it is” (Maurya, 2012, 98). With the idea that the prospective customer may be giving a low-ball figure, I anticipated that any answer could be considered a low estimate for pricing strategies.

5.4 Discussion

In comparison to the approaches described by Maurya, Blank, Dorf, Osterwalder, and Pigneur, the first principles approach described in this dissertation improves initial product development over existing approaches by incorporating brainstorming sessions before initial product development. Including a brainstorming activity gives the NVT space to explore the solution landscape, as well as determine if there are solutions for commercialization that are more viable than the initial product idea.

The brainstorming sessions described in this chapter fill a gap in the entrepreneurship literature about how an NVT should move from identifying a problem to developing a commercially viable solution for that problem, particularly when the initial product idea might not be appropriate for the problem uncovered by the earlier interviews. In *Running Lean,* Maurya directly transitions from describing and applying the problem interviews to describing and applying the solution interviews. The text continues with the assumption that the initial idea that started Customer Discovery is still the most appropriate idea for product development. Similarly, In *The Startup Owner’s Manual*, Blank and Dorf also describe interviews as a means for testing the problem, rank ordering customer data, and “finding out the minimum feature set” for the NVT’s initial idea (Blank & Dorf, 2012, 233). Then they transition to the next chapter which focuses on testing the product solution. In addition, throughout the text there is a bias for web/mobile solutions, which could limit an NVT’s ability to explore solutions that are outside of that scope. In *Business Model Generation*, Osterwalder and Pigneur present a section on brainstorming in regard to business models. However, they do not actually instruct an NVT how to apply brainstorming techniques to determine the solution landscape. Generally speaking, the aforementioned authors emphasize pivoting a potential customer segment to a particular solution category, as opposed to exploring the entire solution space that may solve the customer’s problem.

As described in section 5.1, the goal of Customer Discovery (CD) is to de-risk a new venture. The goal of CD is not to simply find a problem that will serve as justification to commercialize the initial product idea. The product idea that started CD may not be the most appropriate idea for solving the problem or for commercialization. As an NVT continues to meet with potential customers and conducts solution interviews, they are gathering information on how well the initial product idea might meet the Severe Problem identified in the earlier interviews. Then they may adjust the product idea to be a more commercially viable solution to the Severe Problem. Conducting the solution interviews as described in this chapter provides feedback to the NVT to continually check itself as it searches for a viable problem/solution fit.

As described in section 2.1.4, researchers have most likely spent considerable time developing a core technology. For researchers trying to commercialize a technology it can be more difficult for them to be open to other solutions. The sunk costs of developing their initial technology can lead to inventor's bias, serving as a stumbling block to solutions that may be better for commercialization. The approaches described in this chapter, e.g., brainstorming sessions and solution interviews, provide a semi-structured way of moving past that stumbling block to areas of the solution space that are more viable for commercialization than the initial technology.

Although entrepreneurial texts can share some insights for reducing a new venture's risk, entrepreneurial texts cannot consider all contexts and use cases, especially as technology and consumer needs evolve. So, no entrepreneurial text or tool should ever be followed blindly. The insufficiencies of the solution interviews described by Maurya in *Running Lean* illustrate the point that when entrepreneurs, product developers, and researchers are applying any product development methodology, they need to critically think about the relevancy of that methodology within the context of what they are trying to accomplish. The solution interviews described in this dissertation generally followed the approach described by Maurya. Overall, I found the solution interviews and the solution interview exit criteria described in section 5.3.3 as a beneficial method and criteria for further defining the MVP. The solution interviews helped further define the MVP by exploring additional product features, benefits, and pricing, which can help determine a new venture's viability. However, as described in section 5.3.5, some of Maurya's guidance was not directly applicable to this dissertation and probably has limited applicability to other new ventures as well. So, as described in section 5.3.5, I adjusted the solution interview questions accordingly.

Another example is that, in *Running Lean,* Maurya describes a very narrow view for asking participants about pricing, as well as determining a pricing strategy. However, as also described in section 5.3.5, there are many ways besides Maurya's to provide rationale for anchoring a product's price. The point is, as future entrepreneurs, product developers, and researchers explore and apply different approaches, each needs to be thoughtfully and carefully considered for what is relevant to the NVT and what is not.

5.5 Contribution

The contribution from this research question is the addition of a brainstorming session between the problem interviews and the solution interviews. Many entrepreneurial texts use Customer Discovery to identify rationale from the interviews that challenges and supports the NVT's initial idea. However, including a step that tries to explore other relevant ideas for commercialization can help dislodge entrenched ideas about the product and help an NVT find an idea that may be better. In addition, a contribution from this chapter is the design and implementation of a brainstorming session specific to the Severe Problem identified in the problem interviews, with participants who experienced that Severe Problem. Based on the sessions I developed, the contribution includes a set of guidelines for developing similar sessions for other areas of product development. In addition, I demonstrated how to design and conduct solution interviews that support finding problem/solution fit and identify some initial pricing strategies. The interviews were coded and analyzed, resulting in a detailed knowledge of the risks associated with a solution that solves the end user's Severe Problem, as well as provides the beginnings of a business model that focuses on their needs.

5.6 Chapter Summary and Next Steps

In summary, I conducted brainstorming sessions, to explore many potential solutions with US Bike Parents who described the Severe Problem of helmet fit. I conducted the sessions virtually. During the sessions I described the problem they expressed during the problem interviews, and I asked if there were any additional insights they would like to share. In addition, I conducted a brainstorming session where we used the SCAMPER technique in an effort to generate and build upon each other's ideas for solving the problem of helmet fit (Ozyaprak, 2016).

From the sessions some of the ideas we devised were developing a malleable internal padding that will form to the child's head; using an inflatable bladder that inflates every time, to the shape of the rider's head; and fully inflatable head protection. After the sessions were completed, I compiled the ideas and tried to determine which solution best solves the problem, as well as which solution is the best opportunity for commercialization. From all the potential solutions, I determined that a custom fit, 3D printed helmet was still the best solution.

Product development can be an expensive and time-consuming process. To make sure I will be developing the right product, spending both time and money appropriately, it was important to demo the solution through solution interviews. The solution interviews included a low fidelity test or demo of the product, as well as asking about the most important features and benefits. In addition, the solution interviews were used to gauge pricing to understand if there was desire or actual demand for the product. During our solution interviews, additional features and benefits mentioned were a rotational acceleration technology, such as MIPS, a ratcheting mechanism for adjustment, a magnetic buckle, mountain bike style coverage, and a visor. In addition, participants said they would pay $150 for a custom fit helmet with those features. Using Customer Discovery, I identified a Severe Problem, a solution to that Severe Problem, a path for commercialization, and potential pricing. The combination of these findings are strong indicators for problem/solution fit and new venture viability. The next steps for a first principles approach are to begin initial product development which will be described in the next chapter.

Chapter 6 Initial Product Development

The previous chapter explored the application of a brainstorming method, where a solution category was identified, and a final product brief was created. This chapter explores the process of product development, creating a roadmap and determining a place to start development, with the goal of creating the product described in the brief.

Section 6.1 presents an overview of product development, highlighting its different nuances, and provides a strategy for starting. Next section 6.2 applies the product development roadmap to the product brief mentioned in the previous chapter. Then section 6.3 describes and applies the process of ideating and prototyping the product that is the subject of this dissertation, a custom fitted bicycle helmet. Section 6.4 describes and applies the process of testing and iterating for that helmet. Section 6.5 provides a discussion of the chapter, with generalizable lessons. Section 6.6 reemphasizes the contribution of this chapter and section 6.7 summarizes the chapter and describes the next steps.

Research Question 3.1: Once problem/solution fit has been found, how can initial product development begin, developing a workflow to streamline the process and provide a seamless experience for the end user from a first principles point of view?

The contribution from this research question is the addition of a product development process, applied to the product brief in the previous chapter. As described in section 1.2, companies do not always design and develop products to the problem, so it is important to link the creation of the final product to the problem that is driving product development. The product development process includes a roadmap for determining where to begin development, which is described in section 6.2.

In addition, the contribution from this research question includes the application of the product development process described in section 6.1, where an initial product development workflow was created. From the initial product development workflow, there is some supporting evidence that the solution will solve the Severe Problem of bicycle helmet fit. The workflow includes a recombination of technologies, for improved helmet fit, which are described in sections 6.2.1, 6.2.2, and 6.2.3. The recombination of technologies will result in new methods of product development for personal protective equipment. Finally, by ideating and prototyping in section 6.3, as well as testing and iterating in section 6.4, there is supporting evidence that both the workflow and final product can withstand some technical and regulatory challenges.

6.1 Product Development Overview

For those unfamiliar with product development, the process of going from a product brief to a final product can be intimidating. The purpose of this section is to provide an overview of product development, as well as highlight a few relevant development categories. The point of this chapter is that product development can be simple in some cases or complex, depending on the industry, technology, and final product. As product development increases in complexity, a general product development roadmap and process can help an NVT organize, prioritize, plan, and execute the necessary steps to go from product brief to a final product and reduce the risk of new venture failure. The goal is that future entrepreneurs, product developers, and researchers can compare the categories, determine which ones are relevant to their specific application, and create their own product development roadmap.

From my professional experience, product development is largely the process of going from the demo or product brief described in section 5.3 to a minimum viable product (MVP). The process of developing the first MVP should be done while considering final production of the product or service. In product development there is a general process of ideating, prototyping, testing, and iterating common in both engineering and industrial design (Leifer & Steinert, 2011; Norman & Verganti, 2014; Yang & El-Haik, 2009).

Ideating generally refers to the act of coming up with ideas or strategies that can be visual (drawing), digital (CAD), abstract, or specific, by means of brainstorming or TRIZ, in order to innovate or solve a problem (Dumas & Schmidt, 2015; Jonson, 2005; Yang & El-Haik, 2009). Prototyping generally refers to the creation of artifacts that can be physical (sketch, cardboard) or digital (CAD drawing, digital sketch), low fidelity or high fidelity, which represents some aspect of the final design and can be tested (Leifer & Steinert, 2011; Liou, 2019; Yang & El-Haik, 2009). Testing generally refers to an evaluation of the prototype which can include, but is not limited to user studies, component testing, and simulations (Brenner et al., 2016; Leifer & Steinert, 2011; Liou, 2019). Iterating generally refers to dropping, adjusting, or improving an idea or prototype based on testing results (Liou, 2019; Norman & Verganti, 2014; Reinecke, 2016).

Based on the specific application, there can be many variations and nuances to product development. In order to contextualize product development better, different approaches and categories of product development are described and contrasted in the following sections. Section 6.1.1 describes that the key differences of product development processes are the rate at which a product development team cycles through ideate, prototype, test, and iterate, as well as the effectiveness at which they complete each step. In section 6.1.2, radical innovation is compared to human centered design. Next in section 6.1.3, physical products are compared to digital products. Then section 6.1.4 describes the challenges of navigating different approaches and terminology used in product development. Section 6.1.5 describes an overview for creating a product development roadmap. Finally, section 6.1.6 describes an approach to product development specific to this dissertation, through the lenses of radical innovation, human centered design, physical products, digital products, as well as lays out a product development roadmap, highlighting a starting point.

6.1.1 Rate of Innovation and Production/Production Capability

As described in section 6.1, there is a general product development process of ideating, prototyping, testing, and iterating. However, there are other product development processes such as continuous deployment described by Maurya, Blank, and Dorf, or the waterfall model described by Blank and Dorf. Regardless of the exact product development process used, there are similarities and overlaps between the three. The key difference between the three is the rate and effectiveness at which the NVT can cycle through the steps, soliciting feedback from key stakeholders to direct product development, and bring the final product or service to market.

The rate at which the product development team cycles through the process can vary in the length of time they spend on each step, amount, and quality of feedback they determine is necessary, as well as the effort that is put into making updates. The rate at which the NVT cycles through the steps, advancing a technology, can also be referred to as the pace of innovation (Kessler & Chakrabarti, 1996; Tang et al., 2020). The pace of innovation will most likely be directed by the final product or service, as the type of product or service influences manufacturing, sourcing, logistics, and distribution. A faster pace of innovation will most likely be more in line with digital products, whereas a slower pace of innovation will most likely be in line with physical products.

For product development, another important consideration is the effectiveness at which the NVT cycles through the process and “solves problems, maximizes opportunities, and continually learn” (Covey, 1990, 52). The concept of effectiveness is also known as production/production capability (Covey, 1990). True effectiveness is the balance between the final product or service that is created, as well as the ability, asset, or team that produces the final product or service (Covey, 1990). If the NVT has a fast pace of innovation but damages the equipment that produces the final product or burns out the NVT, there may be an increased risk of failure.

Both the pace of innovation and production/production capability can be a competitive advantage for the NVT. In addition, it is important for the NVT to critically assess product development methodologies described in entrepreneurial texts. Although there can be valuable perspectives in each text, there are also biases. One of the most obvious biases being the focus of product development methodologies specific to digital products in entrepreneurial texts such as *Running Lean* and *The Startup Owner’s Manual*.

6.1.2 Radical Innovation Compared to Human Centered Design

One way to segment product development categories is to compare radical innovation to human centered design (HCD) (Norman & Verganti, 2014). Radical innovation is largely driven by technological advancement and does not necessarily require market research or user studies (Norman & Verganti, 2014). In comparison, HCD focuses on understanding the end user and designing the overall user experience (Norman & Verganti, 2014). It should be noted that products can have elements of both radical innovation and HCD. For example, when developing an electric car, new engineering and manufacturing innovations may be required (radical innovation), however, both the driver and passenger experiences are also critical (HCD) to product development.

In relation to this dissertation, as stated in the research question the goal is to figure out how to *develop a workflow that streamlines the process* (radical innovation) and *provide a seamless experience for the end user* (HCD). Compared to traditional off shored injection molded manufacturing methods for bicycle helmets, using additive manufacturing for customized personal protective equipment in localized production can be considered radical innovation. Also, as stated at the beginning of the research question, the goal is to *begin* product development, which requires finding a starting point. So, the focus of this chapter will be initial product development, which begins with technological advancements that directly contribute to developing a workflow and streamlining the process. With the exception of some initial 3D scanning, additional product development that focuses on HCD in order to *provide a seamless experience for the end user* is beyond the scope of this dissertation due to time restraints for product development.

For a new technology that is not widely developed, adopted, or may be new to the new venture team (NVT), every step in technological development can be perceived as a challenge with varying levels of uncertainty. Sometimes the NVT can problem solve technological challenges and other times they cannot. The runway for the NVT to overcome a technological challenge is often tied to how quickly they spend capital reserves, also known as burn rate (Barringer & Ireland, 2016).

A highly publicized example of an entrepreneur who was unable to overcome a particular technological challenge in product development is Elon Musk and Tesla. In 2016, Musk promised that new Tesla vehicles would have level 5 autonomy (Barry, 2021; Tangermann, 2023). Since that promise, Tesla has launched new car models and built Gigafactories (DeBord, 2020). Many of those projects experienced delays due to technical challenges (Lambert, 2022). The product development that went into those accomplishments could also be considered radical innovation. However, as of 2022 none of Tesla’s vehicles or any other vehicles in the world have reached level 5 autonomy (Baca, 2022). The point is, whether it is Tesla or some other new venture on the cutting edge of a technology, every step in technological development can be perceived as a challenge with varying levels of uncertainty. Similar to the way Tesla has been unable to overcome the technical challenges associated with level 5 autonomy, an NVT in another industry may or may not be able to overcome their particular technical challenges.

As a doctoral student who is writing this dissertation, where the goal of my studies is to launch a new venture, there are more days where the new venture seems impossible than possible. Technical challenges are one of the many contributors to the days where launching a new venture seems impossible. Following the guidelines for product development in this dissertation, or any other resource does not ensure success. Rather, the goal for applying the methods described in this dissertation or methods described by other sources is to solicit feedback and expertise, to reduce the possibility of new venture failure**.**

6.1.3 Physical Products Compared to Digital Products

Another way to segment product development categories is to compare physical products to digital products. Depending on the type of product, physical or digital, it can influence the complexities of development. A base knowledge of a product's complexity can help an NVT organize, prioritize, plan, and execute the steps needed to go from product brief to a final product. Physical products generally refer to tangible objects that are designed, developed, and sold to consumers. Some examples of physical products can include clothing, an airplane, or a dog bowl. In comparison, digital products generally refer to intangible objects that only exist digitally and can be experienced through a screen. Some examples of digital products can include apps or software.

For physical products, the complexity of the product can influence the complexity of the product development process. For example, developing an airplane is generally considered to be more difficult than developing a dog bowl. Product development for the airplane would most likely include problem solving aeronautics, aerodynamics, designing the cabin, electronics development, assembly, FAA regulations, and repair, just to name a few challenges. In contrast, for the dog bowl, it may be as easy as designing a circular dish in a 3D rendering software, picking a plastic material, and sending the designs to a manufacturer.

From my professional experience when developing physical products lead times were typically two years. Lead times refer to the amount of time it takes for a product brief to become a physical object sitting on a shelf in a store. In product development, for something such as an airplane the product development process could be years. However, for something such as a dog bowl the product development process could be months.

In comparison, for digital products the complexity of the product can also influence the complexity of the product development process. However, digital products do not necessarily engage with concerns such as sourcing, manufacturing, and distribution, in the same degree that physical products do. When comparing physical and digital products, *In the Startup Owner's Manual,* Blank and Dorf describe that for digital startups the "product development time is far shorter and feedback comes far faster" (Blank & Dorf, 2012, 190). So, product development for digital products can be considered to have shorter lead times when compared to physical products.

For example, developing a digital product could be as simple as using a visual programming language to create an app for food enthusiasts. The app could connect food enthusiasts with each other, share recipes, and source local ingredients. When going from product brief to the final product it could be a matter of days, or even hours before the app is available to download.

6.1.4 Other Product Development Considerations

As mentioned in section 6.1, there is a general product development process of ideating, prototyping, testing, and iterating found in both engineering and industrial design. However, there can be variations of these steps in both engineering and industrial design, and navigating those variations can be challenging. In addition, there can be variations of these steps between industries and the personnel who execute the steps. From my professional experience, some personnel follow regimented product development methodologies, others rely on their industry experience, while some rely on the expertise of their industry partners. There can be other approaches and variations to those approaches. From my experience, approaches to product development can be contradictory, even from experts in similar fields. Navigating different product development steps can be challenging. An NVT's ability to identify and address these challenges will directly relate to their ability to launch a new venture.

Another challenge in product development is variation in terminology. For example, in industrial design the word *design* can refer to the function, usability, experience, or aesthetic of a product or service that is being created (Woelfel et al., 2013). Whereas, in engineering the word *design* can refer to mathematical, material, and technological development of a product or service, with less of a focus on the user experience (Woelfel et al., 2013). However, it should be noted there can be overlap between industrial designers' and engineers' use of the word *design* (Woelfel et al., 2013).

The variation in terminology between disciplines has presented communication challenges in both my professional experience, as well as my interdisciplinary PhD program. An entrepreneur's personal perspective on the terminology may or may not be correct, and they may be within their rights to argue about semantics and cause friction between themselves and others. Or they can make an effort to see the situation from other people's perspectives in order to communicate, collaborate, and delegate more effectively.

The point is that an entrepreneur's role is to make an effort to see a situation from another's perspective, whether in seeing the product from the perspective of a potential customer or in seeing the development process from the perspective of a potential product development partner. Seeing the situation from a potential product development partner's perspective may result in adjusting the terminology that an entrepreneur uses, developing a shared terminology, or training others to use a new terminology. Effective communication and using a common language are aspects of doing challenging things with people. It should be noted that making an effort to see a situation from another's perspective does not mean an entrepreneur must pander or cater to everyone's needs. Rather, an entrepreneur must find a balance, which is another challenging aspect of trying to launch a new venture.

6.1.5 Creating a Product Development Roadmap

Regardless of the category of product development, the NVT will need some type of product development roadmap. A product development roadmap generally refers to a plan or the anticipated steps needed to develop a new technology or go from the product brief to a finished product (Münch et al., 2019). For technical and capital-intensive products, prioritizing the technical challenges of development through a roadmap can help align the team on the work needed for development (Münch et al., 2019). Once a roadmap has been developed, as the NVT progresses in product development, the roadmap is expected to change and be updated.

Regardless of the specific roadmap that the NVT lays out, product development is a continually iterative process of soliciting feedback, executing, soliciting feedback, adjusting, until relevant key stakeholders agree the product or service is ready for market. Specific to this dissertation, the roadmap was developed in my ME 5644 course. For the final project, our project team identified the steps needed for product development, as will be described in section 6.2. Then, a more detailed roadmap was developed for the Link, License, and Launch Proof of Concept Funding with specific milestones and a timeline (Proof of Concept Grant, 2023).

6.1.6 Understanding Product Development Described in this Dissertation

For the product development specific to this dissertation the goal is to design and develop a custom-fit, additively manufactured helmet. The decision about how to begin developing the helmet took into consideration several of the factors described earlier in this section. The pace of innovation and production/production capability (section 6.1.1) are important considerations when cycling through the steps ideate, prototype, test, and iterate. The amount of product development conducted through this doctoral program has been limited, as there have been constraints with classes, funding expectations outside of research, and dissertation writing. With those limitations in mind, it was difficult for the product development teams that I have worked with throughout this dissertation to cycle through the process quickly or effectively.

When designing and developing such a helmet, the process can be both radical innovation and HCD (section 6.1.2). Product development in this dissertation falls under radical innovation, because there is a process of manufacturing the helmet that needs to be developed. Product development also falls under HCD as there are equally important considerations needed for usability, aesthetics, and the overall user experience. There can be both physical and digital components to the product development process (section 6.1.3). For a custom-fit, additively manufactured helmet, the product development process is physical because it is a tangible object, with specific manufacturing and sourcing needs. The product development process is also digital as it includes scanning the end user's head, as well as optimizing digital processes such as editing the scan and creating the mesostructure.

One other consideration was that a roadmap (section 6.1.5) can be a useful tool when developing a new product or service. For this dissertation, the roadmap was separated into three categories. The first category was fit, which involves surface generation. The second category was protection, which involves mesostructure design. The third category was a design feedback loop, which involves exploring methods for mesostructure evaluation and selection. Each category will be described further in section 6.2.

With these considerations in mind, to determine a starting point for product development, I asked, "What is expected to be the largest technical hurdle with the longest lead time?" The reason for asking this question was, if the NVT cannot get past the largest technical hurdle, it does not necessarily make sense to pursue the other components of product development. Specific to fit, protection, and an evaluation feedback loop, the product development focus was on the second category, protection. The primary reason for focusing on protection was, if we cannot get past the technical hurdle of designing a mesostructure that can pass the CPSC impact attenuation test, which is the regulatory body for bicycle helmets, it does not make sense to pursue additional product development (CPSC, 1998).

A secondary reason we focused on protection was because production of the mesostructure is directly related to the manufacturing process. Traditionally, when producing bicycle helmets the central focus of the manufacturing process is the foam injection molded impact mitigating liner. Historically, when introducing new technologies for bicycle helmets, such as MIPS, Koroyd, and WaveCel, they are integrated into that assembly line. However, when using additive manufacturing for production, the manufacturing process has fundamentally shifted and new variables have been introduced, which creates uncertainty for manufacturing. So, the focus was on the second category protection, because if we cannot develop a 3D printed mesosturcture using an additive manufacturing process with consistent part quality, we will not be able to manufacture a custom-fit 3D printed helmet.

Section 6.2 describes a product development roadmap specific to this dissertation. Section 6.3 specifically describes ideating and prototyping by coming up with design strategies and creating lattice structures. Then section 6.4 describes testing and iterating, where the designs were impact tested, then we iterated by transitioning impact testing from a design focus to production focus. The concept of transitioning from a design focus to a production focus will be described further in section 6.4. Normally, iterating might refer to adjusting the mesostructure designs based on impact testing results, however, because there were issues with production, iterating in this specific application was a much more drastic change.

It should be noted that determining a starting point for product development was my best guess, based on my experience and education, in collaboration with our project team. The challenge with doing anything new is that “you don’t know what you don’t know” and there will be unexpected technical hurdles along the way. The NVT’s ability to creatively problem solve hurdles can be the difference between success and failure for the new venture. If the NVT does not have the technical competency to create the product or service, it is the team’s responsibility to onboard new talent and delegate to those who can.

6.2 Product Development Roadmap Applied to This Dissertation

As mentioned in the previous chapter, the Customer Discovery interviews were categorized through a formal coding process. From that coding process, a final product brief was created. It should be noted that in a perfect world the product brief would be completed before any initial product development. However, as mentioned in section 2.4, the product development conducted in this dissertation is a part of a framework and not a step-by-step process. In addition, when creating a product development roadmap there could be multiple approaches that could be correct.

The product brief in this dissertation included the use of additive manufacturing for personalized fit. A product development roadmap was created which has physical and digital components and can be considered radical innovation and HCD. The product development roadmap was broken down into three categories. The first category was fit, which involves surface generation. The second category was protection, which involves mesostructure design. The third category was a design feedback loop, which involves exploring methods for mesostructure evaluation and selection. A visual representation of the initial product development roadmap is shown in Figure 6.1:

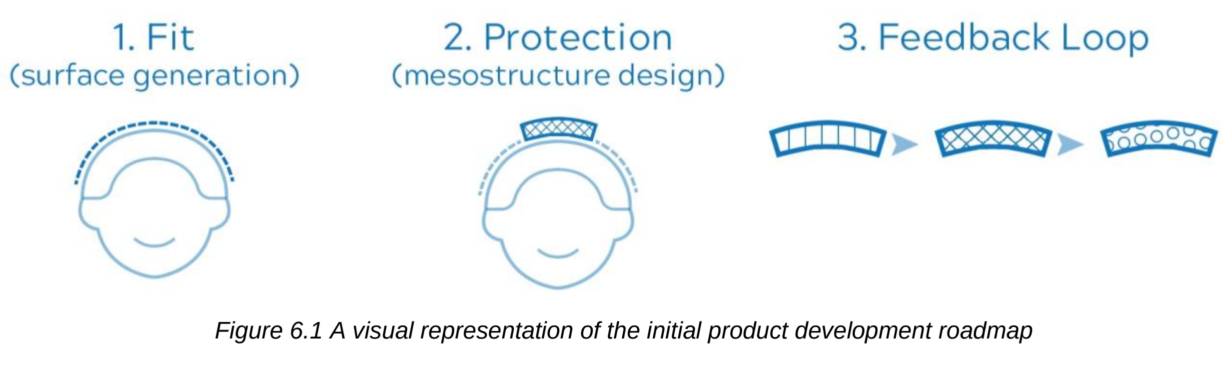


Figure 6.1 A visual representation of the initial product development roadmap

6.2.1 Designing for Fit

The helmet size and head shape are two of the driving components for helmet fit (Thai, McIntosh, & Pang, 2014). So, a process for collecting head size and shape measurements for a custom fit was needed. The first part in the process was to collect anthropometric scan data from which to generate a 3D surface, as shown in Figure 6.1. For surface generation, two techniques were explored, 3D scanning and photogrammetry. 3D scanning was chosen due to its ability to generate a high-quality 3D image. Photogrammetry was chosen for its accessibility to the end user, as photogrammetry can produce scan data with just a smart phone and no additional equipment.

6.2.2 Designing for Protection

The material that reduces peak linear acceleration (PLA) is the driving component for protection (Mills & Gilchrist, 2006). So, the second part of the process involved designing mesostructures that would reduce PLA in a dynamic loading scenario. Historically, Expanded Polystyrene (EPS) has been the most commonly used material for bicycle helmets to reduce PLA to the brain in the event of a crash (Bhudolia et al., 2021). Due to the material's ability to reduce PLA, it is still commonly used (Kroeker et al., 2020; Mills, 1990).

In 2014, Smith Helmets introduced the Overtake (Patterson, 2014). The Overtake's helmet liner was a combination of EPS and a material called Koroyd, an extruded thermoplastic structure (Bland, Zuby, et al., 2018; Gokhale, 2016). In 2019, Bontrager released the next iteration of structure-based helmets with the introduction of WaveCel (Turman, 2020). WaveCel helmets are a combination of both EPS and Wavecel, a stacked origami thermoplastic structure (Bliven et al., 2019; Harris, 2017). WaveCel is a more complex structure than Koroyd and reduces both PLA and rotational acceleration (Bliven et al., 2019). In 2021, Hexr's additively manufactured hexagonal helmet, is one of the most recent iteration of helmets with thermoplastic structures (Jafferson & Pattanashetti, 2021). Despite the developments in both design and manufacturing technologies, the safest commercially available bicycle helmets as of February 16th, 2023 are entirely EPS based helmets according to Virginia Tech's Helmet Ratings (Virginia Tech Bicycle Helmet Ratings, 2023). However, the one exception is the Bontrager Specter WaveCel helmet, just making the top 30 (Virginia Tech Bicycle Helmet Ratings, 2023).

As stated in Chapter 4, the goal of designing additively manufactured structures was not necessarily to produce a "safer" helmet. Rather, the use of additive manufacturing was to create a better fitting helmet, which can be difficult with traditional injection molded foam helmets. For this dissertation, the primary focus for product development has been mesostructure design. The three different mesostructure design strategies are described in section 6.3.

6.2.3 Exploring a Feedback Loop for Mesostructure Selection

The third part of the process involved exploring a feedback loop for mesostructure selection, in an effort to determine what geometries are best suited for reducing PLA. Due to the limiting nature of printing and impact testing every conceivable design, additional analysis methods for down selection, namely static and dynamic finite element analysis (FEA) were explored. Ideally, some combination of static FEA, dynamic FEA, and impact testing will direct the iterating process. The goal is that FEA simulation could be verified using impact testing to predict the performance of future iterations. Ideally, a correlation between FEA simulation and impact testing should guide mesostructure design for future tests to progressively and iteratively achieve better results.

For my additive manufacturing course, ME 5644, our project team conducted some initial explorations in both static and dynamic FEA. For static FEA, the team used nTopology's built in FEA tool, to measure the pressure and stress the test coupon experienced (nTopology, 2021). However, the correlation between static FEA and the material's ability to reduce PLA in impact testing was unclear. For dynamic FEA the team attempted to use the FEA modeling software Abaqus. However, there were challenges with the number of elements being used, as well as modeling breaking mechanics in the program. As a result, the dynamic simulations were also inconclusive.

Ultimately, the complexity of the mesostructures were too computationally intensive for both static and dynamic FEA to produce any meaningful results. Due to the current limitations of both static and dynamic simulation, impact testing was used to assess material performance. Results from the impact testing will direct future mesostructure development.

6.3 Ideating and Prototyping for Step 2: Designing for Protection

Section 6.1.6 described how the second step, designing for protection, was considered to be the largest technical hurdle, so it has been the starting point for product development. The purpose of this section is to describe the application of ideating and prototyping, specifically applied to the second step of designing for protection.

Sections 6.3.1 to 6.3.4 describe how we ideated, meaning the project team brainstormed design strategies, as well as created designs based on those strategies using the latticing software nTopology (nTopology, 2021). Those sections also describe how we prototyped, meaning the project team printed the test coupons. The test coupons can be considered a prototype because they represent a component of the final product. However, it should be noted that with digital design tools and additive manufacturing the lines between ideating, prototyping, and production can become blurred, as the tools used for prototyping may also be the tools used for production. Figure 6.2 shows the step of designing for protection, highlighting the subsequent strategies for ideating and prototyping when designing mesostructures.

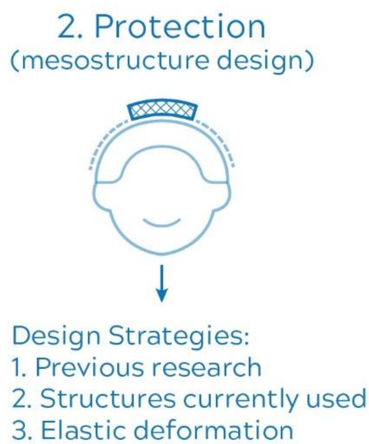


Figure 6.2 The second step, design for protection, which includes the design strategies used for creating the mesostructures

For the designing for protection step, I explored three design strategies for initial product development, which are shown in Figure 6.2 and will be described further in sections 6.3.1, 6.3.2, and 6.3.3. The three design strategies were, 1.) designing structures using previous research; 2.) reverse engineering structures currently used on the market; and 3.) designing structures that allow for elastic deformation. In an effort to remove variables in testing, all of the test coupons were designed using the same base curvature. In practice, the same base curvature means I scanned ISO headform A, one of the ISO headforms used in the CPSC helmet testing standard (CPSC, 1998). Then I used the digital curvature from the headform scan as the basis for each test coupon. The reason that I used headform A, as opposed to the other ISO headforms was headform A is the smallest ISO headform and generally resembles the size of a toddler's head, which is the group of end users I am targeting for product development.

Another reason for using the same curvature from ISO headform A is that it can improve the design's impact mitigating characteristics. A matching curvature between the test coupon and the headform maximizes the amount of contact area for the least amount of stress. From left to right, Figure 6.3 shows ISO headform A, the resulting scan, and finally a 3D print from the scan to see how well the scanned curvature interfaces with the headform. Then I was able to apply Conformal Lattices to the resulting scan of ISO headform A.

Figure 6.3 From left to right, ISO headform A, the resulting scan, and a 3D print from the scan

Finally, when designing the lattice structures, material selection was another important consideration. We initially used PA12 because that was the material that was available at the DREAMS Lab. In addition, some of the parts were printed in PA11 because that was a material that the 3D printed bicycle helmet company Hexr was using (Our Manufacturing Process, 2023).

As I was determining which contract manufacturers and printing companies to use, I would often speak with their in-house engineers, describe the project, and ask if they had any material recommendations. Often, they would recommend PA12 because it was usually less expensive than PA11 and from their perspective had similar material properties to PA11. A few times companies were so confident in PA12 they would even print the parts for free. However, every time the PA12 parts were impact tested, they always performed poorly compared to PA11. Navigating which materials to use was challenging. It was also challenging to draw clear conclusions from the material data sheets about material performance during impact testing.

6.3.1 Design Strategy: Prior Research

For the first design strategy we consulted prior research by looking at the force displacement of various structures as a correlate for reducing peak linear acceleration (PLA). Specifically, Type 1 (circular) and Type 2 (diamond) structures were examined as shown in Figure 6.4 (Calladine & English, 1984). Type 1 structures generally have a lower peak force and can absorb more energy than Type 2 structures (Harris, 2017). However, it is possible for Type 2 structures to have greater energy absorption than Type 1 structures, but when a Type 2 structures does absorb more energy than a Type 1 structure, it can also have a greater peak force (Harris, 2017). Due to the Type 1 structures generally having a lower peak force, it was anticipated that they would be better at reducing peak linear acceleration. Regardless of the specific properties of Type 1 and Type 2 structures, "both must be considered in the design of protective structures" (Harris, 2017, 9). While absorbing more energy is generally a desirable property for a bicycle helmet, greater energy absorption cannot come at the expense of exceeding the peak linear acceleration limits of the helmet testing standard.

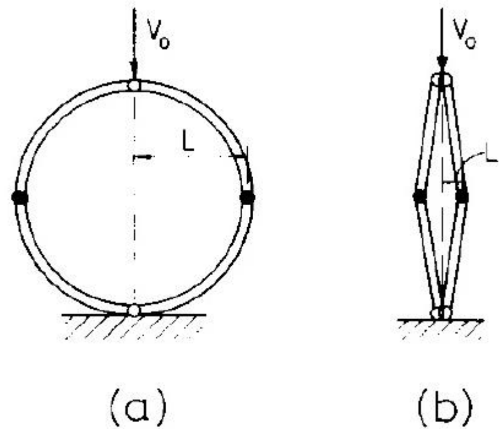
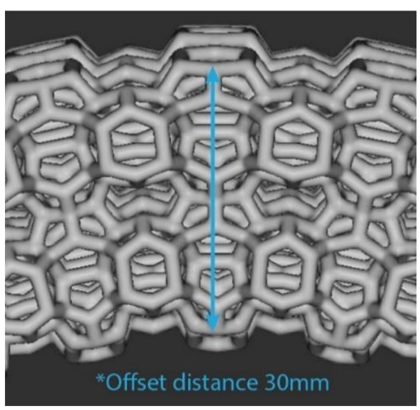


Figure 6.4 a) Type I (circular) and b) Type II (diamond) structures, used with permission from Elsevier

To design the mesostructures, we used the latticing and topology optimization software nTopology (nTopology, 2021). In nTopology, they have twenty-four preset unit types. Our goal for mesostructure design was to represent the Type 1 and Type 2 structures, using the available unit types and tools, as shown in Figure 6.5. We adjusted the unit types using the UVW Divisions and Thickness tools. When making our adjustments to the designs we tried to keep the mass for each design as close to 36 grams as possible, with a Printed Part Density of 0.00102 g/mm^3. However, there was some difficulty keeping the mass equal between all designs. Also, there was some inconsistency between the mass that nTopology projected and the final printed part. For all the test coupons we gave them all the same offset distance of 30mm. The offset distance is the distance from the initial scan of ISO headform A, as shown in Figure 6.5.

a) 

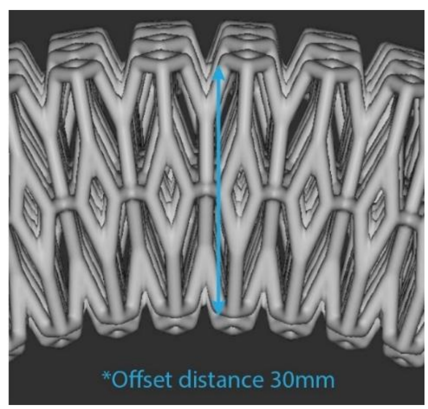
b) 

Figure 6.5 Representations of a) Type 1 structure using a Weaire-Phelen unit type, b) Type 2 structure using a Kelvin unit type

From the same research, Harris describes the potential benefits of functionally graded materials for impact protection (Harris, 2017). However, there is some competing literature as to the benefits of graded structures compared to uniform structures of equal mass (Harris, 2017). To explore the potential advantages and disadvantages of graded structures compared to uniform structures, we incorporated thickness gradients into some of the mesostructure designs. Thickness gradients were applied to the designs by leveraging nTopology's field-driven design, using the Ramp Block. The Ramp Block gives the mesostructure a gradient that starts out thin at the interior (side closest to the wearer’s head) and thickens at the exterior of the test coupon. Digital renderings of the mesostructures with thickness gradients are shown in Figure 6.6.

a) b)

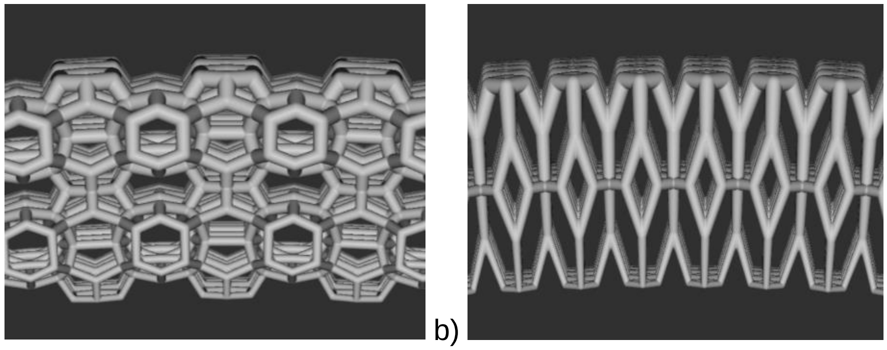


Figure 6.6 Thickness-graded mesostructures for test coupons a) Weaire-Phelan unit type, b) Elongated Kelvin unit type

6.3.2 Design Strategy: Structures Currently Used

The second design strategy focused on mesostructures currently being used on the market. For mesostructures currently being used on the market, we started with Hexr’s hexagonal pattern and iterated from a visual assessment of the design. In the latticing software nTopology there is a Hexagonal Honeycomb unit type, which is similar to Hexr’s hexagonal cell. In nTopology, we manipulated the unit type through cell wall thickness and UVW Divisions. A digital recreation of Hexr’s hexagonal pattern using nTopology’s Hexagonal Honeycomb unit type is shown in Figure 6.7.

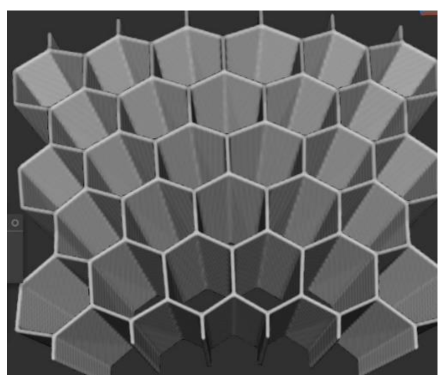


Figure 6.7 Digital recreation of Hexr’s Hexagonal geometry using nTopology’s Hexagonal Honeycomb unit type

On Hexr’s website, the impact mitigating qualities of the helmet are attributed to the “hexagonal cells in a honeycomb structure” (How a HEXR Is Made, 2023). In nTopology, there are other honeycomb units, so we explored the Square Honeycomb unit to compare performance between the hexagonal unit type and the square unit type. The Square Honeycomb unit is shown in Figure 6.8.

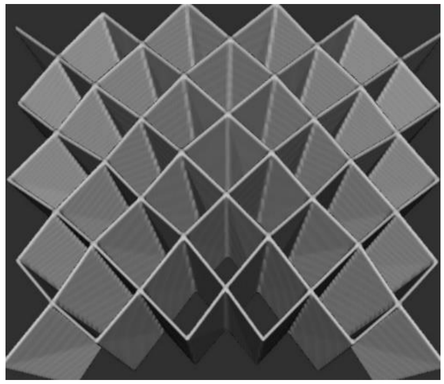


Figure 6.8 Iteration of the honeycomb design, using the Square Honeycomb unit type

Both the Hexagonal Honeycomb and Square Honeycomb unit types are connected columns defined by a singular shape, the hexagon or the square. By impact testing the different honeycomb shapes, we can determine whether or not there are design advantages to each. Similar to the Type 1 and Type 2 design strategy, thickness gradients were incorporated into the designs using nTopology's Ramp Block. Other similarities between the designs included the same offset distance of 30mm and the same target weight of 36 grams.

6.3.3 Design Strategy: Elastic Deformation

The third design strategy focused on stock geometries in nTopology that have qualities for elastic deformation. In nTopology, the Body Centered Cubic unit type had a similar square cellular structure to the Square Honeycomb unit type. However, the Body Centered Cubic unit type also incorporated a lattice within the cell wall, as shown in Figure 6.9.

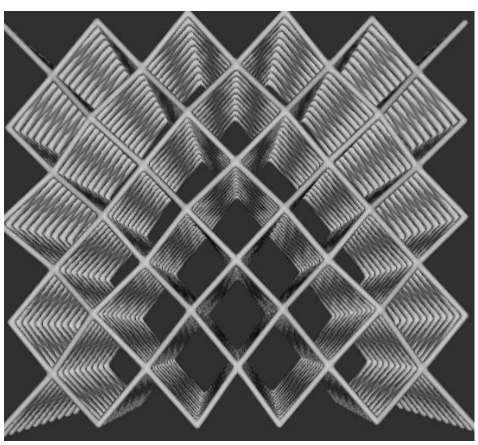
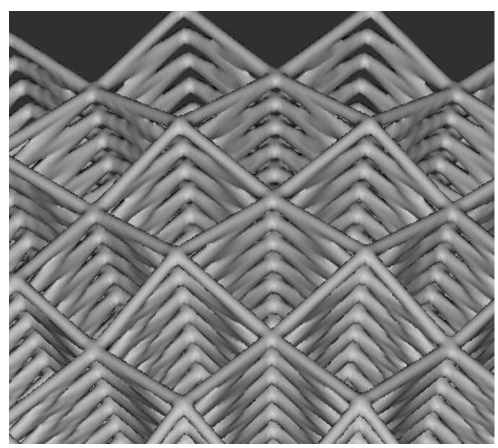
a)  b) 

Figure 6.9 a) Iteration of the Square Honeycomb unit type, using the Body Centered Cubic unit type, b) A close up of the Body Centered Cubic unit type highlighting the lattice within the cell wall

The Body Centered Cubic unit type could be considered a Type 2 structure, however, it is unclear how closely the internal geometry should reflect the diamond structure in Figure 6.4, to be considered as such. We anticipated the lattice within the cell wall would allow for some elastic deformation during an impact. Additional design explorations within this design strategy included variations in UVW Divisions and strut thickness for the Body Centered Cubic unit type. Similar to the previous design strategies, thickness gradients were incorporated into the designs using nTopology's Ramp Block. Other similarities between the designs included the same offset distance of 30mm and similar target weights.

6.3.4 Design Limitations

It should be noted that there were design limitations when creating the mesostructures. The most notable limitation is the number of unit types available in nTopology. For the first design strategy, when designing the Type 1 structure, there was no circular unit type available, so we tried to make the structure as circular as possible within the limitations of the software.

For the second design strategy, there were also design limitations. The first limitation was we did not have a Hexr helmet available to measure the size of the columns and wall thicknesses. The second limitation was other thermoplastic structures are currently available on the market, such as Koroyd and WaveCel, but nTopology had no similar unit types to base a design on. So, we did not design or test similar structures.

6.4 Testing and Iterating Overview

This section describes the cycle of testing and iterating on the prototype mesostructure designs of section 6.3. As described in section 6.1, there is a general product development process of ideating, prototyping, testing, and iterating. Section 6.4.1 describes the initial round of impact testing of the test coupons for the designs created in section 6.3. At a certain point, these initial test coupons started to perform inconsistently, so section 6.4.3 describes how we iterated, meaning we stopped impact testing parts to evaluate design strategies and instead started impact testing parts to evaluate production methods, where six companies printed the same part, and we impact tested those parts.

6.4.1 Phase 1 Impact Testing

For this section we tested, meaning the project team impact tested the designs created in sections 6.3.1 to 6.3.3 to evaluate the performance of the designs. For impact testing we started with an impact velocity of 3.1m/s. The reason for the impact velocity was the test coupons were experimental and as the metal headform collides with the anvil, it was possible to damage the equipment. Then, as I moved to subsequent phases of testing, I iteratively increased the impact velocity to 4.8m/s, 5.5m/s, and finally 6.2m/s, which is the CPSC impact velocity for the flat anvil (CPSC, 1998). Initially, impact testing focused on evaluating part performance based on the three design strategies mentioned in section 6.3.

Phase 1 impact testing was funded through a SEAD Grant awarded from Virginia Tech's Institute of Creativity, Arts, and Technology. The product team included graduate students Dominic LoPinto, Dr. Emily Kieffer, and myself. With the funding we tested a total of 14 different designs and 37 test coupons.

As mentioned in section 6.3, our first design strategy was to focus on prior research, specifically, trying to reproduce Type 1 (circular) and Type 2 (diamond) structures for reducing PLA. Our second design strategy was to focus on mesostructures currently being used on the market. Our third design strategy was to focus on stock geometries in nTopology that have qualities for elastic deformation. Test parts were printed in both nylon materials PA11 and PA12.

Our impact testing questions were:

- How do Type 1 structures compare to Type 2 structures when reducing peak linear acceleration?

- How do structures with thickness gradients compare to structures without thickness gradients when reducing peak linear acceleration?
- How do hexagonal unit types compare to square unit types when reducing peak linear acceleration?
- How do structures with elastic properties compare to structures without elastic properties when reducing peak linear acceleration?
- How does PA11 compare to PA12 when reducing peak linear acceleration?

6.4.2 Testing Results and Discussion

After impact testing and measuring the PLA values, the parts were assessed visually and rated on a qualitative scale. The qualitative scale included four grades, each representing the amount of deformation they experienced during the impact, as shown below in Figure 6.10. After reviewing the high-speed footage of the impacts, Virginia Tech Helmet Lab Technician, Ethan Harris developed the rating scale with feedback from Dr. Steve Rowson, director of the Virginia Tech Helmet Lab. The first grade, which is shown in green, represented test coupons that experienced no break (plastic deformation) and some elastic deformation. The second grade, which is shown in light green, represented test coupons that experienced no break (plastic deformation) with very little elastic deformation. The third grade, which is shown in yellow, represented test coupons that experienced partial break (plastic deformation), as well as moderate elastic deformation. The fourth grade, which is shown in red, represented test coupons that experienced total failure, meaning they completely shattered. In Figure 6.10, the asterisks next to the sample IDs represent parts that were damaged during printing.

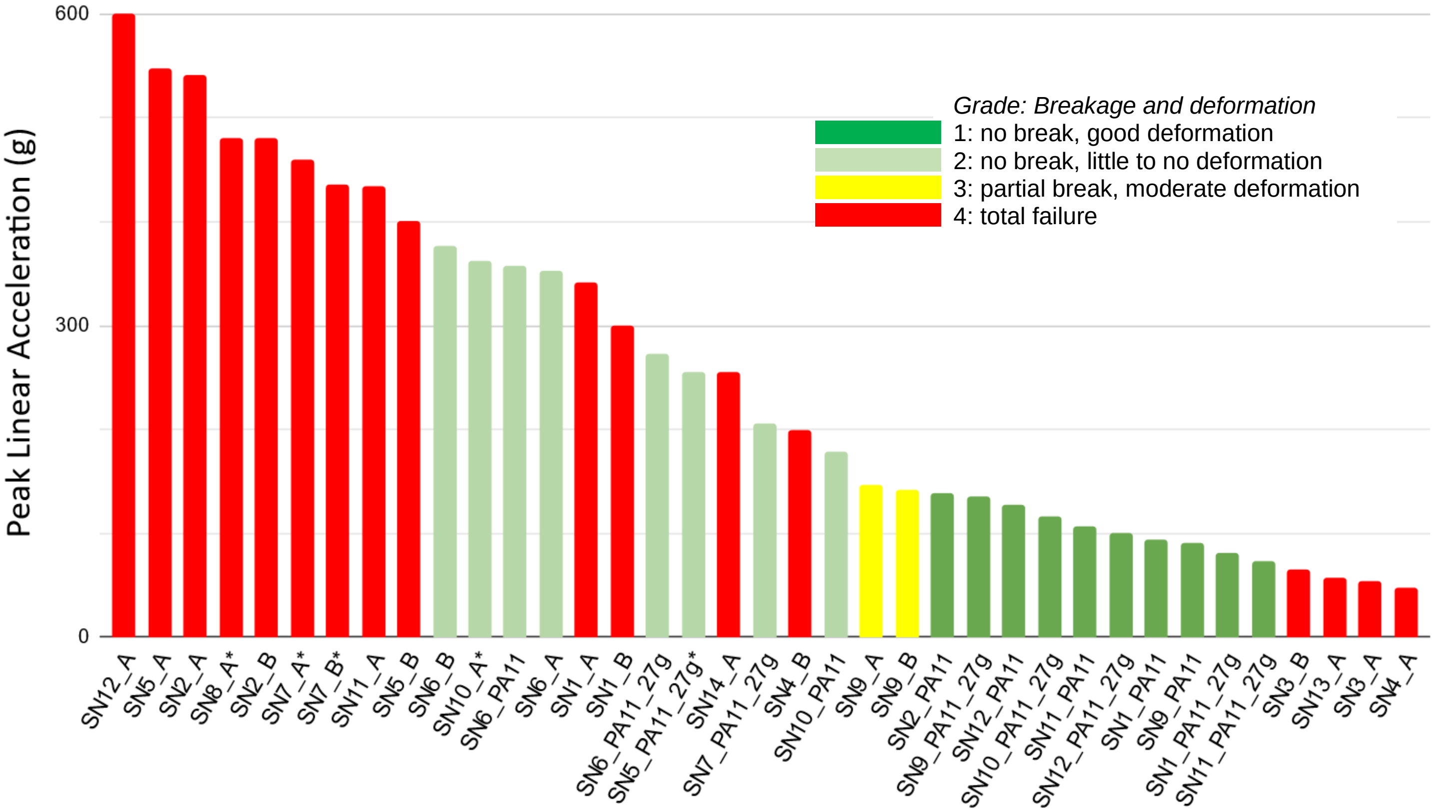


Figure 6.10 Results from Phase 1 testing, comparing the peak linear acceleration values to the type of deformation the test coupon experienced during the impact as well as the plastic and elastic behavior of the material. (Green: no plastic deformation, some elastic deformation. Light green: no plastic deformation, very little elastic deformation. Yellow: plastic deformation, moderate elastic deformation. Red: total material failure)

As per the CPSC Safety Standard for Bicycle Helmets, PLA values cannot exceed 300g (CPSC, 1998). So, a combination of the grade the part received, as well as its acceleration value, determined whether or not that part would make it to the next round of testing. In an effort to err on the side of caution, only test coupons that were Grade 1 made it to the next phase of impact testing at 4.8m/s. It is assumed that as the impact velocity increases, both the PLA values and deformation (elastic and plastic) will increase as well.

The ten test coupons that received a Grade 1 and had PLA values below 300g, were all made of PA11 and experienced elastic deformation through a combination of the material and geometry. Of those ten test coupons, 7 of the 10 had cellular structures with an internal lattice; 5 of the 10 had a thickness gradient and the other 5 of the 10 did not have a thickness gradient. None of the Type 1 designs (circular) received a Grade 1 and had a PLA value below 300g. As stated earlier there were no circular unit types available, which may be the reason for the poor performance. Also, none of the Hexagonal Honeycomb and Square Honeycomb designs received a Grade 1 and had a PLA value below 300g. The Hexagonal Honeycomb and Square Honeycomb designs were based upon Hexr’s Hexagonal geometry. The poor performance of the honeycomb designs may be due to my crude attempt at visually trying to reverse engineer Hexr’s Hexagonal geometry.

From the Phase 1 testing results it was difficult to draw clear conclusions. The reason it was difficult to draw clear conclusions was that the goal was not necessarily to determine performance characteristics at 3.1m/s, but rather at 6.2m/s. So, it is unclear how part performance will change as the impact velocity increases.

Additional phases of impact testing were conducted at 4.8m/s, 5.5m/s, and 6.2m/s, with the purpose of evaluating the design strategies described in section 6.3. Unfortunately, during impact testing parts began performing inconsistently and shattering, which I attributed to issues with production. As mentioned in section 6.1.2, when developing a new technology, each technological hurdle can be perceived with varying levels of uncertainty. Success is not guaranteed, and failure can seem like the norm. It is not possible to anticipate all the potential types of failures and ways to avoid them in advance. A product development process must be flexible enough to deal with unexpected failures. As an example, for section 6.4.1, I assumed that the manufacturer was printing quality parts, but I was wrong. In response, we iterated, normally iterating might mean adjusting the mesotructure designs. However, in this case, because of the production issues, I shifted impact testing from a design focus to a production focus, which will be described further in the next section.

6.4.3 Iterating and Proof of Concept Funding Phase 1 Impact Testing

This section describes how we iterated, meaning based on the testing results, we stopped what we were doing and changed directions. Specific to this dissertation, we stopped impact testing parts to better understand design strategies and we started impact testing parts to evaluate company's production methods. In practice, evaluating production methods meant I reached out to seven manufacturers, five contract manufacturers, and four regional manufacturers, all with powder bed fusion capabilities or similar technologies. Three contract manufacturers and three printing companies were willing to print parts.

For each company, I sent them the same file, with the same geometry. Each company used powder bed fusion or similar technologies to print the parts in PA11. The parts were printed in PA11 because, as described in section 6.4.2, those were the only parts that received a Grade 1 and had a PLA under 300g. The printing companies and contract manufacturers printed four parts from the file I sent them. The goal was that there would be one part for each impact velocity at 3.2m/s, 4.8m/s, 5.5m/s, and 6.2m/s. A total of twenty-four parts were printed. Testing was conducted at the Virginia Tech Helmet Lab. The goal of impact testing was to determine which contract manufacturer's and printing company's parts performed the best, as well as the most consistently.

This phase of impact testing was funded through Virginia Tech's Link, License, and Launch Program's Proof of Concept Funding. The goal for the funding was additional product development and impact testing, moving towards commercialization. As mentioned in section 6.4.2, the parts were performing inconsistently, which was believed to be a production issue. Some of the reasons for inconsistent production could have been powder blending rations, print parameters, or a malfunction with the equipment. However, the contract manufacturer I worked with in section 6.4.1 was unwilling to troubleshoot the production issues. So, I iterated and adjusted the impact testing strategy from a design focus to a production focus, as mentioned in section 6.4.2.

6.4.4 Testing Results and Discussion

On July 26th, 2022, we began impact testing. Table 6.1 shows the results from the Proof of Concept Funding Phase 1, comparing PLA values to the deformation the part experienced. As shown in Table 6.1, in the left-hand column, at a target velocity of 3.2m/s, six parts were impact tested. The part with the sample identification of POC_P1_Formlabs_A shattered. So, none of the parts from the printing company Formlabs were included in the subsequent rounds of testing at 4.8m/s, 5.5m/s, and 6.2m/s. As shown in the table below, the next target velocity was 4.8m/s. The parts with the sample identifications of POC_P1_HP_B, POC_P1_Protolabs_B, POC_P1_Shapeways_B, all experienced internal fracturing. So, none of the parts from HP, Protolabs, or Shapeways were included in the subsequent rounds of impact testing at 5.5m/s or 6.2m/s.

In Table 6.1, the next target velocity was 5.5m/s. The parts with the sample identification of POC_P1_Autotiv_C and POC_P1_Stratasys_C experienced PLA values below 300g and experienced minor internal fracturing. The amount of fracturing was small enough that it was deemed acceptable for the next round of impact testing. The final target velocity was 6.2m/s. Again, the parts with the sample identification of POC_P1_Autotiv_D and POC_P1_Stratasys_D experienced PLA values below 300g and experienced minor internal fracturing. From the test results, I concluded Autotiv and Stratasys were able to produce quality parts for that phase of impact testing. However, from my professional experience, quality control should be evaluated regularly, as consistent production quality is never guaranteed.

Table 6.1 Results from Proof of Concept Phase 1 testing, comparing the peak linear acceleration values to the type of deformation the test coupon experienced during the impact. If a coupon from a company failed at a given velocity, that company's coupons were not tested at higher velocities.

Target Velocity (m/s)	Measured Velocity (m/s)	Sample ID	PLA (g)	Deformation Notes
3.2	3.24	POC_P1_Autotiv_A	92	
3.2	3.13	POC_P1_Formlabs_A	50	Shatter
3.2	3.17	POC_P1_HP_A	115	
3.2	3.19	POC_P1_Protolabs_A	124	
3.2	3.2	POC_P1_Shapeways_A	152	
3.2	3.19	POC_P1_Stratasys_A	166	
4.8	4.86	POC_P1_Autotiv_B	135	
4.8	4.74	POC_P1_HP_B	153	Internal fractures
4.8	Speedgate didn't register	POC_P1_Protolabs_B	166	Internal fractures
4.8	Speedgate didn't register	POC_P1_Shapeways_B	187	Internal fractures
4.8	4.76	POC_P1_Stratasys_B	201	
5.5	5.44	POC_P1_Autotiv_C	193	Minor internal fractures
5.5	Speedgate didn't register	POC_P1_Stratasys_C	212	Minor internal fractures
6.2	6.18	POC_P1_Autotiv_D	211	Minor internal fractures
6.2	6.3	POC_P1_Stratasys_D	256	Minor internal fractures

6.4.5 Limitations with Evaluating Production Methods

For Proof of Concept Funding Phase 1 impact testing, the goal was to evaluate production methods for the parts. For additive manufacturing the print parameters and powder blending ratios can influence the part performance. Unfortunately, I was unable to get companies' print parameters and powder blending ratios. Having that information would have added additional insights for evaluating each company's production methods.

6.5 Discussion

The purpose of this chapter is to explore how to use a first principles approach to begin initial product development, in a way that provides a streamlined workflow and provides a seamless experience for the end user. This section will generalize from the specific case of a custom-fit bicycle helmet to discuss how the approach might apply to NVTs with other types of products and services that are also technical and capital-intensive. There is an expectation that a first principles approach may be more applicable to physical products than digital ones, however, there still may be some aspects that apply to digital products as well.

An NVT should critically think about the advantages and disadvantages of the process they are trying to apply. As described in section 6.1, product development can be simple or complex. The level of complexity can be attributed to the industry, technology, and final product. A product development roadmap and process can help an NVT navigate the complexities of product development. A roadmap and process can help an NVT organize, prioritize, plan, and execute the necessary steps to go from product brief to a final product and reduce the risk of new venture failure. However, regardless of the exact product development methodologies described by entrepreneurial texts, an NVT should critically think about the advantages and disadvantages of the process that is being described. In addition, an NVT may want to explore other methodologies, and thoughtfully consider the time and effort needed for each step.

Initial Product Development

In contrast to the approaches described by Maurya, Blank, Dorf, Osterwalder, and Pigneur, the first principles approach described in this dissertation improves initial product development over existing approaches by applying a product development roadmap to the product brief. The product brief describes the minimum viable product (MVP), which was described in section 5.3.4. A product development roadmap helps an NVT organize and prioritize technical challenges related to creating the MVP. In addition, the first principles approach improves initial product development over existing approaches by including a generalized product development process which starts with *ideate.*

Compared to the first principles approach, Maurya's *Running Lean* describes the importance of defining an MVP, and then applies a traditional product development cycle of *requirements, development, QA,* and *release* to create the MVP (Maurya, 2012). However, he does not describe a process for organizing and prioritizing the technical challenges for an MVP.

Similarly, Blank and Dorf's *The Startup Owner's Manual*, describes that an MVP consists of the most "important and indispensable features" …that can "work as a standalone product" (Blank & Dorf, 2012, 61, 82). However, if the most important or indispensable feature has large technical challenges that require multiple steps for development, Blank and Dorf provide no strategy for organizing or prioritizing those technical challenges. For a high-fidelity MVP, Blank and Dorf use all the latest buzz words and describe that it is the result of "agile development with continuous deployment and continuous product and feature refinements" (Blank & Dorf, 2012, 330). However, they do not actually describe how to begin product development. In addition, Osterwalder and Pigneur's *Business Model Generation* focuses on business models, however they do not explicitly connect business model creation to developing an MVP.

For products that are not technical or capital intensive, such as a simple dog bowl or an app made with a visual programming language, a roadmap may not be necessary. However, as mentioned in section 6.1.5, for technical and capital-intensive products, prioritizing the technical challenges of development through a roadmap can be good practice. The roadmap illustrates to the NVT and key stakeholders the vision for the product (product brief), aligning the team on the work needed to develop the product (Münch et al., 2019).

Once a roadmap has been created and technical challenges have been prioritized, a first principles approach includes a generalized product development process which starts with *ideate,* and then includes prototype, test and iterate. Compared to the first principles approach, Maurya's *Running Lean* describes a generalized process of *ideas, build, product, measure, data,* and *learn* (Maurya, 2012). However, the process is applied to Customer Discovery and creating a business model, the process is not applied to product development. Similarly, compared to the first principles approach, Osterwalder and Pigneur's *Business Model Generation* applies methods such as customer insights, ideation, visual thinking, prototyping, storytelling, and scenarios to business modeling (Osterwalder & Pigneur, 2010). However, those methods are not applied to product development. The first principles approach improves product development over existing approaches by including a product roadmap, as well as a generalized development process. The advantages of including a roadmap and generalized process are the roadmap organizes and prioritizes technical challenges, then the product development process is flexible enough to address those challenges.

Streamline the Process

In contrast to the approaches described by Maurya, Blank, Dorf, and Ulwick the first principles approach described in this dissertation improves initial product development by starting with a product development roadmap to streamline development for products with technical challenges. Organizing and prioritizing technical challenges related to the MVP by using a product development roadmap could help streamline the process for creating that MVP. In addition, the first principles approach streamlines product development over existing approaches by connecting the product development process described in this chapter to the Abstraction Ladder, which is described in the next chapter. The Abstraction Ladder gives the NVT the space and tools to critically think about each step in the process, which can include product development related activities, which will be described further in this discussion.

Compared to the first principles approach, Maurya's *Running Lean* describes the product development steps of *requirements* and *development*, and briefly mentions "continuous flow techniques" developed by Toyota, to eliminate waste in development (Maurya, 2012, 113). Although eliminating waste in development can aid in streamlining a process, it does not organize or prioritize technical challenges related to development. Then Maurya continues to describe continuous deployment in relation to software, as well as measuring and validating the customer lifecycle. However, Maurya does not describe any strategies for streamlining a technical process (Maurya, 2012).

In Blank and Dorf's, *The Startup Owner's Manual,* they also fail to include a strategy for streamlining technical challenges. Blank and Dorf describe the importance of "crafting the company's long-term vision and listing the product's features and benefits" (Blank & Dorf, 2012, 82). However, once the features and benefits are listed, no plan is described for organizing or prioritizing the technical challenges associated with them. Blank and Dorf describe "using agile development and continuous deployment" for web-based startups but describe no further product development strategies outside of that scope (Blank & Dorf, 2012, 82). For building a low fidelity MVP, they describe a simplified process of building a website (Blank & Dorf, 2012). Then, for a high-fidelity MVP test, they describe it as an invitation for "a limited number of customers to experience the MVP" without describing a strategy for building the MVP (Blank & Dorf, 2012, 237).

In relation to physical products, Ulwick's *Jobs To Be Done* describes how Bosch's product planning team was able to quickly conceptualize a solution for a circular saw once they knew their customer's unmet needs. However, to meet their customer's specific combination of unmet needs, Bosch's final solution was simply repackaged features and benefits that already existed in individual circular saws from various brands (Ulwick, 2016). Ulwick does not describe any new technological advancements that must be developed which might require a creating a new streamlined process. When an NVT's product does require a technical challenge to be addressed, the first principles approach improves product development compared to *Jobs To Be Done* by incorporating a roadmap for organizing and prioritizing technical challenges associated with development, which is especially relevant for technical and capital-intensive products. The roadmap can align a product team and serve as a reference point for the NVT for overcoming those challenges.

For Maurya, Blank, and Dorf, digital products with relatively minor technical challenges were the focus of their texts. For those situations, a product development roadmap may not be necessary, as many digital products can have fewer technical challenges compared to some physical products as described in section 6.1.3. For physical products that leverage established manufacturing processes, such as the circular saw described by Ulwick, a product development roadmap may also not be necessary. However, as described in section 6.1.5, for products that require technological advancements (radical innovation) and diverge from established technologies, manufacturing processes, or user experiences, creating a product development roadmap, as well as critically thinking about product development related activities can be good practice. If the NVT hopes to develop a product with technological advancements but does not have the technical competency to develop it, the NVT will either need to develop those skills or delegate to those that do. As the NVT progresses in product development they may also consider other resources, such as Gantt charts or other digital project management systems for planning and organizing.

Provide a Seamless Experience

In addition to streamlining product development, the first principles approach can also provide a more seamless experience of the product for the end user when compared to existing approaches. In contrast to the approaches described by Maurya, Blank, and Dorf, the first principles approach described in this dissertation can provide a more seamless user experience by giving the NVT a generalized process that allows for variation. As described in section 6.1.1, when applying the generalized product development process of ideate, prototype, test, and iterate, variation can include the rate at which the NVT cycles through the steps, as well as the amount and quality of feedback needed for each step. In addition, by giving the NVT a process that allows for variation, the NVT can adjust the process as necessary based on user feedback and adapt it to a variety of manufacturing and product types. Allowing for variation empowers the NVT to adjust the process as necessary to provide the best experience for the end user. In addition, the first principles approach provides a more seamless experience for the end user over existing approaches by connecting the product development process described in this chapter to the Abstraction Ladder, which is described in Chapter 7. Applying the Abstraction Ladder allows the NVT to critically think about the problem that is driving product development and its foundational elements to provide more value to the end user.

Compared to the first principles approach, Maurya's *Running Lean* describes continuous deployment for developing the user experience. Continuous deployment in this context (for digital products) makes sense as the NVT can write new code and iteratively adjust it, serving as "a feedback loop for continuous learning and improvement" (Maurya, 2012, 114). For many digital products there can be a lower barrier for quickly releasing incomplete versions of the product, putting it in front of users, soliciting feedback, and improving the user experience, when compared to physical products (Maurya, 2012). For digital products, some of the reasons for the lower barriers to product development are revising the product can be as simple as adjusting or writing new code, also an end user can use the product as long as they have the ability to download it (Maurya, 2012). Maurya describes how to improve the product experience through customer trials for "quick, actionable learning" (Maurya, 2012, 136).

Similar to *Running Lean*, Blank and Dorf's *The Startup Owner's Manual* also describes continuous deployment for developing the user experience. Blank and Dorf describe the importance of "user interface testing" and "the long-term value of design" (Blank & Dorf, 2012, 202). However, the importance of the user experience is described specifically in the context of digital products, where there can be a lower barrier for product development when compared to some physical products. For digital products there can be a lower barrier for quickly releasing incomplete versions, making adjustments, and improving the user experience of a product, when compared to physical products.

For digital products with few technical challenges, following the product development methodologies described by Maurya, Blank, and Dorf could very well be appropriate. However, for physical products with more complex technical challenges, trying to follow continuous deployment is most likely not an appropriate approach for improving the user experience. Depending on the technical challenges of the product and user feedback, a first principles approach allows the NVT to adjust the rate and effectiveness at which they cycle through ideate, prototype, test, and iterate to provide a seamless experience for the end user.

Another way that the first principles approach provides a more seamless experience for the end user over existing approaches is by connecting a generalized product development process to the Abstraction Ladder, which will be described in the next chapter. By applying the Abstraction Ladder to the process, the NVT can critically think about the problem that is driving product development and its foundational elements to provide more value to the end user. For example, in this dissertation, the problem driving product development is bicycle helmet fit. Helmet fit is more than defining sizes as small, medium, large, or extra-large. In addition, for a custom fit 3D printed helmet, helmet fit it is more than scanning a rider's head and offsetting a lattice structure from that scan. Rather, understanding bicycle helmet fit involves understanding helmet stability, fit, and comfort, which will be described further in the next chapter. It is anticipated that understanding bicycle helmet fit at a foundational level will create a more seamless experience for the end user and provide more value to them.

Discussion Summary

Finally, the product development process described in this chapter is not necessarily a radically new approach to entrepreneurship or product development. Rather it is a shift, as it is an entrepreneurial resource for product development without an overbearing bias towards digital products. Similar to the way continuous deployment is not relevant for many applications, the product development process described in this chapter may not be relevant for other applications. The advantages and disadvantages of each process highlights the importance of critical thinking, exploring other methodologies, and thoughtfully considering the time and effort needed for each step. As stated in section 6.1.5, regardless of the specific process or roadmap that an NVT follows, product development is a continually iterative process of soliciting feedback, executing, soliciting feedback, adjusting, until relevant key stakeholders agree the product or service is ready for market.

6.6 Contribution

The contribution from this research question is the addition of a product development process, that is not through the lens of digital products and allows for variation. The product development process includes a roadmap for determining where to begin product development. The addition of a product development process to Customer Discovery has resulted in a workflow, which has begun to streamline the various technical processes needed for development (radical innovation).

The product development workflow has been achieved through a recombination of technologies for improved fit. The recombination of technologies included a brief overview of scanning, surface generation, and finite element analysis (FEA), as well as a more in-depth exploration of mesostructure design, evaluation, and production. The recombination of these technologies resulted in a new approach of product development for PPE.

6.7 Chapter Summary and Next Steps

In summary, section 6.1 describes an overview of product development, which includes a general process of ideating, prototyping, testing, and iterating. In addition, the section compares and contrasts different categories of product development. Finally, the section provides an overview of the product development process, as well as the different categories of product development and how they are applied specifically to this dissertation.

Then section 6.2 describes a product development roadmap, starting with what is perceived to be the largest technical hurdle. For this dissertation, I determined that the second step, designing for protection was the largest technical hurdle, so product development started with ideating and prototyping test parts in section 6.3. Then, in section 6.4, the next step of the product development process was to test, so the parts were impact tested, evaluating their design characteristics. Unfortunately, the test parts began performing inconsistently. The next part of the product development process was to iterate, so we adjusted impact testing to evaluate company's production methods.

Chapter 6 has described some initial product development, which is now underway. Chapter 7 will describe a concurrent step to product development, which includes critically thinking about contextual factors of the new venture by performing a feasibility analysis, as well as critically thinking about the Severe Problem, and solution. From the initial product development, there is some supporting evidence that the final product can withstand technical challenges and pass relevant regulatory bodies. Although a general roadmap for developing a final product has been identified, I anticipate there will be many additional hurdles. For a First Principles Approach to Product Development in Entrepreneurship, a concurrent step to initial product development is to pause Customer Discovery and critically thinking about both the Severe Problem and the solution, which will address Research Question 3.2, the subject of Chapter 7.

For Chapter 7, taking time to critically think about both the Severe Problem and the solution in a broader context seems to be a competing objective to initial product development. The reason for this reflection was that initial product development directly contributes to the minimum viable product and product/market fit. However, critically thinking about those in a broader context can be time and resource intensive, where the long-term benefits are not readily identifiable. Understanding the broader context of both the Severe Problem and solution will set a foundation and provide strategic guidance for the new venture's long-term vision.

Chapter 7 Pausing Customer Discovery and Assessing the Larger Context of Problem/Solution Fit

The previous chapter explored the process of product development, creating a roadmap, and determining a place to start development, with the goal of creating the product described in the brief. The purpose of this chapter is introspection assessing the potential new venture by performing a feasibility analysis, as well as assessing Customer Discovery and the problem driving product development by applying the Abstraction Ladder.

Section 7.1 begins by pausing Customer Discover and conducting a feasibility analysis which is necessary to perform a formative assessment to guide the NVT's next steps. As the NVT pauses Customer Discovery, section 7.2 describes the process of critically thinking about the problem driving product development (specifically bicycle helmet fit) by applying the Abstraction Ladder. Then section 7.2 critically evaluates the completed product development process (specifically Customer Discovery). Section 7.3 concludes with a discussion of the methodologies used in this dissertation and their general application. Section 7.4 describes the contribution from the chapter and section 7.5 summarizes the chapter.

Research Question 3.2: With problem/solution fit identified, how can one pause Customer Discovery, and begin to critically think about the broader context of problem/solution fit in order to improve the product development process?

The primary contribution from this research question is an improved product development process. The product development process is improved by pausing Customer Discovery and including a step for critically evaluating the Severe Problem and the product development process. The improved process includes the application of the Abstraction Ladder in order to critically think about the problem driving product development in order to direct development and improve the MVP. In addition, the improved process includes a critical evaluation of Customer Discovery to make sure it is the most appropriate process for reducing the risk associated with launching a new venture. Lastly, the contribution from this research question is the demonstration of a feasibility analysis, so the feasibility analysis can serve as a reference point for the NVT and key stakeholders.

7.1 Pausing Customer Discovery

The purpose of this section is to assess what has been learned through Customer Discovery, and consider other contextual factors learned from secondary research, which can be documented in a feasibility analysis (Barringer & Ireland, 2016). Similar to the way a product brief serves as a reference point, the feasibility analysis can also serve as a reference point to the NVT, as well as other key stakeholders. A feasibility analysis is a process used in entrepreneurship to assess the potential new venture's viability, highlighting its strengths and weaknesses, and determine if it should be "dropped or rethought" (Barringer & Ireland, 2016, 77). In addition, a feasibility analysis includes identifying a supporting business model, ultimately building a team and culture around the product or services the NVT is trying to create (Barringer & Ireland, 2016).

Section 7.1 is organized by the various components of a feasibility analysis. The analysis starts with an executive summary in section 7.1.1, which includes a summary of the product/service feasibility, market feasibility, industry feasibility, organizational feasibility, and financial feasibility. Then, section 7.1.2 describes the product/service feasibility, which assesses the appeal of the product or service, specifically looking at its desirability and demand (Barringer & Ireland, 2016). Next, section 7.1.3 describes the market feasibility, which considers whether the target market is large enough to build a business around (Barringer & Ireland, 2016). Section 7.1.4 describes the industry feasibility, which examines the top qualities for determining an industry's attractiveness (Barringer & Ireland, 2016). Section 7.1.5 describes the organizational feasibility, which explores an NVT's management prowess and resource sufficiency, both of which will be explained in greater detail in the section (Barringer & Ireland, 2016). Finally, section 7.1.6 describes financial feasibility, which serves to understand the startup capital needed, as well as the new venture's potential financial performance (Barringer & Ireland, 2016). Leveraging this process can help future entrepreneurs assess the key areas of a new venture, thinking about it holistically, as opposed to simply the product or service.

7.1.1 Executive Summary

Based on the overall feasibility analysis the proposed new venture is an opportunity worth pursuing. In regard to product/service feasibility, gauging desirability and demand, there is perceived demand, as parents of riders said they would pay $150 for a helmet that solves the problem of fit. In regard to the market feasibility, determining the target market, there is an estimated 4,420 parents in the US with children between 1 to 3 years, who bought a high-end balance bike and are experiencing Severe Problems with helmet fit. For the industry feasibility, the bicycle industry has a large amount of fragmentation, it is growing, and there is a growing trend where parents want their children to have high quality biking experiences and are willing to buy high-end bikes (*Kids Bicycle Market Size, Trends & Forecast, 2023-2033*, 2022). In regard to organizational feasibility, the team was assessed through management prowess and resource sufficiency. For management prowess, the most important consideration is that I finish my interdisciplinary PhD, so I can shift my focus to the new venture full time and attract talent specific to optimizing the digital and physical workflows, as well as managing cash flows. For resource sufficiency, there are strategies in place for recruiting appropriate personnel, building relationships, finding physical space, acquiring the necessary equipment, and protecting the business. Finally, for financial feasibility, the initial material cost per helmet is expected to be $70.31. However, labor and operation costs should be considered as well, as product development progresses.

7.1.2 Product/Service Feasibility

As stated in section 7.1, the product/service feasibility analysis assesses the appeal of the product or service, specifically looking at its desirability and demand (Barringer & Ireland, 2016). Examining appeal is conducted through a demo, test, or even a description of the product or service with potential early adopters (Barringer & Ireland, 2016; Maurya, 2012). Challenging or supporting product/service feasibility can be done through interviews with potential early adopters, leveraging internet-based ads and a landing page, or other secondary research (Barringer & Ireland, 2016). Ultimately, the goal of examining product/service feasibility is "to gauge customer reaction to the general concept of what you want to sell" (Barringer & Ireland, 2016, 83). In Table 7.1, the left column shows the product or service's expected qualities, referring to desirability and demand. The right column of Table 7.1 shows the specific qualities that relate to the potential new venture described in this dissertation.

Table 7.1 The desirable qualities for product/service feasibility, demonstrating demand for a custom fit, 3D printed bicycle helmet

Product/Service Qualities	Qualities Specific to this New Venture
Desirability	Participants described interest in a custom fit, 3D printed helmet
Demand	Participants said they would pay $150 for such a helmet

For this dissertation, I started with secondary research. Secondary research included examining the pricing differences between lower-end balance bikes and higher-end balance bikes, as a benchmark for lower-end kids helmets and higher-end kids helmets. Then, I conducted six solution interviews with potential early adopters, giving them a general description of the solution and asking about pricing. The solution interviews are described further in section 5.3.2. From the solution interviews, two of the six parents said they would pay just under $100. Two of the six parents said they would pay about $150, and two of the parents said they would be happy to pay at least $200 for such a helmet. Those results lead me to believe that there is demand from potential early adopters for a custom fit, 3D printed helmet. As product development continues, a focus should be creating a solution to bicycle helmet fit that is priced at under $100 for consumers and optimizing the production process to further reduce costs. Focusing on these activities will most likely increase product demand, transitioning from a market of early adopters to one that includes the early majority. It should be noted that at the time of writing this dissertation, inflation in the current economic climate has likely affected the pricing differences I initially found from secondary research, and most likely would affect participants' answers to what they said they would pay.

7.1.3 Market Feasibility

A target market is a smaller group of customers with a similar problem, segmented from a larger market (Barringer & Ireland, 2016). For a new venture, the goal is to find a market large enough to start a business, but small enough to not be noticed by larger firms, in an effort to circumvent direct competition with established firms (Barringer & Ireland, 2016). The market feasibility analysis is an assessment of the target market’s attractiveness (Barringer & Ireland, 2016). The assessment is completed by determining the target market’s estimated size, as well as whether or not the target market is large enough to support a new venture. For Table 7.2, the left column shows desirable qualities for a market, while the right column shows the specific market qualities that relate to the potential new venture described in this dissertation.

Table 7.2 The desirable qualities for market feasibility, demonstrating the target market may be large enough to support a new venture

Desirable qualities	Qualities specific to this new venture
Target market size	Roughly 4,420 US Bike Parents
Large enough to support a new venture	Possibly

The market can be a combination of both the customers and end users. Specific to this dissertation, the customers are the parents who will be paying for the product. The end users are the children who will be using the product. For this market feasibility analysis, the target market is US Bike Parents, referring to parents that purchased a bike from a US kids specific bike company with children experiencing the Severe Problem of helmet fit. So, determining the number of US Bike Parents will serve as an estimate for the target market. An estimate of US Bike Parents includes determining the age range of their children from the primary research conducted during the problem interviews. Then, the next step is to determine the total number of US Bike Parents based on population statistics from secondary research.

Another consideration should be understanding how the market fluctuates. For US Bike Parents, market fluctuation can happen when parents enter and exit the market. The market grows as new parents get their kids on balance bikes. However, the market shrinks when their children grow and have more sizes of mass-produced helmets available, reducing their need for a custom-fitted helmet.

Determining an age range:

- Of the 8 parents who experienced Severe Problems with helmet fit, at the time the parents were interviewed, their children's ages were between 9 months and 11 years, the median age was 6.2 years.
- Of the 8 parents who experienced Severe Problems with helmet fit, as they were experiencing the Severe Problem, their children's ages were between 9 months and 3.5 years, the median age was 2.3 years. One challenge for determining the children's ages was that during the interview the children were not the same age as when the parents were experiencing the Severe Problem with helmet fit.

As stated previously, the second step for determining the size of the target market is to estimate the total number of US Bike Parents, based on secondary research. For this dissertation, the target market was estimated by multiplying the percentage of parents with children between the ages of 1 to 3 by the number of cyclists in the US. In this estimate, there is an assumption that parents who ride bikes are encouraging their children to ride balance bikes.

To begin, an estimate of the US Population is 328 million (Population Clock, 2021). There are roughly 20 million children in the US between the ages of 0 to 4 (Child Population by Age Group in United States, 2021). An estimate to include only children between the ages of 1 to 3 is 12 million children, which is 3.6% of the US population. There is an assumption that each child has at least one parent, so it is inferred that there are 12 million parents of children between the ages of 1 to 3 in the US.

There are roughly 47 million US road bikers and 8 million US mountain bikers (Mountain Biking Participants US, 2021; U.S. Americans Who Went Bicycling 2021, 2021). In order to provide a conservative estimate, US road bikers and US mountain bikers were not combined as cyclists can be multidisciplinary. Then, I multiplied the number of US road bikers by 3.6%, to determine there are 1.7 million parents with 1- to 3-year-olds on balance bikes in the US. It is uncertain how many of the balance bikes are high-end bikes, so an estimate could be 1% of bikes (considered to be a conservative estimate), which would mean there are at least 17,000 parents who own balance bikes sold by Woom, Cleary, Prevelo, Pello, and Guardian.

To further refine the target market estimate, the 17,000 parents with high-end balance bikes were multiplied by the percentage of US Bike Parents with a Severe Problem of helmet fit. As a result, the target market was estimated to be 4,420 US Bike Parents. In addition, it is anticipated this population would turn over every two years, as children grow into more helmet options that are available and new parents enter the target market.

It should be noted that there is more than one term, as well as overlapping terms, for describing the group of people that have been identified as most likely to buy and use the NVT's product or service. Two commonly used terms to describe such a group are target market and early adopters (Barringer & Ireland, 2016; Maurya, 2012). In addition, there is more than one way to segment and describe the larger group that the target market and early adopters are a part of. Some commonly used terms that describe the larger groups that they are a part of are: serviceable addressable market, total addressable market, as well as early majority and late majority.

7.1.4 Industry Feasibility

An industry is the group of companies or firms that produce similar products and services (Barringer & Ireland, 2016). The industry feasibility analysis is an assessment of the industry's overall attractiveness (Barringer & Ireland, 2016). The top three qualities for determining an industry's attractiveness are the industry is young; the industry is early in its lifecycle; and the industry is fragmented (Barringer & Ireland, 2016). Additional qualities of industry attractiveness include industries that are growing; selling products customers "must have"; operating with high margins; and not dependent on low priced commodities (Barringer & Ireland, 2016). For Table 7.3, the left column shows the top industry qualities, while the right column shows the specific industry qualities that relate to the potential new venture described in this dissertation.

Table 7.3 The desirable qualities for industry feasibility

Industry qualities	Qualities specific to this new venture
Industry Age	The children's high-end bicycle market is young
Industry Lifecycle	The bicycle industry is continuing to grow
Industry Fragmentation	The bicycle industry is fragmented

The first quality for determining an industry's attractiveness is the industry's age. The bicycle industry has been around for over a hundred years and could be considered old, with adult push bikes dating back to the 1800's (Wilson, 2004). However, as described in section 4.6.2, a starting point for the US children's balance bike market could be 2007 with the launch of Strider Bikes. Then, from 2012-2017 the industry surged with the launch of thirteen new, high end, children's specific bicycle companies. As the industry has continued to grow in 2017 and 2018, two children's specific bike part companies were launched producing another level of high-end aftermarket parts for children's bikes. Although the children's specific bicycle industry has begun to mature, there is no high-end helmet company that solely focuses on kids helmets.

The second quality for determining an industry's attractiveness is if the new venture is entering the industry's life cycle early in that life cycle. As previously mentioned the bicycle industry has been around for over a century, however despite its venerable nature, it is still growing. In 2016 the global bike industry was estimated at 45 billion dollars and is expected to reach 62 billion dollars by 2024 (Global Bicycle Market Size in 2016 and 2024, 2023). Similarly, despite the bicycle industry being around for over a century, high-end kids bikes and balance bikes have only been around the past decade. In addition, there is a growing trend in demand for high end bikes from parents who want a high-quality biking experience for their children (Kids Bicycle Market Size, Trends & Forecast, 2023-2033, 2022). The third quality for determining an industry's attractiveness is if the industry is fragmented (Barringer & Ireland, 2016). In the bicycle industry, there are a few large parent companies such as Accell, Dorel, and Vista Outdoor who own a variety of bicycle and helmet companies (Adult Bikes Market, 2023; Carlier, 2022). There are also large bicycle companies such as Giant, Trek, Merida, Specialized, as well as other international brands who make bicycles, helmets, and related accessories. In addition, there are several other independent bicycle and helmet brands. In regard to children's bikes, in the US there are five high-end kids specific bike companies, as well as aftermarket parts companies and product reviewers for kids bikes. In summary, there are many large and small bicycle and helmet companies in the US, where that type of fragmentation presents an opportunity for new ventures.

Finally, there is a segment of companies in the bicycle industry who solely focus on customized cycling products. The most prominent example of customization in the bicycle industry is that there are over 150 custom bicycle builders in the US (TheFramebuilders, 2023). In addition, there are custom-fit cycling shoe companies throughout the world (Shumpert, 2017). In the last five years, two 3D printed custom-fit helmet companies launched, further demonstrating high end customization throughout the bicycle industry (Jafferson & Pattanashetti, 2021; Overholt, 2022).

There are additional qualities that make an industry attractive. One of the attractive qualities for an industry is to sell a product the customer "must have" (Barringer & Ireland, 2016). As previously mentioned in section 4.5.1, the parents described a Severe Problem of bicycle helmet fit, referencing a "must have" problem.

Another attractive quality for an industry is to have high operating margins. When producing a custom-fit 3D printed helmet the material costs are high, which means the operating margins are low, compared to traditional overseas injection molded manufacturing processes. Within the last decade, new helmet safety technologies, such as MIPS, Koroyd, and WaveCel, have been integrated into the production processes for injection molded foam helmets. Overall, the advantages of traditional manufacturing seem obvious, as there are higher operating margins, as well as less friction for incorporating new technologies. For custom-fit 3D printed helmets, lower operating margins and having to develop manufacturing processes may seem like a disadvantage. Those disadvantages would most likely be less attractive for established firms and other new ventures. These disadvantages would apply to the new venture I am trying to launch. Although, there will be opportunities to improve the process and increase profit margins over time.

7.1.5 Organizational Feasibility

The organizational feasibility analysis examines if the NVT has the ability to launch a new venture. The characteristics the team is expected to have are "management expertise, organizational competence, and resources" (Barringer & Ireland, 2016, 89). Those characteristics are evaluated through management prowess and resource sufficiency (Barringer & Ireland, 2016). For Table 7.4, the left column shows the desirable organizational qualities for a new venture. The right column shows the specific organizational qualities that relate to the potential new venture described in this dissertation.

Table 7.4 The desirable qualities for organizational feasibility are shown, where the table highlights the qualities that are specific to this new venture

Desirable qualities	**Qualities specific to this new venture**
Management Prowess	Finish PhD, find appropriate personnel
Resource Sufficiency	Access to a labor pool, key relationships with incubators and universities

Management Prowess

Management prowess refers to the NVT's ability to launch a new venture, which includes evaluations of the individual founder, as well as the team (Barringer & Ireland, 2016). The two factors for evaluating the individual founder and team are their passion for the new venture, as well as their ability to understand their target market and total market (Barringer & Ireland, 2016). Additional considerations are the NVT's professional and social network for identifying individuals who will add value to the NVT, as well as the board of directors or board of advisors (Barringer & Ireland, 2016). At the time of writing this dissertation, as I am finishing an IPhD program with the goal of launching a new venture sometime after graduation, it is difficult to objectively assess my own personal qualities. Based on the factors for evaluating a founder, I do have a strong desire to launch a new venture, as well as have some knowledge of the target market, as demonstrated by the market feasibility analysis earlier in this chapter. Additional factors that are relevant to launching a new venture include that I have professional experience designing and developing personal protective equipment (PPE), as well as that I have created my IPhD program in a way that supports the launch of a new venture.

For product development in entrepreneurship, my IPhD program has fostered each individual area needed for developing PPE. Those areas include entrepreneurship, injury biomechanics, mechanical engineering, and industrial design. At the moment, the three areas that have low priority are Customer Discovery (entrepreneurship), injury biomechanics, and industrial design. Although Customer Discovery is an ongoing process, the initial Customer Discovery has largely been addressed through the problem interviews and the NSF I-Corps Program. Injury biomechanics is another important area for the development of PPE, however, when developing a helmet the primary focus is that it passes the CPSC Safety Standard for Bicycle Helmets. Any additional considerations for safety come after passing the standard and launching the new venture. In addition, the primary goal of this new venture is not necessarily to create a "safer" helmet in terms of how much it exceeds the safety standard, but rather a better fitting helmet. That said, there is an assumption that a better fitting helmet will be more likely to be worn and in the right position during a crash, thus leading to improved safety in actual use. Finally, industrial design is exceptionally important when creating a product, however, for the initial product design I can utilize my personal design skills.

The areas that have the highest priority are optimizing the digital and physical workflows and managing cash flows. The first priority is optimizing the digital and physical workflows. Getting a digital scan, editing it in a 3D rendering program and applying a mesostructure in a latticing software is a time intensive process. It is anticipated that much of that digital workflow will be optimized. In addition, the physical process of removing the final print, clearing excess powder, applying finishes, and adding straps and buckles will need to be improved and automated. Developing relationships and finding personnel who add value to improving those processes will be important. The second priority is managing cash flow. At the time of writing this, there is no positive cash flow, and current Customer Discovery and product development is being funded through NSF I-Corps and Proof of Concept Funding grants. The funds for those grants are currently administered through Virginia Tech's Institute of Creativity, Arts, and Technology's fiscal coordinator.

It is expected that a pilot program will be conducted during the Fall of 2023, where a cash flow may need to be managed. Additional considerations for new venture team personnel are managing the day-to-day operations, as well as a helmet redesign. As important as each role is, one of the benefits of finishing the interdisciplinary PhD is that I will have rudimentary competence for each position, which allows me to fulfill the roles until they can be delegated to appropriate personnel.

Other considerations are advisory roles for the new venture (Barringer & Ireland, 2016). At the time of writing this dissertation, it is expected that I will transition from the IPhD program to Virginia Tech's Presidential Postdoctoral Innovation Fellowship at which time my current co-chairs, Dr. Martin and Prof. Schaudt will contribute as postdoctoral mentors. The goal of the postdoctoral program is to launch a new venture and it is anticipated they will serve in advisory roles, where we will navigate the process of onboarding other relevant advisory positions.

Finally, I have an expectation that the new venture team will grow, and additional personnel will be onboarded. As growth happens, personal and team assessments through the Clifton Strengths Assessment should provide insights for team dynamics. I also maintain an active list of skill sets that will be needed, as well as potential candidates that can fulfill those roles.

Resource sufficiency

Resource sufficiency refers to the new venture team's ability to obtain and leverage resources in order to launch a successful venture (Barringer & Ireland, 2016). The focus of resource sufficiency is nonfinancial resources. Nonfinancial resources include access to a labor pool with skills the new venture needs, as well as the ability to protect intellectual property (Barringer & Ireland, 2016). A new venture should be able to list and have a strategy for some nonfinancial resources needed for launching (Barringer & Ireland, 2016). The first nonfinancial resource is access to personnel or a labor pool. Accessing the appropriate skills needed begins with completing my IPhD, so I can leverage my own skills and shift my focus from academic obligations to launching the new venture full time. As mentioned in management prowess, I have identified the next set of necessary skills needed for the new venture, as well as I have a list of potential candidates with those skill sets.

The second nonfinancial resource is the relationships needed for building a new venture. It will be important to continue building relationships with Virginia Tech and other surrounding colleges, so the most appropriate skills are onboarded. Other key support personnel will include people from regional resources such as RAMP, Verge, RBTC, and the CRC. Developing my relationships with bicycle retailers, product reviewers, and bike teams will also be important resources. In regards to the local community, additional considerations include building the cycling community, as well as the continued development of Roanoke as a premier biking destination. Finally, as I transition from initial prototypes to production, I will continue developing relationships with contract manufacturers, as well as identifying where and how to buy similar equipment for transitioning to localized production.

The third nonfinancial resource is physical space. When the new venture is able to transition from contract manufacturing to localized production, it will be important to have physical space available and leverage local business relationships with RAMP, Verge, RBTC, CRC, and other Virginia Tech resources. Resources for such a transition include finding office space, lab space, and manufacturing facilities.

The fourth nonfinancial resource is the key equipment needed. The largest capital equipment costs will be the 3D printers. Other equipment needed in relation to production includes post processing prints, cutting and sewing straps, adding trims, packaging, and shipping the finished product. Additional equipment includes program licenses and general equipment to support information technology.

Finally, the last, but not least, nonfinancial resources are focused on protecting the business. Protecting the business includes protecting intellectual property, which will initially be in collaboration with Virginia Tech's Link, License, and Launch, as we transition from the provisional patent application to the utility patent. Another key resource for protecting the business will be acquiring insurance for the business.

7.1.6 Financial Feasibility

The financial feasibility analysis is an initial financial assessment of the new venture (Barringer & Ireland, 2016). The initial metrics used to assess financial feasibility are the "total start-up cash needed, financial performance of similar businesses, and the overall attractiveness of the proposed venture" (Barringer & Ireland, 2016, 92). If the new venture moves past the feasibility analysis stage, the next step would be to prepare a pro forma, projecting the new venture's first three years (Barringer & Ireland, 2016). For Table 7.5, the left column shows the initial metrics used to determine a new venture's financial feasibility, while the right column shows the specific metrics that relate to the potential new venture described in this dissertation.

Table 7.5 The initial financial metrics are shown, where the table highlights the metrics that have currently been determined

Initial Metrics	**Metrics specific to this new venture**
Total start-up cash needed	Initial costs are printer and material costs
Similar businesses	Not/Available
Overall attractiveness	Not/Available

The first step is to assess the total start-up cash needed, which includes all capital purchases and operating expenses. When transitioning to localized production, the largest capital expenses will be buying printers, as well as initial material costs. The number of printers needed for production is determined by the annual projected number of helmets to be sold, the printer's build volume, referring to how many helmets can fit in each print, as well as print time, referring to the time it will take to complete each print.

As stated in section 6.3.1, the parts used during impact testing were made using powder bed fusion and PA11. The specific type of printer that was used was an EOS P396. The cost of an EOS P396 can range from $230,000 - $300,000 (*Cncmachines.Com*, 2023; *Treatstock.Com*, 2023). Next, the material cost depends on the volume at which the material is purchased at, as well as the material's reusability. Ordering the material SLS Ultrasint PA11 White directly from BASF, the material cost is $53/kg, when a minimum order quantity is 240 kg. The material cost per build was found using (Gibson et al., 2015):

$$M = k_s * k_r * N * v * C_m * \rho$$

Where k_s is the support material, k_r is the recyclability of the material, N is the number of parts per build, v is the part volume, C_m is the cost per mass of the material, and ρ is the density. The material cost per helmet is estimated to be $70.31.

Now that there are estimates for printer and material costs, there is some supporting evidence of financial feasibility. However, as product development progresses, additional considerations for determining the cost per part are labor and operation costs. Additional considerations for financial feasibility are maintaining printers, insurance, office space, lab space, manufacturing space, potential estimates for contract manufacturers, key management employees, key support personnel, additional equipment costs, IP protection, local government subsidies, and business partnerships.

7.2 Abstraction Ladder Overview

By conducting the feasibility analysis, another reference point has been developed for the NVT. The purpose of this section is to describe an approach for critically thinking about the Severe Problem and solution. A First Principles Approach to Product Development in Entrepreneurship includes critically thinking about the process and the resulting problem/solution fit. Critical thinking generally refers to "analyzing arguments, making inferences by using inductive or deductive reasoning, judging or evaluating, and making decisions or problem solving" (Lai, 2011, 41-42). Critically thinking about the process and problem/solution fit does not require any formalized technique, however one recommended technique is Abstraction Laddering (LUMA Institute, 2012). Applying the Abstraction Ladder can help identify areas for long-term planning and future work that if explored further may provide additional value to the end user. However, the areas identified by the Abstraction Ladder will most likely require their own in-depth level of review and research.

The Abstraction Ladder is a semi-structured technique for navigating the critical thinking process (LUMA Institute, 2012). Abstraction Laddering involves framing a problem, "at different levels of focus" for a more comprehensive understanding of problem/solution fit and the relationships between disciplines (LUMA Institute, 2012, 52). An overview of the Abstraction Ladder is shown in Figure 7.1. The application of the Abstraction Ladder helps connect disciplines that may seem disconnected at first. The technique works by expanding the scope of the inquiry by asking "Why?" questions and narrowing the scope of the inquiry with asking "How?" questions (LUMA Institute, 2012). The Abstraction Ladder begins with an initial problem statement (LUMA Institute, 2012). An initial problem statement can be cultivated by using a statement starter (LUMA Institute, 2012). A statement starter can help state an issue as a question (LUMA Institute, 2012). An example of a statement starter is the phrase, "How might we…" (LUMA Institute, 2012, 51). Applying a statement starter can help explore a problem in a variety of ways and can increase "the possibility of finding new and better solutions" (LUMA Institute, 2012, 50).

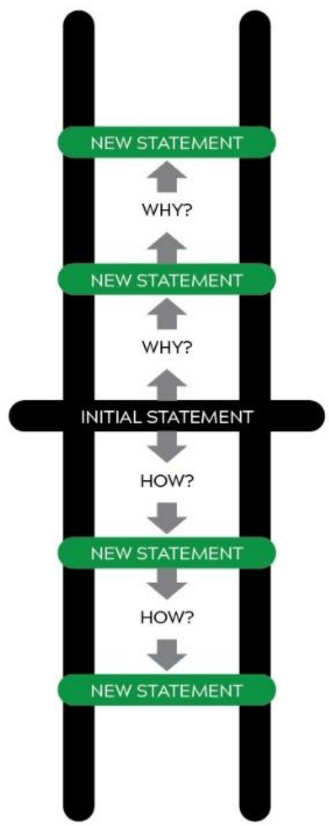


Figure 7.1 The Abstraction Ladder, used with permission from the Luma Institute

An example of the Abstraction Ladder applied to the product development framework described in this dissertation is shown in Figure 7.2. Here the Abstraction Ladder is applied to an initial statement of, “make a better fitting helmet.” In the middle of the right column, Figure 7.2, shows a list of potential questions, also referred to as statement starters, to help determine the initial statement. Then, in Figure 7.2 in the right column, the question circled in green shows the statement starter that was picked as the basis for the initial statement. The statement starter used for the initial statement was also used for the brainstorming sessions described in section 5.1.2, which led to an exploration of many potential solutions to the problem. Additional questions relating to, “How might we make a better fitting helmet using 3D printing?” and “How might we create a mesostructure?” were explored in Chapter 6. Chapters 7 and 8 will primarily focus on “Why?” questions broadening the scope of inquiry, with a few supplemental “How?” questions.

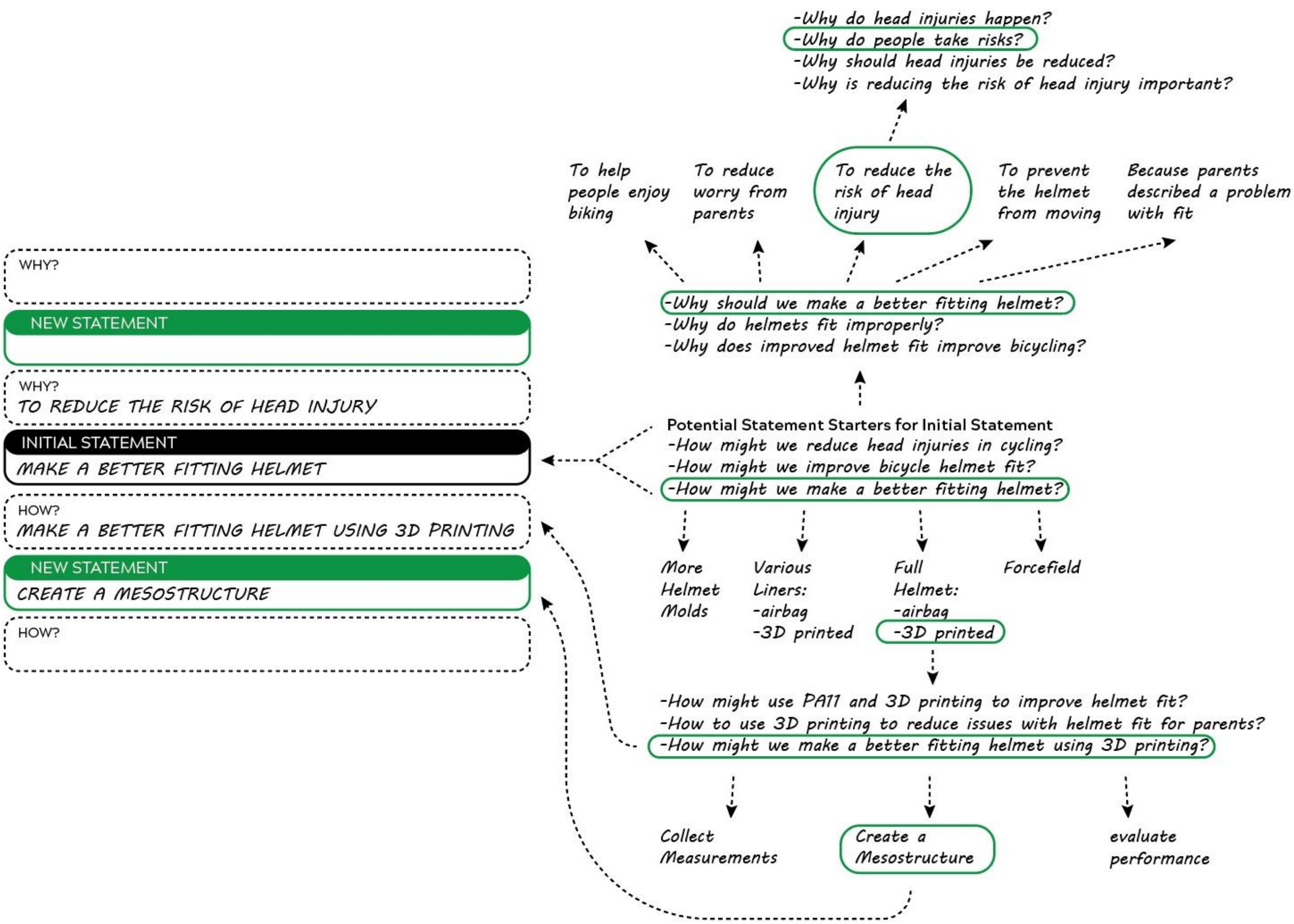


Figure 7.2 The Abstraction Ladder, highlighting the statement starters and the initial statement, used with permission from the Luma Institute

The Abstraction Ladder shares similarities to the more popularized technique for understanding a problem, 5 Whys (Benjamin et al., 2015). The 5 Whys technique can also be used for discovering the foundational elements of a problem, by asking the question “Why?” five times. Asking the question continuously allows for symptoms of a problem to be separated from the causes of a problem (Benjamin et al., 2015).

The 5 Whys technique is similar to the Abstraction Ladder as there is nothing inherent to a problem that dictates it will be comprehensively understood or solved by asking “Why?” five times. Another challenge with both techniques is that there is nothing inherent about understanding a problem that excludes asking “Who?” “What?” or “Where?” for adding value to the process either. Asking other types of questions can illuminate additional layers of understanding and directions that would not have previously been explored by only asking “Why?” questions. Ultimately, the Abstraction Ladder is simply a tool for critical thinking, by directing the type of questions to ask and ordering those questions. Whether it is the Abstraction Ladder, 5 Whys, or first principles, the goal is to question assumptions and deconstruct problem/solution fit for a more comprehensive understanding of problem/solution fit, as well as the entirety of the product development process.

7.2.1 Initial Assessment of Bicycle Helmet Fit

Asking “Why?” and “How?” questions about the Severe Problem assists in critically thinking about the foundational elements of the problem the user group has experienced. Asking questions and seeking answers will most likely provide an initial road map for understanding the problem at a foundational level. In addition, the process of questioning and seeking answers may provide an overview for how to provide value that directly relates to the MVP, as well as future iterations and product categories.

Specific to this dissertation and the Severe Problem of helmet fit, one of the “Why?” questions asked was “Why do helmets fit improperly?” which is shown in Figure 7.2, in the right column. Secondary research shows one of the reasons for poor helmet fit has been, helmets were wider than the rider’s head (Rivara et al., 1999). In addition, helmets can be adjusted improperly and ride too high on the forehead (Rezendes, 2006). One of the reasons helmets can be too wide is due to the limited number of helmet shapes and sizes (Ball, 2014). To limit inventory, manufacturers will offer extra-small, small, medium, large, and extra-large sizes. However, “each manufacturer establishes their own sizing increments and there is no standardization” (Ball, 2014, 298). Unfortunately, the manufacturing constraints of creating helmet molds for all head sizes and shapes, as well as inventory constraints for having all sizes and shapes available can lead to improperly fitting helmets for various user groups.

With the goal of improving helmet fit an additional question to narrow the scope of inquiry could be, “How do we define, measure, and quantify improved bicycle helmet fit?” During the National Science Foundation’s I-Corps Program, our instructors also challenged our team with this question. During the program we spoke with pediatricians, coordinators at Safe Kids, the primary volunteer for the Bicycle Helmet Safety Institute, bicycle helmet testing lab personnel, as well as researchers at various universities regarding bicycle helmet fit. They described problems of helmet fit that are most relevant today, as well as strategies for assessing, evaluating, quantifying, and testing helmet fit.

After speaking with industry personnel, as well as conducting an initial literature review, a few themes relating to helmet fit emerged. Unfortunately, simply putting a bicycle helmet on one’s head and buckling the straps does not ensure it will be in the proper position and prevent head injury during a crash (Lee et al., 2009). Proper helmet stability, fit, and comfort can increase the likelihood that the helmet will be in the proper position during a crash (Ellena et al., 2016; Lee et al., 2009; Romanow et al., 2014). Many studies have examined a narrow focus for helmet stability, fit, and comfort. However, less is known regarding how to comprehensively assess, evaluate, and quantify these concepts in an effort to increase the likelihood it will be in the proper position to prevent and mitigate injury.

Helmet stability, fit, and comfort are abstract concepts that are uniquely different. However, there are similarities and overlap between the three, as shown in Figure 7.3. A brief overview and oversimplification of the relationships between the three are: 1.) Helmet stability is the helmet's ability to stay in the proper position while on the rider's head during movement; if the helmet is not stable, it inherently does not fit. 2.) Helmet fit is when the helmet is the correct size and shape and is in the proper position and contributes to no other pain points when worn. If the helmet does not fit, it is most likely also uncomfortable. 3.) Helmet comfort includes the aforementioned criteria for helmet fit, as well as characteristics such as thermal comfort and weight. However, characteristics such as thermal comfort and weight do not directly contribute to the helmet's comprehensive fit. Comfort is the most subjective concept of the three, relying on an individual's perception of comfort. If the helmet is not comfortable, challenges may arise such as, the rider may participate in the activity less, may decide not to wear the helmet, or may quit the activity altogether. While riding with an uncomfortable helmet, it may distract the rider, putting the rider at risk, or they may not enjoy the ride as much.

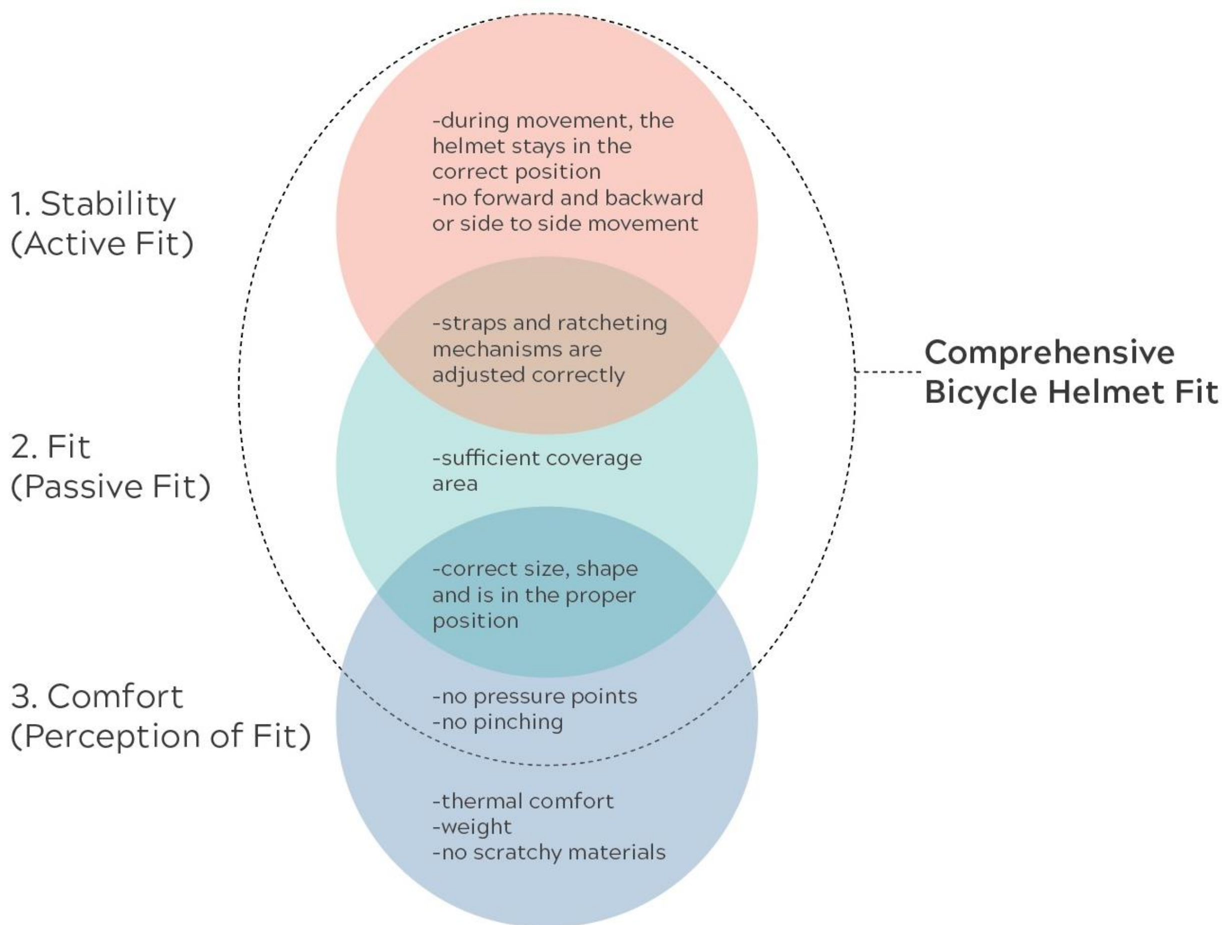


Figure 7.3 The overlapping components for Comprehensive Bicycle Helmet Fit, which comprises of 1.) Stability, 2.) Fit and 3.) Comfort

In reference to the Stability concept shown in Figure 7.3, helmet stability is the helmet's ability to stay in the proper position while on the rider's head. Helmet stability can include movement while a rider is trying on a helmet at a store shifting their head from side to side, movement while riding, but most importantly movement during a crash. As stated earlier, simply putting a bicycle helmet on one's head and buckling the straps does not ensure the helmet will not move forwards, backwards, or sideways (translate or rotate) (Thai, McIntosh, & Yen Pang, 2014). Movement of the helmet may obscure the rider's vision or expose their head to a direct impact (Thai, McIntosh, & Yen Pang, 2014). Unfortunately, it can be common for riders to wear helmets that can move out of the correct position, because the helmet is the wrong size or adjusted incorrectly (Thai, McIntosh, & Yen Pang, 2014).

In reference to the Fit concept shown in Figure 7.3, a bicycle helmet fits when it is the correct size, shape, is in the proper position, and contributes to no other pain points when worn. Similar to helmet stability, simply putting a helmet on a rider's head does not ensure it will fit. Factors contributing to improper helmet fit include the helmet may not be the correct size or shape, which may result in gaps between the helmet and the head, or insufficient coverage area of the helmet (Ellena et al., 2016). Improper fit may be the result of the helmet being adjusted incorrectly, which includes the maladjustment of straps and the rear adjustment mechanism (Ellena et al., 2016). Even if the helmet is adjusted correctly, the rear adjustment mechanism may give the appearance of fit, but still allow for the helmet to move forwards, backwards, and sideways (Ellena et al., 2016).

In reference to the Comfort concept shown in Figure 7.3, for a bicycle helmet to be comfortable, it includes the aforementioned criteria for helmet fit. In addition, comfort can include reducing characteristics such as pressure points or pinching. Comfort outside of fit can include thermal comfort and weight (Akbar-Khanzadeh et al., 1995). Comfort is both a subjective and relative term determined by physiological, psychological, and physical factors (Akbar-Khanzadeh et al., 1995).

As mentioned earlier in this section, there are many studies that examine one and occasionally two categories of bicycle helmet fit. However, none of the studies provide a comprehensive evaluation of bicycle helmet fit that includes elements of stability, fit, and comfort. As product development progresses towards solving the problem of helmet fit, improving and quantifying helmet fit should ideally include some combination of all three.

7.2.2 Initial Assessment of Customer Discovery/Lean Canvas and the Results

Typically, the Abstraction Ladder is used to address a problem or issue described in the initial statement. However critically thinking about problem/solution fit can include a reflection on the process that led to the initial statement. Asking questions about problem/solution fit within the context of Customer Discovery can assist in critically thinking about and assessing the process. Questioning the process will begin to develop a more comprehensive understanding of the methodology's value. A reflection of Customer Discovery could begin by asking, "Why use Customer Discovery for product development in entrepreneurship?" The answer to this question is that Customer Discovery, as a component of the Lean Canvas, focuses on what the customer immediately wants, or a pain point they are experiencing. It focuses on pain points they can articulate and are willing to spend money on, reducing the potential for new venture failure. With Lean Canvas, the NVT does not have a "product" and they are not "in" a market. Rather, they have hypotheses about a Severe Problem, current customer solutions to that Severe Problem, and potential early adopters. The NVT is then trying to get feedback from those potential early adopters.

In order to evaluate Customer Discovery, an additional question could be, "What are the advantages and disadvantages of Customer Discovery?" The first advantage of using Customer Discovery is that it provides clearly defined product risk, market risk, and customer risk hypotheses, from which the NVT can assess progress and pivot quickly. The heart of Customer Discovery is the problem interviews. The initial set of interviews allowed us to challenge or support assumptions. Then, if the assumptions were wrong, we pivoted quickly. This lesson was particularly true with our first target market, Pro and Semipro Men. They were end users of bicycle helmets but did not have a Severe Problem with current product offerings and received free products from sponsors, so there was no customer. There were no clear indicators of a viable Severe Problem or potential early adopters, so we pivoted.

The second advantage of Customer Discovery is it can be used for acquiring early adopters as a result of interacting with participants through the problem interviews. When the NVT pivots and finds a Severe Problem, there is a good indication that those participants may also buy the product before the majority of customers. Early adopters found through Customer Discovery allow a new venture to gain traction and can circumvent the immediate need for sales channels and customer acquisition costs.

However, the process is not perfect. One of the biggest challenges of the process is that trusting interviews as the primary source of data relies on participants to know and understand their behavior, with the anticipation that they will be able to articulate that behavior to the NVT. The NSF I-Corps program serves as an example that demonstrates the challenge of relying on interviews as the primary source of evidence for directing the NVT's progress. One of the main goals of the NSF I-Corps Program is "evidence-based business decision making" (Cordova, 2019, 7). The evidence the program is referring to is what the participants said during the interviews to challenge and support an I-Corps Team's business hypotheses. However, the challenge is that teams participating in I-Corps are warned that "customers can have mental blocks that could prevent successful interviews. (e.g., not perceiving the problem as a problem, thinking there cannot be a tangible solution to the problem, having limited resources, having expectations that limit their behaviors)" (Batova et al., 2016, 3).

The fundamental challenge of seeking to understand the behavior of people groups is reflected in anthropology. In fact, anthropologist Margaret Mead describes the challenge of seeking to understand, which is paraphrased as, "what people say, what people do, and what they say they do are entirely different things" (Ewing et al., 2010, 74). Thus, relying on only one source of information, in this context, semi-structured interviews with open-ended questions, leaves an incomplete understanding of what the NVT is seeking to understand, which is, what is a product or service that will sell. The challenge of relying on interviews as the primary form of evidence for business decision making highlights the need for exploring other forms of learning and constantly reflecting on what the interviewees are telling the NVT during the interviews as well. A reflection can guide the choice and wording of later questions during that interview (i.e., the interviews do not have to follow a strict script, it is at best semi-structured) and future interviews; the choice of other people to interview; and the choice for other forms of learning (i.e., other product development methodologies). During Customer Discovery, it can be helpful for the NVT to continually synthesize answers from the interviews and determine how those responses will direct the NVT's next steps.

From an application standpoint, open-ended interviews can make post processing or coding the interviews difficult. During an interview topics, questions, and answers can spill into each other and they are not always linear or consistent with other participants. For example, if the NVT asks "what are some of your likes and dislikes with riding?" there are limitless possibilities to how the participant can answer. It is unlikely, but they may immediately begin talking about helmet fit as a dislike. Unfortunately, the open-ended nature of the interviews and varying ways a participant can respond could skew sections of the interview, resulting in inconsistent feedback, making processing more difficult.

However, despite its shortcomings, Customer Discovery adds breadth and depth to the product development process. It adds breadth by identifying other potential markets for future product development both internally and externally to the bike industry. Also, the process adds depth with insights for a supporting business model.

7.3 Discussion

In contrast to the approaches described by Maurya, Blank, Dorf, Osterwalder, and Pigneur, the first principles approach described in this dissertation improves initial product development over existing approaches by incorporating a feasibility analysis. Including a feasibility analysis at this point in the process can be critical for evaluating the overall business, serving as a reference point for the NVT, and signaling to key stakeholders the new venture is worth pursuing.

So far, the NVT has been evaluating the initial components of an idea by challenging assumptions through Customer Discovery. The problem interviews should have found a problem that can drive product development. Then, if the NVT has progressed to brainstorming sessions and solution interviews, there should be supporting evidence for product/service feasibility. However, as described in section 7.1, there are other important elements of a business that need to be considered, which is the purpose of the feasibility analysis. Without conducting a feasibility analysis, an NVT can be blinded to the “inherent risks associated with the potential business and results in too positive of a plan” (Barringer & Ireland, 2016, 77). Similar to the way in which Customer Discovery evaluates the initial components of an idea, a feasibility analysis evaluates the components of a business through what was learned during Customer Discovery, a as well as secondary research (Barringer & Ireland, 2016).

Although a feasibility analysis is not included in texts such as *Running Lean, The Startup Owner’s Manual,* and *Business Model Generation*, it is included in the text *Entrepreneurship* by Barringer and Ireland. As described in section 7.1, a feasibility analysis can help an NVT assess the new venture’s strengths and weaknesses, to determine what needs to be improved (Barringer & Ireland, 2016). When the NVT can determine what needs to be improved, they can make sure they are spending the necessary time and resources to make those improvements.

Similar to the product brief described in section 5.3.4, the feasibility analysis serves as a reference point for the NVT. When trying to launch a new venture, there can be psychological stresses that put considerable strain on the NVT (Lagorio-Chafkin, 2013). The stresses of trying to launch a new venture have been described as, “starting a company is like eating glass and staring into the abyss” (Lagorio-Chafkin, 2013). Some of the challenges the NVT can experience are technical relating to the development of the product or service, as well as environmental relating to regulatory bodies, distribution, and logistics, all of which are important for the survival of the new venture. As the NVT is pulled in many directions, the feasibility analysis can serve as a reference point to make sure that as the NVT makes progress, their activities are in line with the other components of the business.

After the NVT has completed the feasibility analysis and found the new venture is an opportunity worth pursuing, the feasibility analysis can signal that the company has potential to be successful to key stakeholders (Barringer & Ireland, 2016). Key stakeholders can include new team members, advisors, directors, and investors. So, including a feasibility analysis at this point in the process can be critical for evaluating the overall business, serving as a reference point for the NVT, and signaling to key stakeholders the new venture is worth pursuing.

As the NVT pauses, another opportunity to improve initial product development for the NVT is to consider the foundational elements and broader context of the problem the NVT has identified. Similar to the ways Customer Discovery evaluates the initial components of an idea and a feasibility analysis evaluates the components of a business, applying the Abstraction Ladder serves as a tool for evaluating and critically thinking about the broader context of problem/solution fit. Applying the Abstraction Ladder serves as a critical step for evaluating the foundational elements of the problem driving product development. Authors such as Maurya, Blank, Dorf, Osterwalder, and Pigneur describe how to measure an MVP, verify product/market fit, validate the customer lifecycle, and explore other components of the business model canvas. However, they do not allow space for the NVT to evaluate the problem driving product development or the entrepreneurial processes that determines what the NVT know.

The context of problem/solution fit can include evaluating the problem that is driving product development. If the NVT can determine a new venture is worth pursuing, they should be thinking about the foundational elements of the how their product or service provides value, which can begin with understanding the Severe Problem. A better understanding of the Severe Problem can lead to a better product experience for end users, as well as lead to new product categories, ideas, features, and benefits.

The context of problem/solution fit can also include evaluating the entrepreneurial processes in which problem/solution fit was found. There can be flaws in the entrepreneurial processes that the NVT is following or biases from the authors who are describing those processes. For example, authors such as Maurya, Blank, and Dorf have implicit and explicit biases towards digital products in their texts. Those flaws and biases can negatively affect what the NVT knows about their potential new venture. If there are flaws and biases, the NVT can figure out what needs to be changed and potentially apply more appropriate processes.

When evaluating and critically thinking about the broader context of problem/solution fit, there are multiple methods that can be used such as the Abstraction Ladder or 5 Whys. In addition, there are many ways to ask “How?” and “Why?” questions. An area for future work could include evaluating different methods for critical thinking, as well as how to ask better questions.

Taking time to critically think about both the Severe Problem and the process or method that led to that discovery can seem like a competing objective to initial product development. Initial product development directly contributes to the minimum viable product and product/market fit. However, critically thinking about the broader context of problem/solution fit can be time and resource intensive, where the specific long-term benefits are not readily identifiable. Although the specific long-term benefits may not be readily identifiable, adding a step for critical thinking can help an NVT consider alternative viewpoints, identify areas for future development, and respond to unexpected challenges and opportunities (Souder et al., 2015).

7.4 Contribution

The primary contribution from this research question is an improved product development process, by including a step for critically evaluating the Severe Problem and the product development process. Including a step for evaluation is anticipated to lead to a better product. Critically thinking now about the Severe Problem driving product development can help the NVT begin solving the nuances of the problem earlier than thinking about the nuances of the problem when they have finished developing the MVP. Critically thinking now about the product development process can also improve future product development. For example, if finding a Severe Problem is not the best driver for product development, an assessment of Customer Discovery can help find what may be a better driver for product development for the best early adopter group. In addition, critically thinking about the process used can help an NVT determine if they are using the best and most appropriate process to reduce risk for future ventures and products the NVT may launch. Finally, a contribution from this research question is a demonstration of how to apply a feasibility analysis.

7.5 Chapter Summary and Next Steps

In summary, at this point, the NVT has spent many long days and nights conducting interviews, as well as completed some initial product development. The purpose of this section was to describe two strategies, feasibility analysis and the Abstraction Ladder, for critically thinking about the foundational elements of a potential new venture. As the NVT pauses Customer Discovery, they should assess what they have learned through a feasibility analysis. The feasibility analysis in section 7.1 found primary and secondary research which supports that a new venture should be pursued further. As the NVT pauses Customer Discovery, section 7.2.1 describes a process for the NVT to critically think about the foundational elements of the problem they are trying to solve by applying the Abstraction Ladder. Then section 7.2.2 describes how the NVT should also critically think about the advantages and disadvantages of the process they are using.

Using the Abstraction Ladder, a new venture team can critically think about the new venture's foundational elements, namely the product development process that determines what they know, as well as the resulting problem discovered in the interviews. As progress is made, additional exploration of product/market fit can be explored, as well as additional application of the Abstraction Ladder that relates to the product or service. Application of the Abstraction Ladder can be an ongoing process, and leads to the final research question, "How does one reason back from the solution to better understand both the Severe Problem and solution more comprehensively, and at a foundational level to improve product development?" which will be covered in the next chapter.

Chapter 8 Additional Application of the Abstraction Ladder

The previous chapter assessed the new venture by performing a feasibility analysis, evaluated the problem driving product development by applying the Abstraction Ladder, and provided a critical reflection of Customer Discovery. Similarly, this chapter is about critical reflection, evaluating other product development methodologies and applying the Abstraction Ladder to explore other foundational elements relating to developing bicycle helmets.

Section 8.1 begins with a chapter overview. Section 8.2 provides an assessment of relevant product development methodologies, specifically examining Jobs to Be Done and Design Thinking. Section 8.3 describes an initial assessment of injury biomechanics, specifically examining how industry standards relate to the early adopters. Section 8.4 provides an assessment of an end user's relationship to risk in cycling. Section 8.5 describes an assessment of the final solution's foundational elements, specifically examining the engineering and design. Section 8.6 describes the chapter's discussion. Section 8.7 reiterates the contribution from the chapter and Section 8.8 presents a chapter summary.

Research Question 4: Once a solution to the Severe Problem has been found, how does one reason back from the solution to better understand both the Severe Problem and solution more comprehensively, and at a foundational level to improve product development?

The contribution from this research question is a product development process that includes a step for evaluating the environmental factors and foundational elements that shape problem/solution fit. For this specific dissertation, environmental factors can include other relevant product development methodologies for directing future product development, such as Jobs Theory and Design Thinking. In addition, for this specific dissertation, foundational elements that directly relate to problem/solution fit can include an initial assessment of injury biomechanics, psychology, engineering, and industrial design. Due to the critical nature of PPE, beginning to learn about the foundational elements across each discipline should provide improved safety for the rider, by improving performance of the design, as well as reduce potential for product failure. Entrepreneurs, product developers, and researchers can apply the Abstraction Ladder to understand other relevant subjects that shape their own products or services, or other ways to improve product development.

8.1 Chapter Overview

Answering Research Question 4, calls for continued critical reflection, which can help identify areas for future research. A critical reflection can include an assessment of additional product development methodologies. In addition, a critical reflection can include continued application of the Abstraction Ladder for a growing knowledge of problem/solution fit and the relationships between disciplines. The Abstraction Ladder is applied by asking supplementary "Why?" and "How?" questions (LUMA Institute, 2012). For this dissertation, I explored additional foundational elements of problem/solution fit through supporting classes, literature reviews, writing and documenting each silo and relationships between silos. Asking supplementary questions, as well as writing and documenting the process, facilitates a more holistic understanding of A First Principles Approach to Product Development in Entrepreneurship. Continued exploration directed by the Abstraction Ladder is an interdisciplinary process that involves collaboratively identifying new areas for exploration. Identifying new areas for exploration and future work can be important to both scholarly research and entrepreneurship, as they share similarities in that they are both ongoing pursuits that lead to more questions. For this dissertation, by applying the Abstraction Ladder, I have identified future work that is both relevant to research, as well as the new venture.

For this dissertation, based on supplementary questions from the Abstraction Ladder, I have identified three areas of focus. The areas of focus include initial assessments of injury biomechanics, psychological factors for bicyclists, and the final solution's engineering and design. As stated at the beginning of this section, a critical reflection can help identify areas for future work before conducting an extensive investigation on the topic. Each area of focus could require its own in-depth level of review and research. For other entrepreneurs, product developers, or researchers who have identified a different problem/solution fit, they will most likely have different areas of focus.

Section 8.2 continues the evaluation of product development methodologies that may be relevant to an NVT. I reviewed both Jobs Theory and Design Thinking (Plattner et al., 2011; Ulwick, 2016). The reason for assessing these specific strategies is because they have both been promoted in university settings (Chen et al., 2018; York, 2018). In addition, the focus of this dissertation is understanding and applying product development strategies, so an extensive summary was appropriate.

Then section 8.3 continues the application of the Abstraction Ladder from Chapter 7. The next follow up question is, "Why do head injuries happen?" To address this question, the section provides a brief overview of injury biomechanics in relation to bicycling. In addition, some initial directions are presented for assessing the Consumer Product Safety Commission's (CPSC) Safety Standard for Bicycle Helmets 16 CFR 1203 and Virginia Tech's Helmet Standard (CPSC, 1998; Virginia Tech Bicycle Helmet Ratings, 2023).

Next, in section 8.4, an additional follow up question is, "Why do end users take risks?" To address this question, a brief overview is presented on how risk and risk compensation relate to riders and the mechanism of injury they encounter, as well as additional recommendations for further areas of study.

In section 8.5, additional questions are, "How can that particular design be improved?" along with a few supplemental "Why?" questions. To address these questions, some initial directions are presented for exploring the questions further, specifically in relation to mechanical engineering, material science, and industrial design.

A recurrent assessment of problem/solution fit, by applying the Abstraction Ladder, can serve as a continual feedback loop for iterative improvement. The process cannot be fully realized through one individual and is collaborative in nature. The process is also interminable, and a comprehensive understanding of all disciplines and the interactions of those disciplines is beyond the scope of this dissertation, because each area of focus could require its own in-depth level of review and research. However, an initial exploration of each can help provide strategic guidance for the new venture's long-term vision.

8.2 Assessment of Alternative Product Development Strategies

There are other methodologies that could be appropriate for product development, and those methodologies should be evaluated as well, to find additional nuances about the target market, other market segments, or product ideas. As stated in section 7.2.2, critically thinking about problem/solution fit can include a reflection on the process that led to problem/solution fit. As the NVT makes progress when trying to launch their new venture, they may encounter other entrepreneurial programs and instructors which recommend other methodologies. Those methodologies may or may not be appropriate for the NVT and need evaluation as well. In addition, in section 7.2.2, the NVT may have determined that the Lean Canvas was not an appropriate methodology for them. Or, as the NVT moves beyond the MVP and expands the product line, there may be less of need to focus on a Severe Problem to reduce product failure. So, it is appropriate to explore other strategies that do not focus on a Severe Problem for driving product development.

This section provides a critical reflection of two popular alternatives to Customer Discovery, which are Jobs to Be Done and Design Thinking. An NVT has other choices for product development strategies that it might pursue besides Customer Discovery which has been the focus of the previous chapters. The goal of this section is to help an NVT judge which of the alternatives might be appropriate for the NVT's specific needs and next steps.

As detailed in section 7.2.2, Customer Discovery has the advantages of clearly defining hypotheses about product, market, and customer risks; and of being useful for identifying and acquiring early adopters by interacting with them through the interviews. At the same time, the process has the disadvantage of having the interviews as the primary source of data, with the accompanying challenge of understanding the behavior of people based upon what they have said during a brief interview. The remainder of this section will compare advantages and disadvantages of Jobs to Be Done and Design Thinking, two strategies that have also been promoted in university settings for both product development and entrepreneurship (Chen et al., 2018; York, 2018).

8.2.1 Jobs To Be Done

The product development strategy Jobs To Be Done (JTBD) is also known as Jobs Theory (Ulwick, 2016). Two authors on the subject are Clayton Christensen, who is a professor at the Harvard Business School and Tony Ulwick, who is CEO of the innovation consulting firm Strategyn (Christensen et al., 2016; Ulwick, 2016). The following summary and overall assessment of JTBD is based on Christensen's book, *Competing Against Luck,* and Ulwick's book, *Jobs To Be Done*.

JTBD seeks to understand causal mechanisms and the core functional job for a product or service (Christensen et al., 2016; Ulwick, 2016). Christensen observed a problem where companies would accumulate large amounts of data to "predict which ideas will succeed" (Christensen et al., 2016, xi). The companies would use correlations from similar customer profiles or past product performance as a predictor for success (Christensen et al., 2016). Unfortunately, this approach to product development often proved unsuccessful (Christensen et al., 2016). Tony Ulwick describes a slightly different experience, where he observed problems with company's innovation strategies that focus on either solutions (or ideas) or customer needs (Ulwick, 2016). Both authors use an example of JTBD from former Harvard marketing professor, Ted Levitt. In the example Levitt describes, "people don't want to buy a quarter-inch drill. They want a quarter-inch hole… Customers don't want products, they want solutions to their problems" (Christensen et al., 2016, 177).

An overview of JTBD is the "job" could be a problem someone is experiencing or goal they are trying to achieve (Christensen et al., 2016). The "to be done" could be when that problem is solved or the goal completed, focusing on "what consumers care most about in that moment of trying to make progress" (Christensen et al., 2016, 36). Application of the methodology is largely describing the use of qualitative research methods, through questions and observations with key stakeholders (Christensen et al., 2016; Ulwick, 2016). The goal of applying the qualitative research methods is to provide additional layers of context, which includes the functional, emotional, and societal components of the job (Christensen et al., 2016;

Ulwick, 2016). These additional layers of context will then serve as a catalyst for product related ideas or the basis for market segmentation, a product brief, a value proposition, or a mission statement.

From Christensen's perspective, examples of a JTBD are:

- For TurboTax the JTBD was, "completing customers' taxes without their having to answer any questions or input any data" (Christensen et al., 2016, 199).
- For a restaurant selling milkshakes, from the perspective of their customer, the JTBD was, "I need something that will keep me occupied with what's happening on the road while I drive. And also, I'd like this to fill me up so that I'm not hungry during a 10:00 am meeting. I could hire a banana, doughnuts, bagels, Snickers, or a coffee to do this job" (Christensen et al., 2016, 225-226).

From Ulwick's perspective, examples of JTBD are:

- For Keurig, the JTBD was, "prepare a hot beverage for human consumption" (Ulwick, 2016, 87).
- A generic example given was, "get breakfast while commuting to work" (Ulwick, 2016, 90).
- Ulwick is very specific about describing a Jobs statement as, "verb + object of the verb (noun) + contextual clarifier" (Ulwick, 2016, 91).

Using the language of JTBD can be confusing. In Christensen's early development of Jobs Theory, he describes a conversation with Unilever executives where he recounted the theory. In the discussion Christens says, "the conversation did not go well. Perhaps we didn't have the right language at the time to explain our thinking, but the Unilever executives in the room were not moved by what we were trying to say" (Christensen et al., 2016, 13). As a graduate student who has experience in product development, as well as having read both books more than once, there are still parts that are confusing and inconsistent to me. In both books, JTBD is described in a variety of ways, two of the ways it is described are:

- "Customers don't buy products or services; they pull them into their lives to make progress. We call this progress the 'job' they are trying to get done, and in our metaphor we say that customers 'hire' products or services to solve these jobs" (Christensen et al., 2016, 27).
- "People buy products and services to get a job done. The job the end user is trying to get done is the core functional job. A deep understanding of the core functional job enables a company to create product or service offerings that get the job done significantly better than competing solutions" (Ulwick, 2016, 53).

In order to discover or understand the JTBD, both books describe a variety of case studies and examples of companies and existing products. Then both authors question the context of the company's products by peppering the text with many questions about why the customer buys (Christensen et al., 2016; Ulwick, 2016). Christensen even compares his approach to understanding why, to the work of Deming and Juran, in their effort to "identify the root cause of each and every problem," where their focus of understanding was specific to automotive manufacturing (Christensen et al., 2016, 25). However, additional comparisons could be made to Sakichi Toyoda's 5 Whys, where the goal is to understand the foundational elements of a problem (Serrat, 2017). Ulwick provides an example of how to properly ask a contextual "Why?" question, recommending the interviewer ask, "Why are you using that product?" instead of asking, "What job did you hire that product to do?" (Ulwick, 2016, 87).

Now that the theory and methodology have been generally described, the next step is to determine how to apply the theory in order to get actionable results. Unfortunately, both

Christensen and Ulwick provide minimal amounts of practical advice. Christensen describes that the one conducting the interviews should have “a ‘beginner’s mind’ as you walk through a consumer’s decision-making process, looking for clues to the full picture of the struggle” (Christensen et al., 2016, 106). Then as the NVT walks through the customer’s decision-making process, the goal is to cluster insights, as opposed to having a single eureka moment (Christensen et al., 2016). Christensen describes the compelling nature of insights as “you don’t have to convince yourself that it’s important or powerful. You just know” (Christensen et al., 2016, 119). The practical application of the theory appears to be similar to that of the NSF I-Corps program. For this program, much of the advice for conducting interviews is to ask open ended questions, listen and do not talk about the product, where the goal of the interview is veiled in the ambiguity of discovering “aha” moments and insights (Batova et al., 2016; Leatherbee & Katila, 2020).

Both Christensen and Ulwick describe common approaches in qualitative research, anthropology, and product development for discovering the customer’s job to be done (Christensen et al., 2016; Ulwick, 2016). The approaches include interviews, observations, ethnographic research, and focus groups (Christensen et al., 2016; Ulwick, 2016). However, the primary approach that both authors focus on is interviews with key stakeholders (Christensen et al., 2016; Ulwick, 2016). Christensen goes as far as to include a portion of an interview transcript as an example for discovering insights (Christensen et al., 2016).

When trying to discover jobs, by asking open ended questions to key stakeholders, Christensen recommends looking for the following, which is paraphrased as:

- Finding a job close to home, meaning find problems or goals that you have in your own life.
- Competing with nothing, meaning understand why the customer does not buy or use a product or service, and possibly create something that fills that void.
- Workarounds and compensating behaviors, meaning understand what people have created to solve their own problem.
- Look for what people do not want to do, meaning find a behavior, duty or errand they are avoiding.
- Unusual uses, meaning is the customer using a product or service for something other than what it was intended for (Christensen et al., 2016).

Christensen embraces the interpretive nature of qualitative inquiry, whereas Ulwick desperately tries to make it objective. Ulwick goes as far to say, “When it comes to an effective innovation process, cobbling together a hodgepodge of incompatible practices and relying on qualitative insights alone just doesn’t work. What companies need is a comprehensive, customer-centric, data-driven innovation process that is built around Jobs Theory” (Ulwick, 2016, 81). Ulwick attempts to deliver on a data-driven approach through his step-by-step process of Outcome-Driven Innovation. A large component of the process involves quantifying the qualitative data from the interviews.

An example Ulwick uses for quantifying and rank ordering interview responses is Bosch’s application of the process to create a new circular saw. For this example:

- First, they interviewed tradesmen who want to “cut wood in a straight line” (Ulwick, 2016, 97). Tradesmen are the customers, and “cut wood in a straight line” is the Job-to-be-Done (Ulwick, 2016, 97).
- Second, from the interviews they identified 75 desired-outcome statements. An example of an outcome statement is “minimize the likelihood that the cut goes off track when finishing the final cut” (Ulwick, 2016, 104).

- Third, they surveyed 270 users of circular saws, asking them to rate the importance of each desired-outcome statement in relation to their own personal circular saw, as well as competitors circular saws.
- Fourth, they applied their Opportunity Algorithm in order segment which desired-outcome statements were of high importance to the customer, as well as which ones were underserved from current available product offerings (Ulwick, 2016).

After compiling the data, Bosch was able to draw conclusions about what desired outcomes were being met by their competitors, as well as which desired outcomes should be prioritized. It is anticipated that conclusions determined from applying these steps will direct the development of future products. The steps that Ulwick is describing are very similar to the qualitative research approach grounded theory. In grounded theory, first there is the use of open-ended interviews for data collection. The data analysis then consists of coding the interviews, meaning, categorizing ideas or happenings the participant describes (Creswell, 2007). However, in the JTBD process Ulwick describes, he gives the codes a specific name, calling them desired-outcome statements. In addition, Ulwick puts an emphasis on translating the responses from the interviews into quantitative data.

It should be noted that there are some limitations with Ulwick's approach and his determination to translate qualitative answers into quantitative data. The first limitation is Ulwick does not provide any standardized approach to conducting an interview. As a result, what questions are asked, how they are asked, and the level of probing will be different from interviewer to interviewer. The lack of standardization for the interview process will affect which outcome statements surface during the interviews. The second limitation is that Ulwick does not address how to interpret answers from interviews to generate desired outcome statements. The third limitation is Ulwick states that for every JTBD, such as "cut wood in a straight line," 50 to 150 desired outcome statements are needed (Ulwick, 2016, 97). When rating lists of preferences, participants can lose interest or have difficulty understanding the nuanced language between each statement (Ellena et al., 2016). The loss of interest or difficulty with understanding can result in participants copying the same score from statement to statement (Ellena et al., 2016). Finally, the practice of translating qualitative answers into quantitative data should be approached cautiously. Rating the desired outcome statements and applying the Opportunity Algorithm, shares similarities to the Quality Function Deployment (QFD), a common product development tool in engineering (Park & Kim, 1998). However, the value and objectivity of translating qualitative answers into quantitative data may be questionable, as described in section 5.2.4.

8.2.2 Additional Challenges and Benefits of Jobs To Be Done

As previously mentioned in section 8.2.1, a challenge of JTBD is that the language can be confusing. Specifically, use of the term "job" seems like an unnecessary layer of semantics referencing terminology already common in entrepreneurship and product development. Christensen describes that "Jobs Theory is not useful if there is no real struggle for a consumer" (Christensen et al., 2016, 40). The emphasis Christensen puts on the "struggle for a consumer" sounds very similar to Steve Blank's "active (or urgent) problem" or Ash Maurya's "problem worth solving" (Blank & Dorf, 2012, 85; Christensen et al., 2016, 40; Maurya, 2012, 8). In addition, many of the examples that both Christensen and Ulwick provide describe customers that are experiencing problems. So, it could be more appropriate to simply say customer problems instead of customer jobs.

Another limitation of JTBD is Christensen and Ulwick's use of interviews and open-ended questions to uncover problems. Their use of interviews and open-ended questions appears to be a rebranding of existing methods in qualitative research, anthropology, product development, and even entrepreneurship. For Jobs Theory, both the emphasis of a problem when describing a job, as well as the use of interviews and open-ended questions makes it difficult to differentiate from product development approaches such as Lean Canvas, Customer Discovery, and the Business Model Canvas.

Another challenge with Jobs to Be Done is there are inherent competing objectives. The competing objectives are understanding the individual context of a customer in order to develop a compelling product or service, while at the same time ensuring the market is large enough that a business can be built around it. Every customer segment and job to be done could be 1 of 1, however this level of segmentation is unrealistic for most companies. Many of the JTBD examples describe larger companies with established products, such as Arm & Hammer’s box of baking soda (Christensen et al., 2016). In the 1960’s, the company started coming up with new baking soda related products, based on the ways customers were using the product (Christensen et al., 2016). Some of the products they developed for new markets were laundry detergent, toothpaste, and carpet cleaner (Christensen et al., 2016). This example of product segmentation highlights the question, as a product team solicits feedback and begins to understand the context of a product or service, when is the market big enough to segment the market further and launch additional products? Answering this question is beyond the scope of this dissertation because, the new venture that is the topic of this dissertation has not produced its first MVP yet. However, the question should be considered more thoughtfully as the new venture develops its first MVP and begins to move from early adopters to the early majority.

As the product team solicits feedback and begins to understand the contextual use case, another challenge is knowing, what is the appropriate level of abstraction when determining the job? Both Christensen and Ulwick describe the example from Ted Levitt, where “people don’t want to buy a quarter-inch drill. They want a quarter-inch hole" (Christensen et al., 2016, 177). However, people do not necessarily want a quarter-inch hole either. Rather, they want a hobby they can do with a relative, be able to accomplish basic home repair, or learn a trade. Only focusing on one step in the process can exclude additional context relating to the job.

An advantage of applying Jobs Theory is that the theory can reframe the end user’s problem from a solution focus to a jobs focus. For example, an anesthesiologist who is checking up on a patient might look at a computer monitor to do so (Ulwick, 2016). By narrowing in on the doctor’s interaction with the computer monitor, there is a solution focus. Rather, another way to reframe the scenario is, the anesthesiologist is “monitoring the patient's vital signs,” (Ulwick, 2016, 91). By reframing the scenario to a jobs focus, it now describes the goal the anesthesiologist is trying to accomplish, which is monitoring the patient’s vital signs (Ulwick, 2016). Reframing the scenario in this way allows for ideas to solve the problem that are not directly tied to solutions that require interfacing with a computer monitor. Reframing the job and giving it the appropriate level of abstraction allows for solutions from different product categories. When NVT’s are conducting interviews and finding problems that can drive product development, it is recommended to reframe the problem from a solution focus to a jobs focus.

8.2.3 Design Thinking

Design Thinking was also considered, as variations of the methodology have been around for decades. It was given structure in the 1980's through David Kelly and IDEO, and popularized in the 2000’s through Stanford’s D.School (D. Kelley & Kelley, 2013; Kimbell, 2011; Plattner et al., 2011). Design Thinking consists of five stages: empathize, define, ideate, prototype, and test (Sarooghi et al., 2019). The methodology focuses on developing solutions for people as a whole. Also, it is more abstract than either Lean Canvas or JTBD and does not require entrepreneurship or even product development as a solution. However, the framework for Design Thinking shares many parallels to Customer Discovery.

The first two steps of the process, empathize and define, most closely relate to the Customer Discovery Process through establishing hypotheses around a product, market, and customer segments, as well as conducting problem interviews. The third step in the process, ideate, closely aligns with brainstorming sessions as they both rely on divergence, exploring a wide range of solutions. Finally, the last two steps, prototype and test, closely relate to the solution interviews, as both methodologies rely on converging on a single solution at various forms of development and soliciting feedback.

The biggest advantage of Design Thinking, compared to Lean Canvas and Customer Discovery is that Design Thinking can take a much broader, deeper, and holistic effort to understand the end user and their needs, focusing on what is best for them. Design Thinking can be exceptionally open ended and seeks the ideal solution (Liedtka, 2014). However, a disadvantage with the methodology is that it can be time intensive. Another potential disadvantage for NVTs is that Design Thinking solutions do not have to be product oriented. The process looks at any solutions for solving pain points or reaching objectives, so it is not always best suited for a new venture.

In entrepreneurship and product development many authors reference and have varying perspectives on Design Thinking. For Customer Discovery, Ash Maurya recommends observation, interviewing, and techniques from Design Thinking for understanding a customer's problem (Maurya, 2012). When comparing Jobs Theory to Design Thinking, Christensen describes that both approaches, "prioritize users' experiences over product attributes" and are complementary to each other (Christensen et al., 2016, 122). However, whether it is an accurate observation or not, he makes the distinction that "Jobs Theory provides a *causal* explanation for why customers will embrace some innovations and not others" (Christensen et al., 2016, 122). Ulwick views Design Thinking differently as his primary criticism of the approach is that it is, "more of an art than a science" (Ulwick, 2016, 43). However, when describing Design Thinking in that way his biggest criticism is that the approach does not necessarily attempt to quantify qualitative insights.

8.2.4 Product Development Strategies Summary

At the end of the day, Lean Canvas, Customer Discovery, JTBD, and Design Thinking all share a common foundation. For those that want to create things or change behaviors, the methodologies can direct them to learn something, whether that something is about an end user's goal, pain point, or a causal mechanism, by soliciting additional perspectives. Usually soliciting additional perspectives is achieved by getting out of the building, talking with end users, and key stakeholders. From those conversations, it is anticipated that the result from gathering the data will be actionable information that serves as the impetus for the development of a product or service. The success of that product or service can be measured in various forms including, but not limited to sales, user engagement, or company exposure.

When reviewing and describing the theory, methods, and techniques for Lean Canvas, Customer Discovery, JTBD, and Design Thinking, each seems to have its own set of operationally defined terms. Or worse, the authors are using terms such as problems, needs or jobs, but do not define them, which makes them difficult to distinguish from one another. Gerry Katz, the vice president of Applied Marketing Science goes as far to say, "since at least the mid-1980's: wants, needs, requirements, benefits, problems, tasks that the customer is trying to accomplish, and jobs which the customer wishes to get done," are all conceptually similar (Katz, 2008, 3; Ulwick, 2016, 43). Whereas Ulwick and Christensen deny this generalization (Christensen et al., 2016; Ulwick, 2016). Christensen even goes so far as to compare the importance of Jobs Theory to Copernicus's discovery that planets revolve around the sun and not the earth (Christensen et al., 2016). The author boldly claims, "without the right understanding of the *causal mechanisms* at the center of the innovation universe, companies are trying to make sense of the universe revolving around the earth" (Christensen et al., 2016, 42).

Additional considerations would be to explore product development from an anthropological perspective as mentioned in section 7.2.2. Customer Discovery, JTBD and Design Thinking rely heavily on user feedback. Relying heavily on user feedback leads to an unrealistic expectation that human beings can fully understand and describe their thoughts, motivations, and behavior. There is no third-party perspective for what is truly driving behavior. In cultural anthropology, "a combination of observation of what people actually do with verbal data about what people say they do and think is essential for a well-rounded view of a culture," a sentiment that can be equally true for product development (Miller, 2011, 37).

An extension of the process assessment could include anthropologic-based methodologies for finding a problem that can drive product development (Moggridge, 2007). In addition, applying anthropologic-based methodologies could complement interviewing techniques, as described in section 7.2.2, there can be limitations with relying heavily on interviews. Applying anthropologic-based methodologies could also provide a deeper understanding of the problems experienced by the end user to direct additional product development. Methodologies may include, but are not limited to, action research, participatory design, and ethnography. These anthropologic-based methodologies are themselves the subjects of a large body of literature (Asaro, 2000; Barab et al., 2008; Hemment, 2007; Miller, 2011).

8.3 Initial Assessment of Injury Biomechanics

As stated in section 8.1 applying the Abstraction Ladder can help identify areas for future work before conducting an extensive investigation on the topic. However, each area of focus could require its own in-depth level of review and research. Section 1.2.2 described how historically, there has been a severe disconnect between injury biomechanics, standards, and solutions for PPE. The disconnect between disciplines can result in greater risk of injury to the athletes that participate in those activities. Applying the Abstraction Ladder to identify the foundational elements of relevant injury biomechanics and helmet standards could help identify areas for improvement. So, a follow up question could be, "Why do head injuries happen?" In Figure 8.1, the new question is featured on the right-hand side at the top of the figure.

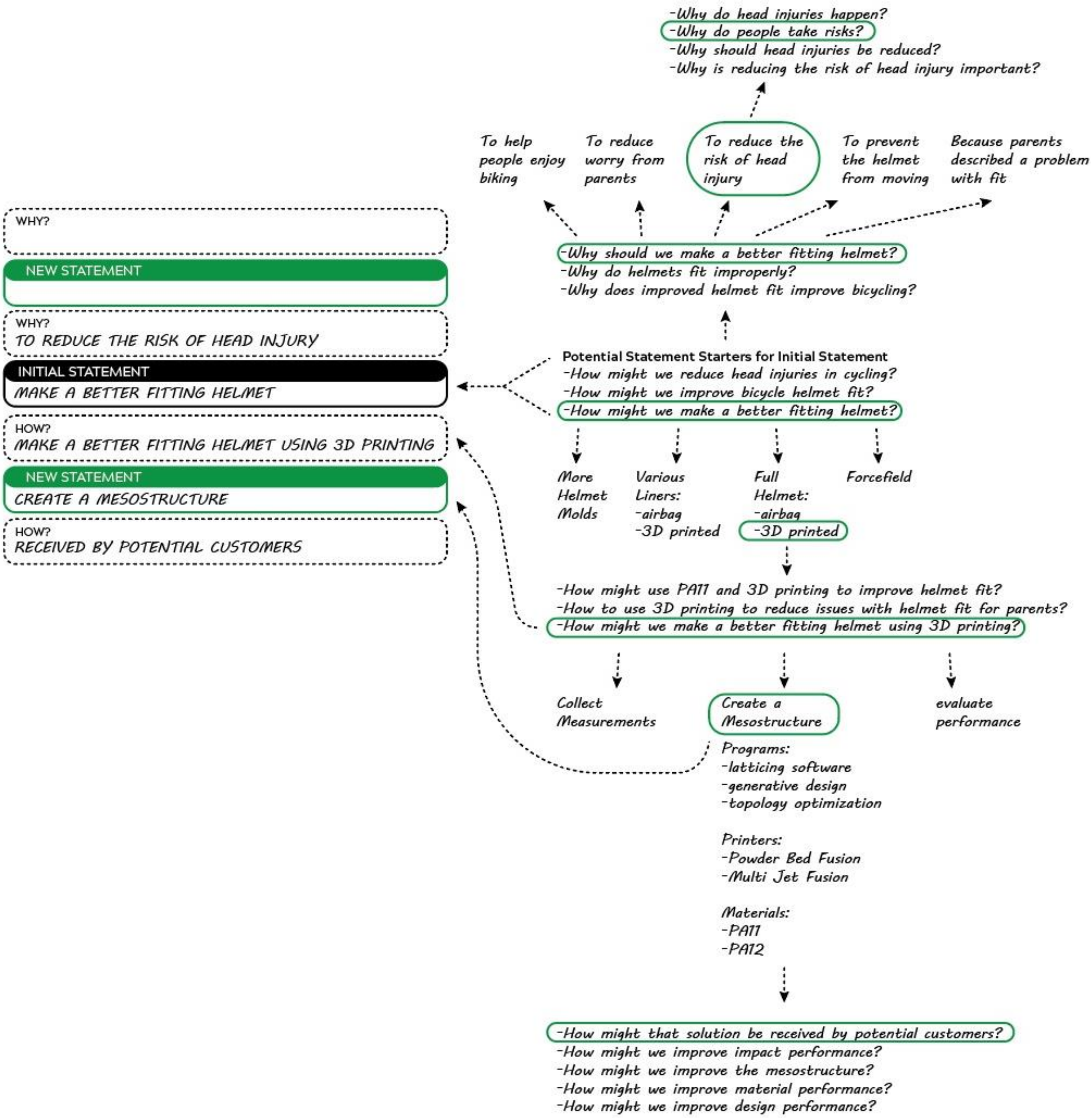


Figure 8.1 Assessing the injury biomechanics landscape using the Abstraction Ladder, used with permission from the Luma Institute

In biking, head injuries are only 9.1% of all injuries (Gaulrapp et al., 2001). Although head injury, and more specifically concussion, can have one of the largest impacts on quality of life for a rider, when compared to other injuries (McGuine et al., 2019). Studies have found that in a head impact, injury tolerances for concussion can be individual specific as there is no easily identifiable injury threshold due to large amounts of biologic variance (Rowson et al., 2018). Also, concussions can be cumulative, where the amount of exposure can affect injury tolerance (Crisco et al., 2011). So, head injury is not always just the result of a single head impact, but rather head injury can be the result of repetitive head impacts as well. Within an epidemiological framework, understanding key determinants and risk factors, meaning the environment that is responsible for the injury, can be an important part of injury prevention in a systematic approach (Peden et al., 2004). A systematic approach may help to develop and quantify an appropriate response within bicycling.

Asking that “Why?” question begins an initial assessment of injury biomechanics, specifically looking at population specific injuries, injury tolerances, and epidemiology. In addition, supplemental “How?” questions to narrow the scope of inquiry, could include an assessment of Consumer Product Safety Commission (CPSC) 16 CFR 1203 and Virginia Tech’s Helmet Standards (CPSC, 1998; Virginia Tech Bicycle Helmet Ratings, 2023). As a result, new approaches to the prevention and mitigation of injury may be identified that can be tailored to better serve target markets. Additional considerations could include using a total mass drop assembly, injury tolerances, and engineering characteristics that relate to adolescents more closely.

Similar to the limitations with helmet design and helmet standards described in section 1.2.2, it is important to continue questioning how safety standards relate to the people they are trying to protect. Identifying engineering characteristics that may contribute to injury can serve as catalyst for designing and implementing additional injury prevention measures. However, any additional exploration of injury biomechanics is beyond the scope of this dissertation, because the first step in product development is to pass the CPSC Safety Standard for Bicycle Helmets. The Job to Be Done, referring to the helmet’s core functional job, is to prevent and mitigate injury. Determining the most relevant injuries, injury tolerances, standards, and advocating for ways standards can be improved could add future value to the product’s core functional job and make future iterations of the product safer.

8.4 Initial Assessment of Risk in Behavioral Psychology

Applying the Abstraction Ladder leads to new questions and new statements. The new questions and statements are shown in Figure 8.1 in the right column, at the top, and circled in green. The new question for this section is “Why do people take risks?”

To investigate “Why do people take risks?” involves an initial review of risk and risk compensation. As safety counter measures are improved and executed, such as improved helmet fit, there can be changes in the users “behavior in response to some changes in perceived injury risk,” also known as risk compensation (Hedlund, 2000, 82). Some studies have found that as safety features are integrated into vehicles, motorists may drive faster, “trading safety for time” (Hedlund, 2000, 83). Despite the additional safety counter measures there was “no effect on overall driving fatalities” (Hedlund, 2000, 83). It has been argued that anything that only modifies the environment or modifies behavior, without affecting a user’s target risk level can be considered useless (Hedlund, 2000). The point is that the concept of risk compensation challenges the relevancy of injury prevention strategies and highlights the importance of understanding user’s behavioral psychology (Hedlund, 2000).

Within behavioral psychology, for thrill/adventure seekers within the target demographic, how the individual navigates both risk and risk compensation can directly relate to the mechanism of injury (MOI) they encounter. Factors that can contribute to the MOI are the objects they hit, impact location, frequency, magnitude, and duration (Crisco et al., 2011). Understanding the athlete’s psychological approach for putting themselves in extreme or challenging situations, how their risk compensation is trending (increasing or decreasing), paired with both impact and concussion history, will serve as a foundational element for understanding and identifying at-risk populations within the sport. Identifying at-risk populations within the sport may help illuminate potential countermeasures.

A variety of studies have been conducted to better understand how bicyclists navigate both risk and risk compensation. Some of those have included focusing on adolescents, looking at how the child's participation in the activity and degree of sensation seeking affect risk compensation (Lasenby-Lessard & Morrongiello, 2011). A focus on risk compensation among adolescents is important because age can drastically affect injury tolerance (Rowson et al., 2016). Other studies have focused on risk compensation for bicyclists in a commuter setting, looking at the relationship between helmet and non-helmet use (Fyhri et al., 2018). Studies that do not have a thrill/adventure seeking component, like commuting are limited as there may be no motivation to increase risk. Other studies have included looking at the differences in risk compensation in extreme sports between men and women, as well as how concussion history affects both helmet use and risk compensation in skiing and snowboarding (Frick, 2020; Taylor et al., 2015).

To date, less is known about the progression of risk compensation for helmeted riders, specifically in mountain biking. As risk compensation increases or decreases for the rider, it is anticipated that there may be a correlation between frequency and severity of crashes the rider experiences. The progression in risk compensation could relate to their injury tolerance based on the cumulative and individual nature of concussion.

As described in section 1.2.2, the football and cycling industries were only designing helmets to the industry standard without any further exploration of the contextual factors relating to head injury. Specific to football and cycling there was an inattention to lower-level impacts and rotational acceleration. A First Principles Approach to Product Development in Entrepreneurship examines the foundational elements of the problem driving product development, with the goal of preventing similar missteps described in section 1.2.2. So, a first principles approach requires exploring other contextual factors relating to head injury, such as risk and risk compensation. As stated in section 8.1 a critical reflection can help identify areas for future work before conducting an extensive investigation on the topic, where each topic could require its own in-depth level of review and research.

8.5 Initial Assessment of Engineered Solutions

As described in section 6.4.2, I made an incorrect assumption that the contract manufacturer was consistently printing quality parts. However, the test parts began performing inconsistently due to production issues. The application of the Abstraction Ladder could aid in discovering other assumptions related to the final product and has the potential to circumvent future issues.

As shown in Figure 8.1, on the right column, at the bottom and circled in green, the next "How?" question, to narrow the scope of inquiry, could be "How will that solution be received by potential customers?" To answer the question, I interviewed ten participants about their perspectives for using both 3D scanning and 3D printing in personal protective equipment (PPE), specifically bicycle helmets. Eight of the participants were active cyclists and two of the participants were parents of kids that ride bikes.

During each interview I described a process for custom fit bicycle helmets, which involves 3D scanning the rider's head and 3D printing the final helmet. After describing the process, I asked "Would you have any issues or reservations with any part of that process, or the technologies involved with that helmet?" Generally speaking, all ten of the interviewees said they would have no issues with using 3D printing for the final solution.

During the interviews, most of the concerns were about 3D scanning as opposed to 3D printing. In regard to 3D scanning, one participant had concerns about privacy and mentioned that they would like to know if the information is only used for building and fitting the helmet.

Then when the helmet is done being built, the scan data is discarded. Another participant mentioned a concern of going through the time and effort of getting a scan and having a helmet made with the possibility of the helmet not actually fitting better compared to a standard helmet size. Finally, another participant mentioned that cutting their child's hair is difficult enough, the participant asked, "how still does the child need to be to get an accurate scan?"

The initial questions asked could be the catalyst for conducting a more comprehensive study regarding people's perceptions of 3D scanning and 3D printing in PPE. Depending on whether that feedback is positive or negative could affect how the final product is advertised and what features and benefits should be highlighted.

As future product development is explored, iterations and variations between solutions that were identified in section 5.1.8 will need to be developed. Each new exploration leads to unanticipated technical challenges. For mechanical engineering, when applying the Abstraction Ladder, additional questions such as, "How might we improve the structure?" can lead to explorations in macro, meso, and micro structures. Other explorations would involve material science in order to minimize production issues and improve part performance, as well as process needs to optimize production and reduce costs.

Within material science, supplementary questions may include questions such as, "How might we improve material performance?" Asking and exploring similar questions are important because the materials used for additive manufacturing are significantly less developed than traditional manufacturing processes, like Expanded Polystyrene (EPS) and injection molding. As the field of additive manufacturing grows and diversifies, explorations in material science will have implications for reducing cost, developing supply chains, and improving performance characteristics.

Within industrial design, supplementary questions may include questions such as, "How might we improve the helmet's design?" Asking and exploring similar questions may result in conducting user studies and explorations in affordances that are intuitive. In addition, asking and exploring similar questions may result in pioneering a new style or aesthetic for the helmet, or applying a design aesthetic the end user is more familiar with. Exploring similar questions, may also include identifying other exciting design opportunities where this workflow can be applied, such as Aerospace.

A First Principles Approach to Product Development in Entrepreneurship examines the foundational elements of the new venture, which can include the foundational elements relating to the final product. The point is, as mentioned in section 6.4.2, I made assumptions about production and part quality, which lead to inconsistent part performance during impact testing. Applying the Abstraction Ladder can identify areas for future work and discover other assumptions about the final product with the goal of understanding and addressing those assumptions before they lead to complications.

8.6 Discussion

In contrast to the approaches described by Maurya, Blank, Dorf, Osterwalder, and Pigneur, the first principles approach described in this dissertation improves initial product development over existing approaches by incorporating a step for critical reflection. The Abstraction Ladder can serve as a tool to help the NVT to critically think about additional areas for investigation and identify areas for future work. The solution described in this dissertation, referring to a custom fit bicycle helmet, is the byproduct of Customer Discovery and the Lean Canvas. It would be easy to assume that Customer Discovery and Lean Canvas are universally applicable to other new ventures as well. However, the over reliance on a singular method, technique, or tool should be met with caution. As the psychologist Abraham Maslow warned, "it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail" (Maslow, 1966, 15-16). Different tools can lead to different outcomes. It is up to the NVT to assess the tools they are using, as well as learn how to use new tools. Learning about new tools such as Jobs To Be Done and Design Thinking may give an NVT additional methods and techniques for launching a new venture and product development.

It is important to properly assess and critically think about a methodology and its application. An example of a potentially inappropriate use of a methodology is the application of Jobs Theory to a potential new venture. As described in section 8.2.1, Jobs Theory focuses on a core functional job an end user is trying to accomplish, where focusing on the core functional job can help the NVT come up with product ideas, segment the market, or create a product brief (Christensen et al., 2016; Ulwick, 2016). In relation to helmet design, the core functional job of a helmet is to prevent and mitigate injury, which can make the rider safer. When I initially started Customer Discovery, I began with the product risk hypothesis, that safety is a primary concern for the majority of Pro and Semipro Men. However, safety was not identified as a Severe Problem for that group of users, so we pivoted. If I had continued developing a product to the core functional job of safety, it is possible I would have created a safer helmet that no one wanted to buy. The point is, new venture teams should continually assess the methods, techniques, and tools they are using, that determine what they know. Although the version of Jobs Theory described by Christensen and Ulwick may not be applicable for a new venture, it may be more appropriate as the new venture scales and is looking for new product categories or ways to segment the market.

Now that a solution to the Severe Problem has been found, by using the Abstraction Ladder, the NVT can reason back from the solution to evaluate the Severe Problem more comprehensively and at a foundational level. In the previous chapter, section 7.2.1, the foundational elements of helmet fit were addressed. As the NVT solves the problem that is driving product development, it is anticipated that new challenges that are associated with the Severe Problem will present themselves. As described in section 8.4, as new counter measures are introduced, greater risks may be taken. For the NVT, beginning to consider the additional context of the problem they are trying to solve could help prevent new problems that may arise.

Now that a solution to the Severe Problem has been found, by using the Abstraction Ladder, the NVT can reason back from the solution to evaluate the solution more comprehensively and at a foundational level. As described in section 6.4.2, when developing the test coupons for impact testing, there were problems with the parts performing inconsistently. So, I needed to transition the impact testing from a design focus to a production focus. Blindly relying on the manufacturing processes would have been disastrous, as it would have led to test parts or helmets that would not perform well in the event of an impact. So, to understand the solution more comprehensively at a foundational level includes, understanding the engineering, material science, and design that goes into the helmet.

As described in section 6.1.2, for new ventures that are largely driven by technological advancement (radical innovation), only focusing the engineering and material science may be a sufficient level of knowledge when creating a product for early adopters. As Blank and Dorf describe in *The Startup Owner's Manual*, early adopters "are buying into your total vision" …so they will "spend money for an incomplete, buggy, barely functional first product" (Blank & Dorf, 2012, 78). However, if the new venture plans on transitioning from early adopters to the early majority, the NVT will need to begin thinking about making the final product easy, intuitive, and exciting to use and engage with (human centered design). For other entrepreneurs, product developers, and researchers, it is anticipated that the technological advancement and usability of their final product will be different than the one that is described in this dissertation.

8.7 Contribution

The contribution from this research question is a product development process that includes a step for critically reflecting on the environmental factors and foundational elements that shape problem/solution fit. Environmental factors can include other relevant product development methodologies. In addition, foundational elements that directly relate to problem/solution fit can identified and explored by applying the Abstraction Ladder. Specific to this dissertation, foundational elements of problem/solution fit can include initial assessments of engineering, psychology, engineering, and design. Due to the critical nature of PPE, development relies on the latest research and advances across disciplines. A rudimentary knowledge of the foundational elements across each can increase the value of the product, its design, and ultimately provide improved safety for riders.

8.8 Chapter Summary and Conclusion

In summary, this chapter has been about critical reflection. In application this chapter has explored alternative product development methodologies and continued the application of the Abstraction Ladder as a means for systematically and critically thinking about the end result of problem/solution fit and its surrounding context. Systematically and critically thinking about problem/solution fit can identify areas for future work, which may be extensive investigations in their own right. For the new venture that is the topic of this dissertation, the surrounding context can include injury biomechanics, psychological factors for bicyclists, and the engineering and design of the final solution.

The goal is to develop a further understanding of the foundational elements, meaning first principles and their relationships, to identify additional and unexpected avenues for adding value to end users. As described in section 8.1, due to the similarities of research and entrepreneurship in terms of leading to more questions, the Abstraction Ladder has been used to identify areas for future work for both scholarly research and the new venture.

For this dissertation, the Abstraction Ladder was specifically applied to product development for bicycle helmets, however, it can be applied to any product or service for exploring the foundational elements that affect it. In practice the application of the Abstraction Ladder does not need to look as ordered. Also, the Abstraction Ladder ignores questions like “Who?” “What?” or “Where?” as well as other ways to frame questions that would also add context for understanding foundational elements.

Additional considerations for the Abstraction Ladder are knowing what breadth of topics defines an exploration as comprehensive, as well as knowing what depth of each topic defines an exploration as truly comprehensive. Finally, the Abstraction Ladder is a continual process, and the goal is not to follow a regimented technique, but rather to question assumptions and deconstruct problem/solution fit in a logical way.

Chapter 9 Conclusion and Reflections

This dissertation has explored a first principles approach to starting a new venture, using a custom-fitted bicycle helmet as the product being developed. This chapter serves as a conclusion and reflection for the entire dissertation.

Section 9.1 describes the contributions from this dissertation. Then, section 9.2 describes an overall reflection of the final dissertation. Section 9.3 envisages areas for future work. Finally, section 9.4 summarizes the work described in this dissertation.

9.1 Dissertation Conclusion and Contributions

The first principles approach described in this dissertation combines different sets of methods, processes, and techniques within an overall framework. The framework starts with business modeling and Customer Discovery techniques, specifically interviews with potential customer segments, described in Chapters 4 and 5. Then a product development process was described in Chapter 6. Next, methods for critically thinking about the new venture and other foundational elements were applied by performing a feasibility analysis and using the Abstraction Ladder, which were described in Chapters 7 and 8. The framework was created to bridge the gaps between entrepreneurship, engineering design, and industrial design. In addition, the framework was created for startups developing physical, capital-intensive products, where the key stakeholder who is describing the Severe Problem is also close to the purchasing decision.

As described in sections 1.2 and 2.1, issues with product development for personal protective equipment and failure rates in entrepreneurship highlight the need for methods of product development in entrepreneurship that address those issues. In addition, there is a need for the application of those methods to be grounded in qualitative research. In response to the need for methods of product development in entrepreneurship that address those issues, the two primary contributions from this dissertation are: 1.) the creation of the framework that this dissertation calls a First Principles Approach to Product Development in Entrepreneurship and 2.) the application of the methods within that framework, as a case study, where the application of those methods was grounded in research.

Additional contributions of this dissertation are in Chapter 4, which described a contribution identifying and applying the appropriate qualitative research methods to the problem interviews, as well as operationally defining Severe Problems, Major Problems, and Minor Issues. Chapter 5 described a contribution of having a brainstorming session in between the problem interviews and solution interviews, in an effort to reduce inventor's bias and find the most appropriate solution for commercialization. The contribution of Chapter 6 was the recombination of technologies, which has resulted in new methods of product development for personal protective equipment. In Chapter 7, the contribution included the inclusion and application of the feasibility analysis and Abstraction Ladder. The feasibility analysis can serve as a reference point for key stakeholders and the Abstraction Ladder can serve as a tool for critically thinking about the problem driving product development. Finally, the contribution of Chapter 8 was to describe the further application of the Abstraction Ladder in order to explore topics that relate to problem/solution fit, with the goal of providing more value relevant to the customer segment.

9.2 Dissertation Reflections

For entrepreneurs, product developers, or researchers looking to commercialize an idea or research, having an agreed upon framework can help align a team as to what they are doing and how they are doing it. In addition, an agreed upon framework can provide a common language throughout the many processes the framework encompasses. There can be many different methodologies, processes, and techniques for understanding an end user's problem or goal as a means for driving product development. Some of those methodologies, processes, and techniques can be based on interviews, but can also include other types of qualitative research such as ethnography, user studies, focus groups, or participatory design to name a few. In addition, there can be many methods for critically thinking about the end user's problem or goal to understand it at a foundational level and provide additional value that relates to the MVP. Some of those methodologies, processes, and techniques can be the Abstraction Ladder, 5 Whys, and root cause analysis.

If an NVT is new to entrepreneurship, it can be helpful to follow established Customer Discovery methodologies through a framework. As described in section 4.8, for products that can be capital intensive or require significant technological development, following the framework described in this dissertation can help find evidence to challenge and support an NVT's initial idea through primary research. In addition, following the framework described in this dissertation can help reduce the risk of failure by acquiring early adopters as a result of interacting with participants through the problem interviews. Participants with a Severe Problem can be a good indication that those participants may buy the product before most customers. Customer Discovery can help an NVT acquire and activate potential early adopters, as well as reduce the NVT's initial customer acquisition costs.

However, with experience, the NVT may be able to identify which parts of the framework are most relevant to their particular situation and which ones are not. Then they can begin including or substituting new methods, processes, and techniques. As mentioned in Chapter 8, the methods, processes, and techniques described in this dissertation are tools and different tools will lead to different outcomes. The NVT needs to assess the tools they are using and learn how to use new tools. In addition, the tools are only as good as the team using them, so it is important for the NVT to be persistent, ask for feedback, and commit to executing.

As described in section 3.3.2, while conducting the interviews, I listened under the assumption that participants were telling the truth to the best of their ability. However, regardless of whether or not participants are telling the truth, there is still uncertainty regarding their ability to identify and articulate problems they are experiencing or have experienced. In *Running Lean*, Maurya shares the perspective that, "given the right context, customers can clearly articulate their problems, but it's your job to come up with the solution" (Maurya, 2012, XXII). However, other product development practitioners claim that "very often, users are themselves not capable of expressing their needs…Even if they can, very often their personal perspective is too limited to truly understand the problem" (Leifer & Steinert, 2011, 164-165). The point is that there is some uncertainty about participants' ability to identify and articulate problems they are experiencing. Although interviews can be used as a starting point for challenging and supporting initial hypotheses, as described in sections 7.2.2 and 8.2.4, other methods of data collection may be helpful for directing product development and business decisions.

Finally, critically thinking about the foundation and broader context of problem/solution fit can be appropriate for other types of new ventures as well. For the first principles approach described in this dissertation, I identified the scope of application to technically challenging and capital-intensive products. As the amount of time and capital required for a new venture increases, the amount of risk also increases. As described in section 6.7 an important step for a first principles approach is to apply the Abstraction Ladder to critically think about both the foundation and broader context of problem/solution fit to provide strategic guidance for the new venture's long-term vision. However, taking the time to critically think about both the foundation and broader context of problem/solution fit is not limited to technically challenging products, capital-intensive products, or even personal protective equipment. Rather, critically thinking about the foundation and broader context of problem/solution fit can be appropriate for other types of new ventures as well.

As described in the acknowledgments section, this dissertation has been an exercise in deciding to look, which has involved deconstructing an initial idea, stating hypotheses, conducting customer discovery interviews, and ultimately finding problem/solution fit. Hopefully other NVT's have also found evidence that supports the launch of a new venture, but now the NVT must decide what type of new venture they want to build. Or as Steve Jobs put it, "Do you want to sell sugar water for the rest of your life or come with me and change the world?" (Gallo, 2016).

9.2.1 What is an Appropriate Number of Interviews?

As described in the acknowledgements section, this dissertation has been an exercise in deciding to look, by deconstructing an initial idea, stating hypotheses, and conducting Customer Discovery. However, an important consideration can include asking "How many interviews does it take before an NVT has gathered enough evidence to stop looking?" The answer is, evaluating the components of either the Business Model Canvas or Lean Canvas through Customer Discovery can be a continual process. It is up to the NVT to determine the time, effort, and interviews needed, which can be based on their team preferences, feedback from advisors, or programs they are participating in.

For the problem interviews Maurya has determined that an NVT "might be able to do this with as few as five customer interviews" (Maurya, 2012, 63). However, he later goes on to say, "as a rule of thumb, prepare to interview 30 to 60 people over a four to six-week period, which means talking to two or three customers a day, with some time built in for iteration" (Maurya, 2012, 76).

As described in section 3.3.2, for a grounded theory study, typically 20 to 30 interviews are considered to be appropriate (Creswell, 2007). In relation to the NSF I-Corps Program they put an emphasis on conducting at least 100 interviews (Nnakwe et al., 2018). In relation to other forms of qualitative research, ethnographer Ellen Issac describes the conflict between effort and learning as "it can take awhile" and that what they were trying to learn "didn't really come into focus for us until the fourth city and over 1000 photos and videos" however, "once we noticed it, it was obvious" (Isaacs, 2013, 8:42).

In more general terms, in *Running Lean* Maurya describes that "your initial goal is to get a strong signal (positive or negative)" and that "the actual numbers could vary based on the strength of the signal you receive, your specific path to customers, and your business model" (Maurya, 2012, 63, 76). An NVT is done with Customer Discovery when they "stop learning anything new from the interviews" and "can accurately predict what the customer is going to say just by asking a few qualifying questions" (Maurya, 2012, 76). Similarly, as described in section 3.3.2, in qualitative research the general goal of a grounded theory study is to conduct interviews "until the new information obtained does not further provide insight into the category" (Creswell, 2007, 160).

Although asking questions about the number of interviews or time needed for Customer Discovery can be good practice, a better question could be, "what type of entrepreneurs does the NVT consist of, serial or lifestyle entrepreneurs?" If the NVT consists of serial entrepreneurs, there may be a tendency to capitalize on the latest trend, and the NVT's depth of interest may only last as long as the trend is around for. However, if the NVT is composed of lifestyle entrepreneurs, the number of interviews and time needed for Customer Discovery depends on how obsessed the NVT is, as well as their ability to think creatively and put themselves in a position to be successful. An example of an NVT putting themselves in a position to be successful could be an NVT reducing their costs as much as possible to extend the runway for Customer Discovery. The point is, understanding the components of the BMC or LC through Customer Discovery can be a continual process and the NVT needs to determine what is appropriate for them, based on their team preferences, feedback from advisors, and programs they are participating in.

9.2.2 Is Finding a Problem Really Necessary?

After conducting Customer Discovery through both the lens of the Lean Canvas (LC) and the Business Model Canvas (BMC), a question arises, "is finding a problem that can drive product development really necessary?" Or, is Customer Discovery's real value that it allows the NVT to consider the perspectives of potential early adopters, build relationships with them without trying to sell anything, understanding their wants and needs, with the goal of directing product development, and business modeling.

A focus of the LC and the problem interviews is to find a problem that can drive product development. As mentioned in section 8.2.2, the exact definition of a problem is described differently by various authors. As described in section 3.4.2, when conducting and coding the interviews, during Customer Discovery, I knew I was looking for a problem, but the word "problem" can be ambiguous, contextual, and application specific. So, I operationally defined terms such as Severe Problems and Major Problems, as the themes emerged from the interviews. Then, as described in section 4.1.5, from the interviews I found a Severe Problem with bicycle helmet fit for US Bike Parents. However, when I conducted interviews with personnel at high-end US kids specific bike companies, as a potential sales channel, they did not seem to find helmet fit as a problem, despite them having significant interaction with parents and children. The focus on a particular problem to drive product development raises the question, "Is finding a problem that can drive product development actually necessary?"

Participating in the NSF I-Corps Program helped explore this question further. During the I-Corps Program, the program focuses on the BMC, as opposed to the LC. As described in section 4.1.1, the LC is an iteration of the BMC, where in the BMC there is less of a focus on problems for driving product development. During the I-Corps program, a recommendation to our team was to see if riders who had purchased higher-end bikes also had problems with helmet fit. During the interviews, none of those riders described problems with helmet fit. However, after the interview was over, participants were naturally curious about the idea that was the impetus for Customer Discovery. So, I would describe to them a generalized process of scanning a rider's head and 3D printing a custom fit bicycle helmet. After I described the technology, the rider would often say they would be interested in buying something like that, even though they described no problem with helmet fit during the initial interview. Then, as I continued Customer Discovery, I interviewed high-end bike shops and bike fitters as potential sales channels. Similarly, during the interview, personnel from the higher-end bike retailers and fitters did not describe a problem with helmet fit. However, after the interview, I would describe a brief overview of the technology, and the shop personnel and fitters were very receptive to a 3D printed, custom fit helmet to add to their other high-end product categories.

After examining Customer Discovery through the lens of the BMC and LC, it would seem like there are some advantages to LC, as it can provide focus for finding a problem to drive product development, when compared to the BMC. As described in section 4.8, some of those advantages can be reducing the risk of failure by acquiring early adopters as a result of interacting with participants through the problem interviews. Participants with a Severe Problem can be a good indication that they may buy the product before most customers, which may lower the friction of product adoption. However, if finding a problem to drive product development is not always necessary, perhaps the real value of Customer Discovery is to build relationships with potential early adopters and key stakeholders, without trying to sell anything, understanding their wants and needs, to direct product development and business modeling.

9.3 Future Work

This section will focus on future work, which has been mentioned in previous sections throughout this dissertation. As described in section 6.2, a product development roadmap was created that included designing for fit, protection, and a design feedback loop. Chapter 6 primarily focused on designing for protection. Future work can include designing for fit, which could include exploring additional scanning technologies, as well as evaluating and quantifying fit. In addition, future work could include developing a feedback loop for designing and evaluating mesostructures, which could incorporate static and dynamic FEA.

In order to identify other areas for future work, the Abstraction Ladder was used to ask questions about and explore both the Severe Problem and solution to set a foundation and provide strategic guidance for the new venture's long-term vision, as described in Chapters 7 and 8. Section 7.2.1 described an overview on comprehensive bicycle helmet fit, future work for bicycle helmet fit can include additional review of helmet fit literature, as well as research focused on evaluating and quantifying fit. Then section 7.2.2 described how only relying on interviews as the primary form of evidence for business decisions can have limitations, so another area for future work could be to learn about, asses, and apply other forms of qualitative research and product development methods to identity new target markets, pain points, goals, or product ideas. Section 8.2 described the advantages and disadvantages of the product development strategies Jobs to Be Done and Design Thinking, as an NVT moves beyond the MVP and develops new products, future work can include the assessment and application of other methodologies. As described in section 8.3, there are limitations with helmet design and helmet standards, so future work can include the assessment of safety standards, as well as researching relevant injury biomechanics that relate to the target market. As described in section 8.4, when safety countermeasures are improved and executed, such as improved helmet fit, there can be changes in users' perception and approach to risk taking behavior, so future work can include researching contextual factors relating to head injury, such as risk and risk compensation. As described in section 8.5, product development beyond the MVP is a continual process so there could be future work related to mechanical engineering, material science, and industrial design, that may be appropriate as well.

9.4 Dissertation Summary

The purpose of this dissertation was to explore a framework that this dissertation calls A First Principles Approach to Product Development in Entrepreneurship. The first principles approach was applied with the goal of reducing the risk of failure for new ventures trying to create technical and capital-intensive products. Additional goals for applying the framework were to bridge the gaps between entrepreneurship, engineering design, and industrial design, as well as to improve safety for bicycle riders.

By applying the framework, I found a Severe Problem of helmet fit for US Bike Parents. Then I conducted brainstorming sessions with the parents who experienced the problem to further explore the solution landscape. After landing on a solution of a custom fit, 3D printed bicycle helmet, I began product development using a generalized process of ideate, prototype, test, and iterate. Once I found some supporting evidence that the product could withstand technical challenges and pass relevant regulatory bodies, a feasibility analysis was conducted to assess the potential new venture's viability. Finally, the Abstraction Ladder was applied to explore the foundational elements and broader context of problem/solution fit in order to provide strategic guidance for the new venture's long-term vision.

Appendix A Summaries of US Bike Parent's Severe Problems

ID_1202

It was important to determine what's the earliest they can safely be on the bike and doing that safely. The determining factor was whether or not they could hold their head up, depending on the kid, that's about nine months old. Helmet choice was completely dependent on the size of the child's head. Another determining factor was, it couldn't clash with the back of the bike seat, pushing it forward and making the child uncomfortable.

Finding a proper fitting helmet was a very difficult process. Nothing fit locally, so each of their first helmets involved a lot of online research. I build bikes and have a network of shops, even ones that source obscure and hard to find parts. It was only through that network that I found a bike seat and helmet that worked. Had to use a seat from Europe that offered more mobility and a helmet that didn't back up against the seat. The helmet was not domestic, so I inspected it and decided it was good enough for my kids.

ID_1204

We started looking for a helmet when our son was between one and one and a half years old, maybe he's an anomaly, getting on a bike that early. First I did a fair amount of research online with his measurements, but couldn't find anything we thought would work. So, I went to a couple of sporting goods stores that specialize in biking. We tried different brands, nothing was small enough for him, so nothing fit properly. The helmet was always loose and hanging off the back of his head. The problem involved a conversation with my wife.

We do a lot of outdoor activities, so we wanted some kind of head protection. We we're at a sporting goods store and decided to check out the climbing helmets. There was a kids Petzel Picchu helmet that was snug and adjustable, fitting properly over the eyebrows. It stayed on his head with any type of movement. Also, we could put a thin beanie/tuque under it. Even though it's made for top impact and not side to side, it seemed to be better.

ID_1208

They started riding balance bikes when they were two and their heads were small at the time. We looked primarily online, then we looked at local bike shops and tried many different brands. We couldn't find anything that fit. So, we searched online again and eventually we found an all purpose/skateboard helmet that was small enough, however, it still moved around on their heads and there wasn't much ventilation. It was about $45 dollars. When they became older, about five and seven, and their heads grew, we transitioned to proper mountain bike helmets.

ID_1211

It was very difficult to find the right fitting helmet for him. First we ordered a couple of helmets from Amazon based on reviews, product quality and brand. None of those fit, they were too small for him. Then we tried Target, but they had limited quantities to choose from. Finally, we went to a bike specialty store to find a helmet that fit and was comfortable for him. Our first attempts were Amazon and Target because bike stores are not close to us. When we bought the balance bike, we decided not to buy the helmet with it, because it was more expensive and we anticipated he'd grow out of it. We wanted to buy a helmet that was high quality, reputable and not spend a lot. Looking back, I would have just bought it with the bike. The amount of time that we spent looking for a helmet delayed our progress on the bike.

ID_1230

Helmets were a hard search. One child has a regular sized head and the other has an adult sized head. We went through several before we found something that fit them right, that's the only definite dislike. First we went to multiple local bike shops to try stuff on. There isn't enough availability. Most shops only carry one or two models of the house brand they sell, so there isn't much variety and it's not necessarily a great helmet, it's just what's available. We tried kids helmets, adult helmets and nothing worked. Or we'd find one that "fits," but wasn't proportioned properly to their head, or straps wouldn't be in the right place. The frustration was, it was evident the shops had no experience putting helmets on kids. We also tried Dicks Sporting Goods and Walmart. Sometimes we found something that fit in the store, then rode around in it for a couple of days to find out it didn't fit that well. Then we did a lot of internet searching, ordering stuff and returning it. We don't choose helmets with characters on them, we choose the safest and best fit, then go from there.

ID_1232

We bought a couple of kids helmets, but if the kids are not comfortable, then they are complaining. Instead of, "I don't like my helmet," it becomes, "I don't like biking." So we buy something and if it doesn't work we donate it to someone else. Our son's helmet worked great at first, but as we biked more, we got higher end helmets with MIPS. Then, a friend of theirs crashed and skinned up their face, so it was time for full face helmets. My son has a fairly average sized head, so finding a helmet wasn't too difficult. My daughter has a round head that is big for her age, so it was difficult to find a kids size that fit her. We bought three or four helmets before we found one that fit, as few places stock full face kids helmets. We went to REI, as well as local bike shops, but none of them had a kids full face. We even drove an hour and a half to a specialty bike store. Finally, I got in touch with backcountry.com, visited their distribution center in SLC and we tried on every kids and womens full face until we found one that fit, it was about ten helmets.

ID_1241

My complaint is that helmets are uncomfortable and kids don't want to wear them. A helmet can look cool with a mohawk or whatever, but if it's not comfortable, they're not going to wear it, this includes anything that's scratchy or pokey. I will buy the more expensive stuff, if it means the kid is going to wear it, previously that has meant around $50. Also, the more I spend, usually the more I research a product. Anything that involves safety for my kids, I usually research it considerably. The first few times I bought helmets, I'd just go off the age bracket, but soon realized that didn't work for my kids. My boys both have bigger heads and it's been an ongoing issue where they need to wear adult sizes. So, I actually started measuring their heads and reading the sizes, but I've still had really bad luck with helmets. I've purchased helmets at Target and Big box stores, however never online as it doesn't usually work out. With their helmets, I went into the bike store and actually Googled them and read reviews, before I purchased them. However, as soon as the kids got into the adult bracket, it seemed like the options opened up significantly.

ID_1249

My daughter's head is pretty small, smaller than average, so helmet options didn't fit and move around no matter how much we adjusted it. First we searched extensively on the internet for the smallest helmets available. Once I found the helmet I thought was best, I picked it up at the local bike shop. It's acceptable, but not ideal, I still wish it would fit better. We've even looked at different options, but haven't bought anything because they all seem to fit the same.

Appendix B Summaries of US Bike Parent’s Major Problems

ID_1209

Really emphasized the importance of actually going to the bike shop, leveraging the expertise of the sales rep and trying on helmets to make sure they fit, as he thinks the proper helmet fit is important. Both him and his son went to the bike shop and tried on a variety of helmets, but none fit. They’d try on a helmet and it would move around because his son’s head was too small, as he has a smaller head. Asked the bike shop to order one that’s a size smaller, when it came it fit well. When they would try on helmets they’d move around a lot. He has reservations about ordering it online because he anticipates you won’t get the right fit. Originally the dad tried to get the younger son to use the older son’s hand-me -down helmet, but his son’s head was too small.

Disqualifier

Originally wanted to use his older son’s helmet as a hand me down. Once they ordered the helmet it fit just fine.

ID_1214

It was his first time looking for a kid’s helmet, he went to the bike shop, trusted the sales rep for help, but looking back, he’s not sure if he got the best advice. He only had two choices of helmet and didn’t really know what he was looking for and wished he had looked harder. The helmet keeps rolling back on his kid's head, leaving his forehead exposed. He keeps setting up the helmet, and then shortly after the helmet wiggles back and his head is exposed. As a new dad, his wife is with the kids most of the time, so when he’s out in public by himself with the kids it can be nerve wracking, because he doesn’t know if they’ll start crying or not. When he was at the bike shop and because he was stressed, they put a helmet on his kid real quick, but he didn’t have the bandwidth to make a good decision. The bike shops are not close enough to walk to and require driving, so was hesitant to go back to keep trying on new helmets.

Disqualifier

Fit was a problem, but not enough to go to more than one store and try other options, is kind of ok with the helmet wiggling back each time. But then he says there’s nothing wrong with the helmet. He described the helmet as expensive at $45.

ID_1231

Challenge finding knee pads, elbow pads and full-face helmets, and perceives them as mediocre compared to higher end gear they invest for themselves. However, variety and quality is not available in the smaller sizes. Realize there will be more selection for their kid as they get older. Also, their son will frequently ask to take breaks because helmet is hurting due to fit or head shape and will get marks on his forehead.

Disqualifier

Did not describe going to multiple stores or disregarding a buying option, also they primarily talked about limb armor and full-face helmets.

ID_1233

The son came to the store to try it on, it fit in the store, but then didn’t sit on his head well when they got home. The kid was not comfortable with the helmet, so he ended up doing a lot of additional online research, looking specifically for adjustability. He tries to order on Amazon, because he finds that going to the store and trying them on is hit or miss, brick and mortar stores don’t have much inventory or choices. He finds the lack of choice and inventory is particularly true of big box stores.

Disqualifier

The dad tried to use his son’s previous helmet as a hand me down for his daughter. Was able to find a helmet on the second attempt after doing a lot more online research and finding a helmet through Amazon.

ID_1273

They ordered a Bell helmet online and had some strap issues. The parents kept having to adjust the helmet straps so it would fit properly. They had just adjusted it and their daughter crashed and went over her handlebars and landed on her head. The helmet stayed in place, but it was clear they needed a helmet that fit better, then they found a Nutcase.

Disqualifier
It wasn't until a crash that they decided that helmet fit was really a problem. They were able to find a Nutcase helmet, when they had identified it was an issue.

ID_1279

Looking for a helmet for their infant but struggled to find a helmet that was small enough and fit here safely. Also, on the growth charts, their daughter is not small for her age, in fact she's a little big. With all the helmets they looked at, their daughter was still too small. Finally, they found a Giro helmet, but their daughter was still too small for it. They got it, tried it, it seems to fit ok, so they are using it.

Disqualifier
Even though the helmet was to big and didn't fit properly, they were ok with their child growing into it. Also, they were not able to really go and try stuff on due to Covid restrictions and Sheltering in Place.

Appendix C Co-Triangulation and Process Review

Carey Stewart Final Summary

Based on the coded data from the interviews, Severe and Major Problems that emerged specific to personal protective equipment and bicycle helmets was centered on the ability to find properly fitting bicycle helmets. A Severe Problem that emerged was the difficulty of being able to find properly fitting bike helmets for individuals with smaller sized heads including children, infants, and toddlers. The same theme was repeated in numerous interview transcripts about the lack of availability of properly fitting bicycle helmets for individuals with smaller sized heads. The challenge of finding a proper fitting bicycle helmets was evident in the data coded as a Severe Problem, which was identified forty-two times as, Helmet fit_Severe Problem, as well as two more times as, Helmet_Severe Problem, when the coded excerpts were explored further. The code, Helmet fit_Major Problem, was coded fifty-one times. The code, Disqualifier from a Severe Problem _Major Problem was coded fifteen times. The code, Would prefer they wear a full face_Major Problem, was coded four times.

The code, Crashing_Major Problems appeared twenty-one times reinforcing the need for personal protective equipment including bicycle helmets that fit properly. The code, Traffic_Major Problems was also evident in the data sixteen times which reinforces the need for proper fitting personal protective gear.

As a qualitative researcher, I thought the process went well. I appreciated that the three coders worked independently to individually read and code the interview transcripts. We regularly met to co-triangulate data, we would often read through two to three transcripts during a co-triangulation meeting. The only minor challenge when coding was that some of the codes could be interpreted similarly. For example, the codes, Perfect fit and adjustability_Minor Issues and Helmet fit_Minor Issues, could potentially be used to code the same excerpt. However, that did not impact the severity of the problem referring to Severe and Major Problems, as well as Minor Issues. The similarity in codes became apparent early on during a co-triangulation meeting. The software used to code was satisfactory. One thing I noticed early on was that the qualitative software was not the friendliest to use with the trackpad on my MacBook Air, so I ordered a two-button mouse to use when coding. It sped up the process quite a bit and reduced frustrations. Out of the qualitative software that I have used, Dedoose is the most user friendly. There were times that I had issues with the software and was kicked off, but I was able to log back on. If I continued to have the same challenge, I would completely log off and log back on and continue coding the transcript. If I continued to have the issue, I would submit a support ticket to Dedoose, log off and continue coding at another time.

During the co-triangulation and coding process, consensus was reached when at least two out of three of the coders agreed on the code. I cannot recollect a time when consensus was not reached since the team of coders took the time to discuss and defend their thought process while coding when co-triangulating the data. There were not any unexpected themes that arouse from the interviews.

Logan Layne Final Summary

Severe Problems

The results from the interviews showed several Severe Problems including weight of the helmet, comfort, and helmet fit. Helmet fit seemed to not only occur most often as a Severe Problem compared to Major Problems and General Preferences, but it also was well defined amongst the participants. The parents said that determining if the helmet fit properly or not is the first thing they check when going to a store. Online shopping was often avoided when ordering helmets because it is nearly impossible to know what their child needed, or it would take multiple back and forth exchanges to find the perfect fit. When the parents would describe their experience of trying on helmets it was mentioned that it is very difficult to find a helmet that was able to fit their child's head. This challenge created a lot of frustration and would often lead to the parents finding a helmet whose specific purpose was not for biking, but it provided their child with support for their head while wearing the helmet. Crashing was identified as a Severe Problem which directly relates to the importance of the child having a helmet that fits which would hopefully mitigate any severe damage that could occur while riding a bike.

Major Problems

Major Problems that were identified in the interviews showcased a wide range of codes including expensive, coverage area, should be comparable to an adult helmet, breathability, ventilation, insulation, build quality and price. The type of protection that is used in adult helmets was a sentiment that was shared among the parents in the interviews, the parents feel that their children should not be subject to less quality. The quality of the helmets overall seemed to be lacking from the selection available for children even though the prices were expensive and comparable to the adult helmets. When deciding which helmet to purchase, the parents would often sacrifice aspects of helmets they valued to find a helmet that would fit the child for the time being. The parents were aware that the child would eventually grow out of the helmet which made it more difficult to justify the purchases. Overall, the helmet choices for children lacked many qualities that parents valued and would like to see replicated from adult helmets. The coverage area of the helmets was concerning for children who experienced crashes to include more protection over the eyes and along the jaw.

Co-Triangulation Process

The process of co-triangulation among Will, Carey and myself was very thorough from my perspective. During the process, there were few times that we had to discuss whether we all agreed that a code applied to an excerpt. Our meetings to review the interview transcripts allowed each of us to speak and lead the meetings by sharing the codes we found and asking if others had similarities. Having the person in charge of the meeting change every time we met allowed everyone to have a voice in the process. Where the co-triangulation process consisted of three individuals there was a time when I did not have a code and the others did, which would lead to me deciding if I also thought the code show be included. Providing the space to discuss our opinions is what allowed our team to have rich discussions and lead us to our results.

Appendix D Initial Exploration of Customer Needs, Design Requirements, and Costs in ME 5644

Problem Scope

In a recent study, it was identified that just under 50% of children surveyed were wearing helmets that were unsafe due to damage or not fitting properly [1]. From the product team's own research, we personally learned that the parents of young children as well as children with personalized safety needs (e.g. those with glasses, hearing aids etc) struggle to find properly fitting bicycle helmets. This has resulted in parents settling for those they deem to be "close enough". This poses a huge safety hazard because an improperly fitting helmet doesn't provide as much protection in a crash, increasing the risk of a serious head injury. Current helmet designs for younger children are standardised in size and shape, leading to improperly fitting and uncomfortable helmets children are less likely to wear.

In response to this problem, our project team believes a superior product can be manufactured using additive manufacturing. Additive manufacturing allows for a personalized fit, as well as the ability to create complex lattice structures that have comparable and even better impact mitigating characteristics compared to traditional helmets. In addition, additive is able to circumvent slow and traditional design and manufacturing processes. This will lead to a more agile design process, delivering the product to the customer more quickly.

Design Requirements

In order to better define what our customers seek when purchasing a helmet, we engaged in customer discovery through interviews with the target consumer, cyclists and parents of young children. From these interviews, a list of customer needs for our product was generated, so we could better categorize and rank the most relevant needs The top ten customer needs are listed below in Table 1. These customer needs were then grouped into a few specific categories, the first of those pertaining to safety: protecting the head from injury, fit, and being secure in place in all use cases. In addition, the bicycle helmet must be something a child would like to wear, being comfortable, aesthetically pleasing, lightweight, having ventilation and a sweat mitigating design. Furthermore, the helmet must be accessible to the parent, being minimal in cost and having a short time from order to delivery. Finally, the helmet must sustain everyday wear and tear, withstanding minor impacts and being resistant to scratches.

Table 1: Customer needs for a children's cycling helmet

Customer Needs
Protects head from injury
Fits and is secure in all use cases
Comfortable to wear
Aesthetically pleasing
Lightweight
Sweat mitigation/ventilation
Minimal cost
Short time to customer (End to End)
Withstands minor impacts
Resistant to scratches

The customer needs were used to find engineering metrics that would measure how each need is met. Each engineering metric was given an improvement direction for which way it was desired for the metric value to go, as well as a scale type and units they are measured in. These can all be found in Figure 1. Most of our engineering metrics have a scale type of ratio, because they can be measured. The support structure material is a nominal scale type because it is a yes or no answer. The beginnings of our target specifications for these engineering characteristics can be found in Appendix B.

Engineering Metric	Improvement Direction	Scale Type	Units
Cost of equipment	↓	Ratio	$
Cost of Material	↓	Ratio	$/cm^3
Meterial Degredation from UV Exposure	↓	Ratio	mJ/cm2
Surface Finish (Measured in layer thickness)	↓	Ratio	mm
Allowable Temperature Range	↑	Ratio	C
Material Consistency	↓	Ratio	% error/kg of material
Cost of assembly	↓	Ratio	$/unit
Print Speed	↑	Ratio	cm/min
Build Volume	↑	Ratio	cm3
Support structure material	↓	Nominal	y/n
Material yielding stress	↑	Ratio	MPa
Material Reusability	↑	Ratio	%

Figure 1: Engineering metrics with improvement direction, scale type, and units included.

All of the customer needs were placed into a house of quality matrix, shown in Figure 2 as well as Appendix A, as row headers. The engineering metrics were also placed as the column headers in the house of quality. Each engineering metric was given a 1, 3 or 9, for how it correlated to customer needs, with a 9 being a strong correlation, a 3 a moderate correlation, and a 1 a weak correlation. Each customer need was also given a weighting factor between 1 and 5, 1 being the least important and 5 being the most important. For each engineering metric, the numbers in their columns were multiplied by the weight of their corresponding customer needs and summed to get an absolute score, allowing for the engineering metrics to be ranked. The rankings in Figure 2 reflect material yield stress, print speed, surface finish, and cost as the most important engineering metrics.

Improvement Direction		-	-	-	-	^	-	-	^	^	-	^	^
Correlation Weak-1 Moderate-3 Strong-9	Engineering Metrics	Cost of equipment ($)	Cost of Material ($/cm^3)	Material Degredation from UV Exposure (mJ/cm2)	Surface Finish (Measured in layer thickness [mm])	Allowable Temperature Range (C)	Material Consistency (% error/kg of material)	Cost of assembly ($)	Print Speed (cm/min)	Build Volume (cm^3)	Suuport structure material (y/n)	Material Yielding Stress (MPa)	Material Reusability (%)
Customer Needs	Weighting												
Resistant to scratches	1				3								
Minimal cost	3	9	9		3			9	1	3	3		
Aesthetically pleasing	1				3						1		
Comfortable to wear	3				3								
Protects head from injury	5			3		3	3					9	
Lightweight	3											3	
Fits and is secure in all use cases	5				1								
Long lifespan from natural element exposure	2			3		3	3						
Sweat mitigation/ventilation	3				1								
Withstands minor impacts	4											3	
Customizable to head shape	3		1										
Is aerodynamic	1				3						1		
Easy to clean	1				1							1	
End to End	4								9	3			
Sustainable /recyclable	1												9
Absolute Score		27	30	21	36	21	21	27	39	21	11	67	9
Importance Ranking		5	4	7	3	7	7	5	2	7	11	1	12

Figure 2: Partial house of quality used to establish correlations between customer needs and engineering metrics.

From there, the engineering characteristics that applied directly to the manufacturing processes were singled out and used in a Pairwise Comparison Chart. By comparing metric to metric, it allowed for an improved process selection, as the QFD chart the characteristics were weighted in relation to customer needs, the Pairwise Chart was weighted with the engineering metrics in relation to each other. The Pairwise Comparison can be found in Figure 3. The resulting percent weightings from the Pairwise Comparison are used in the process and machine down selection. Similar to the importance rankings from the QFD, the highest weighted engineering metrics from the Pairwise Chart were material yielding stress and print speed. This makes sense, as material yielding stress is a characteristic that relates to protecting the head from injury, and print speed relates to getting the helmet to the customer in a timely manner.

	Cost of equipment ($)	Cost of Material ($/cm^3)	Material Degredation from UV Exposure (mJ/cm2)	Surface Finish (Measured in layer thickness [mm])	Allowable Temperature Range (C)	Material Consistency (% error/kg of material)	Cost of assembly ($)	Print Speed (cm/min)	Build Volume(cm^3)	Support structure material (y/n)	Material yielding stress (MPa)	Material Reusability (%)	SUM	Weight	Percent Weight (%)
Cost of equipment ($)		0.5	0.5	0.5	1.0	0.5	0.5	0.5	0.5	0.5	0.0	0.5	5.5	0.0833	8.333
Cost of Material ($/cm^3)	0.5		0.0	1.0	0.5	0.0	0.5	1.0	0.5	1.0	0.0	0.5	5.5	0.0833	8.333
Material Degredation from UV Exposure (mJ/cm2)	0.5	1.0		0.5	0.5	0.5	0.5	0.0	0.0	0.5	0.5	1.0	5.5	0.0833	8.333
Surface Finish (Measured in layer thickness [mm])	0.5	0.0	0.5		0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	1.5	0.0227	2.273
Allowable Temperature Range (C)	0.0	0.5	0.5	1.0		0.5	1.0	0.0	0.5	1.0	0.0	0.5	5.5	0.0833	8.333
Material Consistency (% error/kg of material)	0.5	1.0	0.5	1.0	0.5		1.0	0.5	0.5	1.0	0.0	0.5	7.0	0.1061	10.606
Cost of assembly ($)	0.5	0.5	0.5	0.5	0.0	0.0		0.5	0.5	0.5	0.5	1.0	5.0	0.0758	7.576
Print Speed(cm/min)	0.5	0.0	1.0	1.0	1.0	0.5	0.5		1.0	1.0	0.0	1.0	7.5	0.1136	11.364
Build Volume(cm^3)	0.5	0.5	1.0	1.0	0.5	0.5	0.5	0.0		1.0	0.0	1.0	6.5	0.0985	9.848
Support structure material (y/n)	0.5	0.0	0.5	1.0	0.0	0.0	0.5	0.0	0.0		0.0	0.5	3.0	0.0455	4.545
Material yielding stress (MPa)	1.0	1.0	0.5	1.0	1.0	1.0	0.5	1.0	1.0	1.0		1.0	10.0	0.1515	15.152
Material Reusability (%)	0.5	0.5	0.0	1.0	0.5	0.5	0.0	0.0	0.0	0.5	0.0		3.5	0.0530	5.303

Figure 3: Pairwise Comparison Chart

Cost Analysis

The cost per part is an extremely important number to know as it helps determine whether a business venture is profitable/worth pursuing. The cost per part is determined by factors including labor cost, material cost, machine cost, and cost of operation. The full calculations of how cost per part was calculated can be found in Appendix D. The labor cost for our project was determined through

$$L = T_l * C_l \tag{1}$$

where C_l is the cost of labor per hour, \$15 for our model, and T_l is the amount of time a laborer would spend working on each build in starting up and post processing of the parts, estimated to be an hour per build. The material cost per build was found using

$$M = k_s * k_r * N * v * C_m * \rho \tag{2}$$

where k_s is the support material, k_r is the recyclability of the material, N is the, v is the part volume, C_m is the cost per mass of the material, and ρ is the density. The material cost per build was relatively expensive, coming in at \$515.40 per build. This is due to the fact that a powder bed fusion process is being used to construct the helmets, powder bed fusion having the largest amount of waste compared to other additive manufacturing processes. This means the k_r constant is high, for this case being a factor of 7, drastically increasing the material cost per build. Although the EOS P 396 is an expensive machine, with a purchase price of \$250,000, it doesn't add much to the cost per part. The machine cost was found using

$$P = \frac{PurchasePrice * T_b}{0.95 * 24 * 365 * Y} \tag{3}$$

where T_b is the build time and Y is the lifespan. If we estimate the EOS P 396 to be operating 95% of the time with a five year lifespan, the typical lifespan of many additive manufacturing technologies, with a build time of 1.79 hours per build, the machine cost only adds

$10.77 per build, or $5.39 per helmet since the build bed size allows for two helmets per build. The cost of operation for the machine was calculated using

$$O = T_b * C_o \quad (4)$$

where C_o is the machine cost rate. The machine cost rate takes into account the cost of electricity, facility rent, machine maintenance, and cost of the software used to generate the part, Fusion 360. The cost of operation of the machine per part is inexpensive, coming in at $3.81. The cost per part can be calculated using the following equation.

$$Cost\ per\ part = \frac{P+O+M+L}{N} \quad (5)$$

The cost per part was found to be $272.49. This means that our company would have to sell the child's helmet for over $300 to make a decent profit. Due to the costing implications, it's clear that this product is not appropriate for the mass market. The reason for this is most children's helmets on the market today are priced between $20-60, so very few parents are going to want to spend over $300 on a child's helmet. Another consideration is it's anticipated the child will grow out of it in a year or two, making a $300 helmet infinitely less desirable.

However, within the last five years there's been a growing trend of high-income consumers, specifically parents, who want high end childrens and adult bicycles. The reason for this is parents are, "focused on providing their children with an impressive introduction of the cycling world, particularly when it is their children's first bike [20]." So, although a mass market approach may not be an appropriate strategy, we believe that it could be appropriate as a high value, low volume, niche product for a high income market segment. Furthermore, from the team's own conversations with end users, solving the problem of helmet fit for these parents would be an integral component for an "impressive introduction" to bicycling.

Finally, in product development, cost is always a concern, especially when entering new markets. So, identifying bottlenecks around processing needs, especially material costs as it's the largest driving factor. This would include additional material explorations, as well as explorations in the processing of material.

Discussion

For this project, the most important customer need was that the helmet protects the end user's head from injury. The minimum requirement for meeting this customer need is that the helmet passes the industry bicycle helmet standard, CPSC 16 CFR 1203. Although the team was unable to determine this within the time constraints of the project, we were able to send the test coupons to an impact testing lab for that answer. In addition, the team was able to identify additional avenues for answering the question, through static and dynamic simulations. Upon receiving the results from the impact testing lab, we should better understand if there is a correlation. We will know if there are iterations we can make to improve that correlation, and finally apply them for further iterating and downselection.

Helmet fit and comfort were also very important customer needs, as issues with fit served as the foundation for the project. Unfortunately, we were unable to definitively determine whether or not our final digital representation of a bicycle helmet fit our end user, as we were unable to get a fully printed helmet on to an end user's head. However, through 3D scanning and latticing the surface geometry, the team found overwhelming success establishing the initial steps to answering that question. Additional exploration and testing will need to be done to definitively meet the other customer needs.

Conclusion

In conclusion, improperly fitting helmets are a big safety risk for children. By leveraging the advantages of additive manufacturing for personalized fit, we can provide improved safety compared to current industry approaches of standardized sizing. Developing mesostructures, with consistent and comparable impact mitigating qualities as current industry benchmarks, is the first step to providing a product that meets our customer's specific needs. Based on those needs, we've been able to scope engineering characteristics which helped us select Powder Bed Fusion as the most appropriate process for our end use. In addition, those engineering characteristics were integral in the selection of the machine best suited for providing a product that has consistent material qualities, an adequate print speed and practical build volume. Some challenges were, not all of our ideal engineering characteristics were available through machine and material specification sheets. The additive manufacturing selection process highlighted the EOS P 396 as the best machine for our product development needs. The reason for this is, it was 2nd best in pricing and had the best build volume, all the while meeting our material needs for consistency, yielding stress and reusability.

For this helmet design project, we found it to be a very wide process overview, as we explored many different processes and how those processes influenced one another. This began using both a 3D scanner and a photogrammetry phone based application to create an initial surface to work from. Next, a CAD Face was designed as the building block for mesostructure design and exploration. Finally, due to the protective nature of a helmet, it was critical to have objective methods for down selection of mesostructures, as well as being certain that our selections would limit the resulting acceleration to the end user. These considerations were through the use of static, dynamic and impact testing. Other considerations for the project are we did not go in depth on any one process, so further explorations should include, but are not limited to surface generation, mesostructure design and mesostructure selection. Generally speaking, this means simplifying the workflow. That process begins with finding and creating efficiencies for generating a 3D scan, importing the mesh, creating T Splines around the mesh and importing the usable geometry into nTopology. Next, there are severe technological limitations with meshing latticed structures for export. Also, our FEA analysis tool has significant limitations with the amount of surfaces it can import, as well as processing speeds. In its current state, it's a very time intensive process which requires adequate knowledge of various software.

A cost analysis was conducted to find the cost to make one helmet. The cost per helmet was calculated to be $272.49. Due to having to be sold for over $300, it's clear that this product is not appropriate for the mass market. Most children's helmets are priced between $20-60, so few parents will choose to spend over $300 on a helmet their child will soon grow out of. However, there has been a growing trend of high-income consumers that will purchase high end cycling products for themselves and their children. Our team believes that the helmet could be appropriate as a high value and low volume product for this very specific market. SInce cost is always a concern, especially when entering new markets, the team wants to research decreasing material costs, as it's the largest driving factor of the cost per helmet. This research would include additional material and material processing explorations. Also, solution interviews will need to be conducted with the target market for a customer driven approach to pricing. This will give us a better understanding of what's feasible and infeasible, as well as the size of the market we lose or gain with various pricing strategies.

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We have neither given nor received unauthorized assistance on this assignment.
- Noah Haefner, Corbin Hawk, Joshua Hull, Dominic LoPinto, Will Makowski

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