Innovation in Sewn Cooling Products: Three Case Studies Examining the Interdisciplinary Product Development Process

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Dedication

This dissertation is dedicated to Matt and Clement Griffin.

Abstract

The purpose of this research was to explore the interdisciplinary product development process for wearable and sewn products. A case study approach was selected for this research because it supports a holistic investigation of interdisciplinary product development in organizations using multiple sources of evidence (Yin, 2014). Three case studies were conducted for the development of three cool products: a cool tent, flexible cool vest, and cool pad. Eleven companies worked together in various capacities to create the three cooling products. The design process of the cool tent, flexible cool vest, and cool pad all featured the development and integration of phase change material technology into the product. Data was collected from interviews, observation, a site visit, and design development documentation.

Themes that surfaced surrounding how the product development process was conducted in interdisciplinary teams were organization and communication, flexibility and experimentation, and stakeholder support. Themes regarding how the interdisciplinary product development process can lead to the creation of new products were expertise, collaboration and trust, and flexibility and experimentation as part of the business' culture.

Analysis of data collected from the seven companies resulted in a comparison of the cool products' interdisciplinary product development process. The evaluation of the interaction and collaboration between the companies demonstrated that elements of interdisciplinary collaboration occur at every stage of the design process and forms of communication had to be altered in order to work across disciplines. An assessment and

comparison of the cool products' interdisciplinary product development processes to LaBat and Sokolowski's (1999) and Ulrich and Eppinger's (2012) product development processes showed clear similarities and contrasts between the processes. Common features of the interdisciplinary product development process were presented and assessed. A comparison of strategic alliance theories provided a basis for the analysis of how the interdisciplinary process of design and material development led to the creation of new products.

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CHAPTER I

INTRODUCTION

Successful interdisciplinary design requires individuals and teams to combine different tools, knowledge, languages, methods, and processes to create original products (Johnson, et al., 2007). There is evidence that the fields of wearable product design and material development are beginning to align their businesses more closely throughout the product development process. The complexity of diverse factors contributing to interdisciplinary product development has increased the need for understanding the processes used by organizations to facilitate the development of advanced wearable products.

Rationale and Statement of Problem

From nanofibers to drug imbedded textiles, the field of material science is thriving. Recently, over $500 million was been set aside by the United States government to fund innovative materials initiatives (The White House, Office of the Press Secretary, March 18, 2015). Moreover, large technical apparel brands such as Nike and Patagonia are investing heavily in material innovation (Pierrepont, 2014). With the influx of material innovation, the need for designers to work more closely with material developers is abundantly clear.

Innovative materials have contributed to consumer demand for innovative products. Instead of the designer driving the design, the material now plays a much larger role in the design process, allowing the material to inform the application of the design (Colchester, 2007). New material application plays a vital role in developing wearable products that are innovative and transformative, especially in the sports, protective, and medical markets. Wearable product designers and material developers need to be equipped with the tools to work together throughout the design process. The application and new development of materials and products in wearable goods is crucial to moving the field forward.

In the larger field of design, there has been a trend towards designers working more closely with those central to the development of materials. In the book *Ultra Materials*, Quinn writes "…from the traditional to the intangible, from the technical to the tectonic, the exchanges taking place between materials and design are forging a uniquely multi-disciplinary arena" (2010, p. 46). Innovative materials and products have been conceived and developed through collaborative methods between engineers and scientists, and product designers and architects, but design development remains relatively separate from material development in the wearable products industry. In fact, some of the most technologically advanced materials have yet to "…prove their worth, because relatively few practitioners have been able to put them to the test" (Quinn, 2010, p. 46). Lack of accessibility of new materials inhibits many designers' ability to experiment with the advanced technology, therefore they do not get incorporated into new products as easily. Furthermore, it's important to consider the material knowledge of the wearable product designer. If the knowledge base is limited, the "…designs themselves will in turn be constrained." (Beylerian, 2010, p. 17)

While advanced multi-functional materials play a significant role in the development of wearable products, the material only tells half the story (Beylerian, 2010). It takes both an innovative material and a designer who is knowledgeable about materials, has resources available, and time for experimentation to develop an innovative product. One method of encouraging progressive product design and innovation in wearable products is to place the designer and the material developer side by side throughout the design process (Colchester, 2007). In the book *Extreme Textiles: Designing for High Performance*, McQuaid and Beesley (2005) discuss the importance of this type of interdisciplinary collaboration:

> There is not an area of our world unaffected by the advances in technical textiles. Architecture, transportation, industry, medicine, agriculture, civil engineering, sports, and apparel have all benefited from the tremendous progress and the unique collaborations that have taken place in the field. Principles of textile science and technology merge with other specialties such as engineering, chemistry, biotechnology, material/polymer science, and information science to develop solutions unimaginable a century ago. These are achievements that rely on an interface between many disciplines, and require a willingness to experiment time and time again. (p. 13)

Echoing that statement, Frumkin and Weiss (2012) emphasize that a substantial driver of originality in products and materials involves teamwork of individuals from diverse fields. Wearable product and material experts have been known to work together to improve innovation in materials and design. Examples of the wearable product and material being designed together can be found in Nike's Fly Knit shoe and Patagonia's Yulek/Nexkin wetsuit. However, we know very little about how interdisciplinary groups implement their ideas and products in the wearable product design industry.

Successful wearable products are created through a complex product development process that requires multiple sources of knowledge in the fields of apparel design, materials, technology, business, and science, to name a few. Jones (1992) discusses the complexity of design, concluding:

> …designing should not be confused with art, with science, or with mathematics. It is a hybrid activity, which depends, for its successful execution, upon a proper blending of all three and it is most unlikely to succeed if it is exclusively identified with any one. (p. 80)

This quote is an excellent example of the interdisciplinary nature of the problems that need to be solved related to wearable products. Designers and materials developers must be able to look inside and outside of their respective fields in order to seek out solutions to complex problems. The problems that wearable product designers and material developers need to solve are not one-dimensional; therefore, the teams in which they work should not be one-dimensional in scope either. As the complexity of a design problem increases, interdisciplinary approaches can improve the outcome and impact of the end product (Lerch, MacGillivray, & Domina, 2007).

The quest for better and more innovative products is beginning to bring wearable product designers and material developers closer together throughout the product development process. Despite little information available regarding how teams are formed in wearable product companies, research has shown that interdisciplinary teams are driven by internal company initiatives and by strategic alliances between companies.

New product development is a function of a company's scientific, technological, and managerial skills (Deeds, DeCarolis, & Coombs, 1999). In order to improve a company's knowledge and capabilities in areas of science and technology, many enter into strategic alliances with other companies (Deeds et al., 1999; Grant & Baden-Fuller, 2004; Rothaermel & Deeds, 2004). There are instances of strategic, interdisciplinary alliances occurring for the purpose of improving product innovation in the textile and wearable product industries (Horne, 2012). Horne (2012) describes one such partnership between the textile firm Maharam and Nike:

> Maharam, a family-run business over a hundred years old, creates 'innovative textiles through the exploration of pattern, material and technique' (Maharam, n.d.). Primarily for the contract market, Maharam textiles are known for their high performance, married with innovation. Maharam embraces the knowledge and experience of leaders in various disciplines, while focusing on cultural and societal trends. These directions are synthesized with emerging technologies and textile engineering knowledge to create new lines, often incorporating unexpected materials. An ongoing Maharam partnership is with Nike Sportswear. Nike, known for their innovation and designing toward performance and sustainability, has reinterpreted two of their famous shoes, the Nike Oregon Waffie and the Nike Blazer, using horsehair textiles. Nike x Maharam takes advantage of Maharam's extensive material knowledge, reinterpreting [Nike's] famous silhouettes in luxurious textiles. (p. 76)

Furthermore, Shishoo (2005) found that "eight out of ten sporting good executives expect joint ventures and alliances [in textiles] to be important growth engines for the future," (p. 21).

In the wearable product industry, interdisciplinary relationships between design and material companies have resulted in products that create both incremental and revolutionary change to the product being developed. These alliances can be led by the material or design company, as well as through alliances within a large business organization or through business acquisition. An example of incremental design development led by a design company is the Patagonia Yulex®/Nexkin® wetsuit. Patagonia, a sportswear company where sustainability is a core business initiative, had been producing traditional wetsuits using neoprene, a non-biodegradable material that is manufactured from non-renewable fossil fuels. The alliance with Yulex, a natural rubber and material company, to create the first bio-degradable and sustainable wetsuit was a natural interdisciplinary collaboration between two companies with different strengths, working together to create an environmentally friendly product (Cardwell, 2014). The Patagonia/Yulex wetsuit became available for purchase in 2014 and is now in its third design iteration. This design development can be described as an incremental development, because the overall shape of the wetsuit remained the same.

An example of revolutionary product design development in sportswear that relied on interdisciplinary alliances between companies was the development of the LZR Pro and LZR Elite competition swimwear by Speedo, a swimwear manufacturer, for the 2008 Olympics. The LZR bodysuit swimwear was developed between Speedo, Mectex, an Italian textile and manufacturing company, Petratex, a textile and manufacturing company in Portugal, and the Australian Institute of Sport. They worked together to develop a new material and design that improved oxygen flow to muscles, held the body in a hydrodynamic position while swimming, reduced water drag, and improved racing times (Hogg, C, 2008; Rodi, J.B., 2008). Before this revolutionary design development, competitive swimmers wore brief-like swim trunks. This new design covered the swimmers' full torso and legs, a design shape never worn in competitive swimming before its development. Swimmers wearing the new LZR suit in the 2008 Beijing Olympics performed so well that the governing body has since created new regulations banning full-body swimwear and placed restrictions on material. Research examining collaborations between businesses offer clues to how interdisciplinary relationships are formed from a team and business perspective, and aid in our understanding of the future of the wearable product industry.

Despite the benefits of interdisciplinary product development, this type of design work is complex. First, as Gray (2008) points out, "transcending the well-established and familiar boundaries of disciplinary silos, poses challenges for even the most interpersonally competent scientists," (p. s124). The challenges of developing an integrated project vision between disciplines has been chronicled in science, business, and in cross-sector and global collaborative teams (Gray, 2008). Designers and material developers typically have significantly different background training, and often lack the knowledge, skills, and values to successfully work through the product development process together. There are numerous variables that need to fall into place in order for interdisciplinary design work to occur. Beyond the difficulties of forming a team with designers and materials developers, the individuals' roles in organizations do not always allow for close collaboration. In business organizations and the corporate environment, there are many unknown organizational practices that may inhibit or encourage interdisciplinary work. Through researching these unknowns, a greater understanding of interdisciplinary interaction and the use of the product development process in these settings could be discovered.

Of particular interest is how interdisciplinary practices affect the product development process in the wearable product field. Developing a deeper understanding of how designers and material developers work together through the product development process is essential for nurturing innovation in the field of wearable product design. Supporting this need for research, West (2003) states:

> Researchers eager to understand group creativity must focus more on the implementation of ideas than their generation in the workplace. It is the implementation of a good idea that advances our progress as a species, not merely the private creative idea-generation process. Too little research effort has been directed at implementation…The task a team performs is key to understanding innovation implementation. It is motivating and challenging tasks that lead teams of innovative people with diverse backgrounds and perspectives to innovate. (p. 267)

Each phase of the product development process involves the implementation of specific tasks, whether it is through understanding the problem, writing the design requirements, or producing the prototype designs. By directing this research towards understanding how interdisciplinary teams of designers and material developers work through the design process, it fills a need in the body of knowledge and will inform how designers and organizations approach wearable product design in the future.

Understanding the product development process from an interdisciplinary perspective can inform applied design research practices. Applied design research practices for wearable products, especially at the University level, are becoming more interdisciplinary as society's problems become more complex. A holistic view of organizational practices in design and an understanding of how the product development process is used, can translate into more efficient interdisciplinary research practices in a University or research setting.

Purpose of research

The purpose of this research was to understand the process by which wearable product designs are achieved in interdisciplinary teams: how team members engage in the practice of design and use the design process, how they interact to develop innovative new products, and how products are brought to market through this interdisciplinary interaction.

Structure of the Dissertation

The research study is set forth in six chapters. Chapter I, Introduction, presents the rationale for research, statement of problem, and purpose of the research. An overview of the structure of the dissertation and definitions are also provided.

Chapter II, Review of Literature, examines common product development processes, material development and wearable product design, individual and group creativity, and interdisciplinary alliances. The literature review contributed to the development of the research questions, found at the end of Chapter II.

Chapter III, Methods, describes the case study methods used for this research, which include research approach and methods selection, data collection procedures, and data analysis procedures.

Chapter IV, Results, reports the findings for three case studies from this research. The interdisciplinary product development process and the interactions between the interdisciplinary companies are explained for each case. Themes relating to the interdisciplinary product development process were compiled from interviews for all three case studies and are described.

Chapter V, Analysis, presents the examination of the results. A comparison of the interdisciplinary product development process between the three case studies is offered, along with an in depth examination of literature in comparison to the results of the research.

Chapter VI, Conclusion, provides a summary and conclusion from the research, as well as suggestions for future research.

Appendices include interview questions and supplementary interview questions.

Definitions

Creativity: The generation of new ideas (Paulis & Nijstad, 2003).

Innovation: The development of a new idea, technology, or product that is adopted by society (Rogers, 2010).

Interdisciplinary: The collaboration of one or more disciplines on a project.

Materials: a broad term for the substance, fiber, textile, or fabric that make up the main components of a wearable product.

Material Development Company: a company that develops materials at any stage of material manufacturing from molecular to structure to fabric finishes.

Phase Change Materials (PCM): A material substance that absorbs and releases thermal energy as it transforms from liquid to solid state through melting and freezing. PCMs have different melting temperatures and are used in products for heating or cooling.

Product Development Process: The sequence of steps or activities that a business or company employs to conceive, design, and commercialize a product (Ulrich & Eppinger, 2012, p. 12).

Sewn products: Products developed from a synthesis of technical (or engineering) design and product design that are produced using stitching methods of manufacturing. For this research, sewn products are limited to products developed for human use, such as a tool or a product for protection from the environment. These products are also differentiated from typical sewn products because they feature advanced functional capabilities for human athletic performance, protection, medical applications, or sustainability.

Wearable products: Products worn on the human body, typically developed from a synthesis of technical (or engineering) design and apparel design (adapted from Ashby & Johnson, 2014, p. 35). For this research, wearable products are differentiated from typical apparel products and feature advanced functional capabilities for athletic performance, protection, medical applications, or sustainability. Wearable products are a subset of sewn products.

CHAPTER II

LITERATURE REVIEW

This chapter covers a review of literature related to product development processes, material development and new products, individual and group creativity, and interdisciplinary strategic alliances.

Product Development Processes

Wearable products are typically designed using a form of the product development process. According to Ulrich and Eppinger (2012) a product development process is the “sequence of steps or activities that an enterprise employs to conceive, design, and commercialize a product,” (p. 12). There are many types of processes that organizations use to create products, but most design processes contain similar characteristics that require designers to use elements of divergent and convergent thinking, analysis of the problem, and synthesis of the information (LaBat & Sokolowski, 1999; Ulrich & Eppinger, 2012). This section covers major product development processes used in product design, engineering, and apparel.

General product development processes. Koberg and Bagnall (1981) describe the product development (design) process as a “problem-solving journey, a process of creative, constructive behavior” (p. 16). The general process they describe was influenced by the characteristics of many problem-solving processes, including those processes used by General Electrical and the military. The authors describe the design process as a series of phases that include intentions, decisions, solutions, actions, and evaluations (Koberg & Bagnall, 1981, p. 16). The logical sequence of their design process is as follows:

- *Accept Situation*: This stage encourages the designer to state their initial intentions, accept the problem, and allow the problem to be the principal driving force of the process.
- *Analyze*: The designer should thoroughly research every aspect of the problem.
- *Define*: This stage includes determining the main issues of the problem, conceptualizing the problem, and creating concrete goals around the problem, similar to the creation of design requirements.
- *Ideate*: This is the most creative phase of the design process, and includes generating concepts to solve the problem.
- *Select*: The designer should choose the best design option/s from the concepts developed during the ideation phase. The selection phase requires that the original goals of the problem inform the selection process.
- *Implement*: The designer plans how to create the selected designs and creates prototypes, giving the ideas physical form.
- *Evaluate*: This phase includes reviewing the prototypes and determining the effectiveness of the design/s at solving the problem. At this point in the process,

the designer can begin planning the production of the design or return to previous stages in the process.

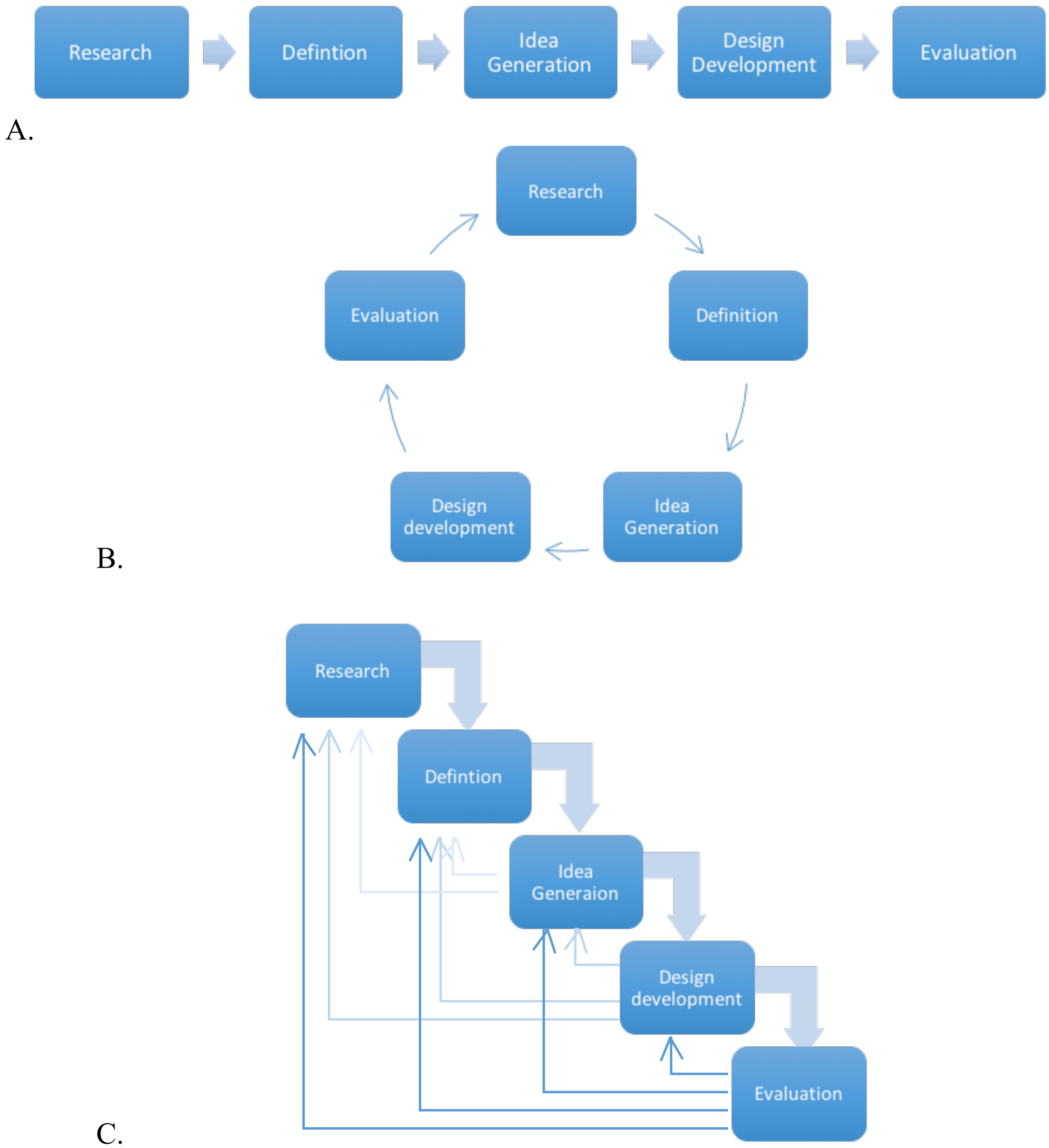

Figure 1: Koberg and Bagnall’s (1981) design process arranged as a (A) linear model, (B) a circular and continual model, and (C) an iterative model that allows the user to return to previous steps. (Koberg & Bagnall, 1981, p. 21; Watkins & Dunne, 2015, p. 3)

Koberg and Bagnall further their design process by describing their model as linear, circular, or iterative, and demonstrating the process as a two, three, five, or seven stage process. Figure 1 is an adapted version of their five-stage design process arranged as a linear, circular, or iterative model (Watkins and Dunne, 2014). In the most basic form, the process is linear with each previous step informing the next. The process, as circular and iterative models, encourages a constant feedback system in which the designer is informed by the previous stage of the process and is always looping back through the process. Koberg and Bagnall's process is one of the first design processes developed and has influenced the development of modern design processes. The circular and iterative nature of their process emphasizes the unknown nature of creativity in new product development. Koberg and Bagnall present detailed problem-solving methods for each stage of their design process.

Ulrich and Eppinger's (2012) generic product development process incorporates a more detailed view of product development and includes perspectives of marketing, design, and manufacturing. This product development process model is a six-step process consisting of planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up. The *planning* stage of Ulrich and Eppinger's (2012) process identifies market opportunity, company strategy, and accesses technology developments. Project goals and design constraints are created based on research. During *concept development*, the needs of the user and target market are determined and designers conduct feasibility testing on initial product ideas. The *system-level design* phase consists of defining the product design, major sub-systems and interfaces, refining the design, and performing component engineering. The *detail design* phase consists of completing product specifications, selecting materials, and developing tolerance levels for manufacturing. *Testing and refinement* involves creating production level prototypes and evaluating them based on the product requirements and specifications, reliability, and durability. The final phase, *production ramp-up,* uses the intended production methods to create the product. This phase is necessary to train the workforce, reduce process errors in production, and make final improvements to the product design. Table 1 represents the detailed generic product development process.

Planning	Concept Development	System-Level Design	Detail Design	Testing & Refinement	Production Ramp-up
MARKETING • Articulate market opportunity. • Define market segments.	• Collect customer needs. • Identify lead users. • Identify competitive products.	• Develop plan for product options and extended product family.	• Develop marketing plan.	• Develop promotion and launch materials. • Facilitate field testing.	• Place early production with key customers.
DESIGN • Consider product platform and architecture. • Assess new technologies	• Investigate feasibility of product concepts. • Develop industrial design concepts. • Build and test experimental prototypes.	• Develop product architecture • Define major sub-systems and interfaces. • Refine industrial design. • Preliminary component engineering.	• Define part geometry. • Choose materials. • Assign tolerances. • Complete industrial design control documentati ons	• Test performance, reliability, & durability. • Obtain regulatory approvals. • Assess environment impact. • Implement design changes.	• Evaluate early production output.
MANUFACTURING • Identify production constraints • Set supply chain strategy	• Estimate manufactur-ing cost. • Assess production feasibility.	• Identify suppliers for key components • Perform make-buy analysis. • Define final assembly scheme.	• Define production processes. • Design tooling. • Define quality assurance processes. • Begin procure-ment of long-lead tooling.	• Facilitate supplier ramp-up. • Refine fabrication and assembly processes. • Train workforce. • Refine quality assurance processes.	• Begin full operation of production system.
OTHER FUNCTIONS • Research: Demonstrate available technologies • Finance: Provide planning goals. • Generic Management: Allocate project resources.	• Finance: Facilitate economic analysis. • Legal: Investigate patent issues.	• Finance: Facilitate make-buy analysis. • Service: Identify service issues.		• Sales; Develop sales plan.	• General Manage-ment: Conduct postproject review.

Table 1. Ulrich and Eppinger's six phase generic product development process featuring typical tasks for key business functions for each phase (2012, p. 14)

In general, Ulrich and Eppinger's (2012) product development process is detailed and provides a clear overview of the organization-wide effort involved in product development. However, the linear format of the process fails to show the complexity involved in the development of a new product and the impact on an organization when the process needs to be more iterative or circular, like Koberg and Banall's (1981). In terms of interdisciplinary product development, this process is successful in showing the different aspects of an organization that are involved, but it doesn't necessarily show how the interaction of different departments affects product decisions. One area of Ulrich and Eppinger's (2012) generic product development process that has potential to change with interdisciplinary teams of wearable designers and material developers is the planning phase in which one of the designer's activities is to assess and research new technologies (highlighted in Table 1). When wearable designers and material developers work together during this phase they can determine with greater accuracy and breadth of knowledge the possibility of new technologies, as well as find gaps in knowledge that could lead to new discoveries and innovation in material and product development.

Engineering design processes. Many conventional design processes follow a systematic model that emphasizes detailed analysis prior to generating solutions. One of the earliest engineering models to propose the basic three-step structure of analysis—synthesis—evaluation was Jones' (1984) prescriptive design process model (Cross, 2007). The analysis stage of Jones' model is defined as creating in depth design requirements and performance specifications based on research. The synthesis stage is when the designer explores all possible solutions. The process at the synthesis stage encourages the designer to develop solutions for the individual design requirements and performance specifications, and then create designs that result in the least concessions. The final stage, evaluation, includes assessing the design solutions for their ability to fulfill performance requirements for divisions such as manufacturing and sales before selecting a final design to move forward.

Archer (1984) developed a more detailed design process for engineering that follows a similar prescriptive model. This model, summarized in Figure 2a, acknowledges the complexity of product development and includes inputs such as clients, the designer's training and experience, manufacturing capabilities, and others. The output of this process includes the communication and specification of a detailed solution. These inputs and outputs are shown as external to the actual design process in the model. Feedback loops are used to encourage iterative steps, similar to Koberg and Bagnall (1981). Archer (1984) describes six dominate types of activity that occur as part of the design process. Those activities are:

- Programming: determine crucial issues related to the design, establish goals, and plan
- Data collection: research and classify data related to the design problem
- Analysis: identify sub-problems, develop design specifications, reassess design time-line and plan
- Synthesis: ideate and create design proposals
- Development: produce prototype designs, validate designs
- Communication: prepare prototype for manufacturing

Figure 2b, is Archer's model in the context of three broad phases: analytical, creative, and executive.

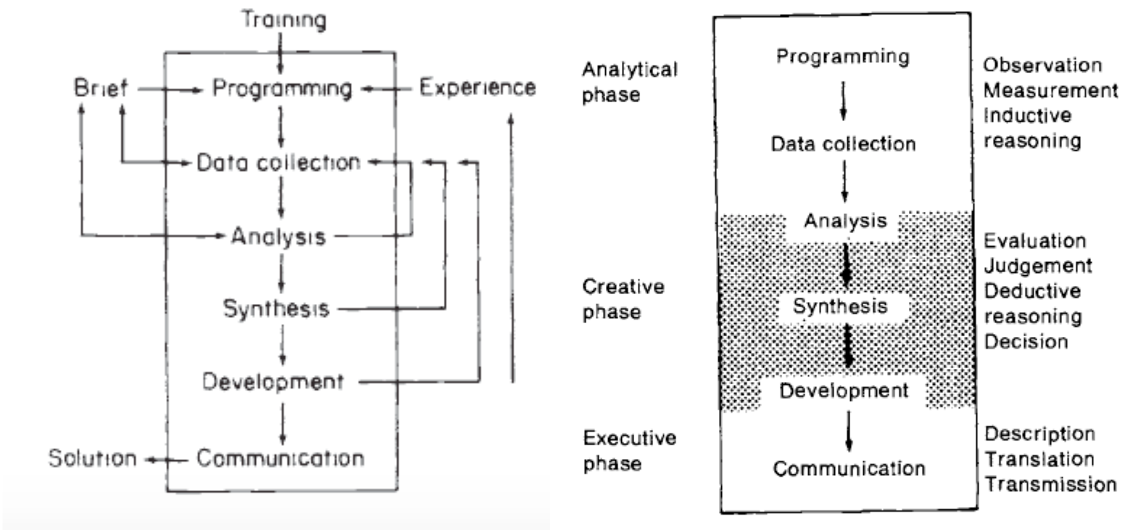

Figure 2. A) Archer's model of the design process (Cross, 2000, p. 35). B) Archer's (1984) three phase summary model of the design process (Cross, 2000, p. 36).

Cross (2007) proposed a seven step engineering design process model in conjunction with his symmetrical problem/solution model (Figure 3) based on the premise of rational design methods. Rational design methods form a checklist for designers and encourage a systematic approach to design. The seven steps of Cross's design model are clarifying objectives, establishing functions, setting requirements, determining characteristics, generating alternatives, evaluating alternatives, and improving details.

With this design process, Cross (2007) emphasizes that the stages and activity methods employed should not be used as a static, linear process, but instead viewed as a series of relationships. The seven-step model placed in the center of the symmetrical problem/solution model highlights the relationships of each step of the process to the problem-solution link of engineering design.

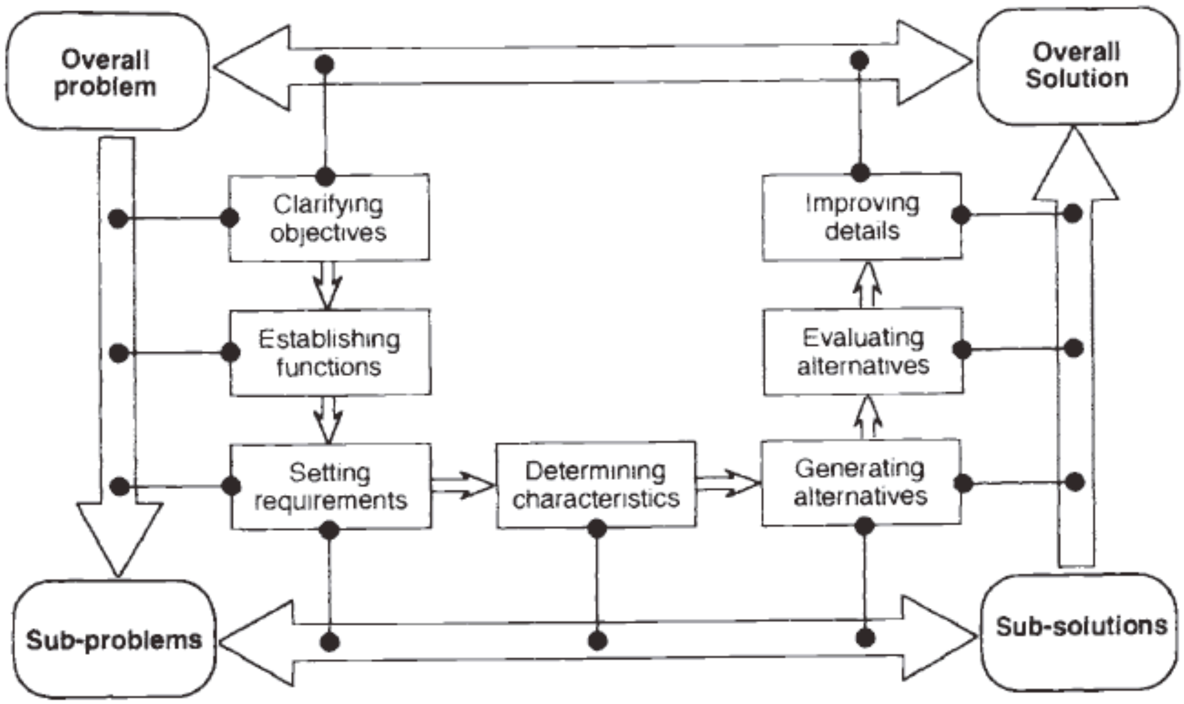

Figure 3. Cross's (2007) seven-phase design process positioned within his symmetrical problem/solution model (p. 58).

Apparel product development process. Many of the apparel product development process models described are heavily influenced by models from other fields and follow similar prescriptive design methods.

Regan, Kincade, and Sheldon (1998) investigated the use of the engineering design process theory, the foundation of the design process, in apparel design to create more complex and better apparel products. The authors used Lewis and Samuel's (1989) engineering design process theory as a framework to determine its applicability in the apparel design process and tested the framework in an apparel industry setting. Lewis and Samuel's engineering design process theory consists of the following stages: (1) problem recognition, (2) problem definition, (3) exploration of the problem, (4) search for alternatives, (5) evaluation and decision-making, (6) specification of solution, and (7) communication of solution (1989). A qualitative study was performed to analyze if the engineering design process that reinforces a looped and iterative progression is relevant in apparel design. The authors conclude that a systematic design process does in fact improve the end products because it addresses complex issues such as manufacturability and user-needs.

Watkins' (1988) design process model refined Koberg and Bagnall's (1981) design process model. The seven-step process Watkins promotes includes:

1. Acceptance of the problem: relating to intrinsic motivation
2. Analysis: where the designer performs in depth research into the problem area and users
3. Definition: the designer sets forth goals for the project and should be based on the previous research done during the analysis phase
4. Ideation: generating ideas based on research and developing a connection between the problem scope, research and the generated ideas
5. Idea selection: determining which design best addresses the requirements
6. Implementation: prototypes are made
7. Evaluate the product

Watkins' design process model for apparel highlights both analytical and intuitive approaches because apparel designers must gather facts and data pertaining to the problem, develop ideas, and put them together in a creative way. Watkins and Dunne (2015) later presented this model as a five step iteration of Koberg and Bagnall's design process. Due to the unpredictable nature of design, the authors emphasized that the model could be used as a linear, circular, or iterative process.

Researchers Lamb and Kallal (1992) originally developed the Functional-Expressive-Aesthetics (FEA) needs model as a method to evaluate and design garments for people with special needs. Their preliminary research found that aesthetic and expressive considerations were important when designing functional garments. Their research, and previous studies, found that consumers were significantly more satisfied with the functional product if it was aesthetically pleasing and expressive of their self. The researchers of this framework projected that it could be used in application and as a design process for all types of apparel design because the consumer (or intended user) was located at the heart of their model. They claim that if a designer identifies the needs and wants of their user or target consumer, their framework can be used to establish design criteria specific to the user. Uniquely, this model does not classify between fashion design and functional apparel design, and the authors propose that it can solve a variety of design endeavors ranging from skating costumes or customized design to personal protective equipment. Using Koberg and Bagnall 's (1981) and Watkin's (1988) design processes as a guide, which emphasize the application of user needs, Lamb and Kallal used the steps of problem identification, preliminary ideas, design refinement, prototype development, and evaluation in conjunction with the F-E-A model.

The Functional- Expressive- Aesthetic (FEA) model (Figure 4) expands the considerations made in the problem identification and evaluation phases by requiring consideration of functional, expressive, and aesthetic needs for each design problem. This approach to apparel problem solving enables designers to think beyond commonly accepted definitions of wearer needs. Furthermore, identifying the needs and wants of the target consumer helps to establish more focused design criteria.

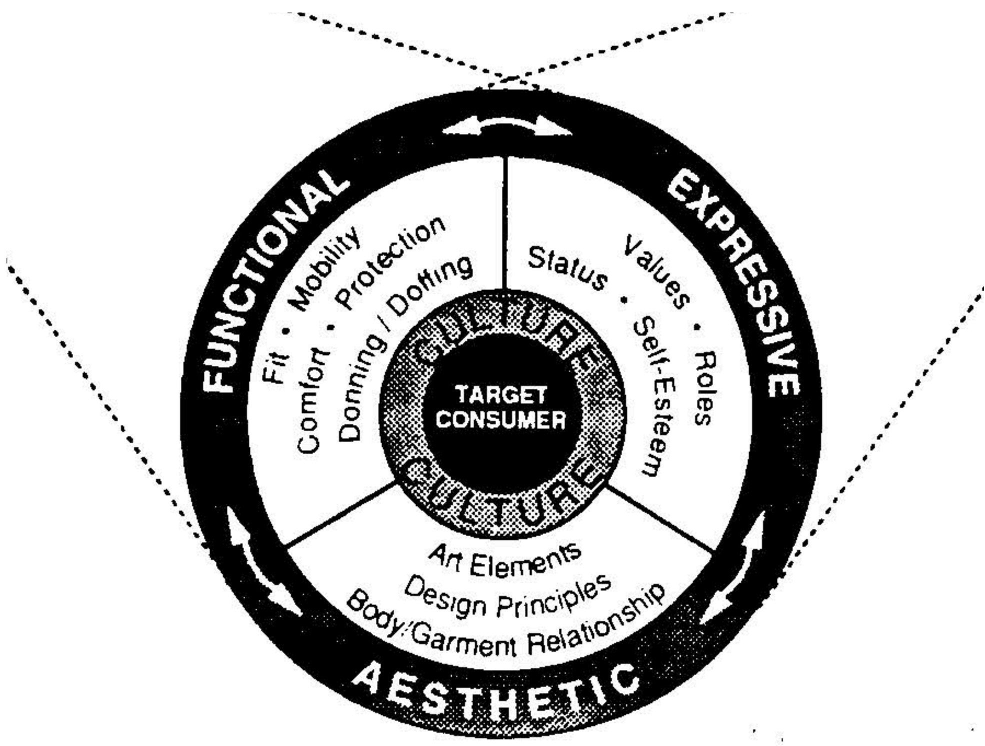

Figure 4. FEA consumer needs model (Lamb & Kallal, 1992).

LaBat and Sokolowski (1999) examined commonly used design processes in architecture and environmental design, engineering, industrial product design, and clothing design. They found that there were major over-lapping characteristics across the processes that could be summarized in three major phases: 1) Problem Definition and Research, 2) Creative Exploration, 3) Implementation. After determining the major stages of the design processes in fields that produce three-dimensional products, the authors elaborated the process by including specific steps that can be utilized in textile product design development. Figure 5 is the detailed textile product design development process. A case study involving a university and industry collaboration tested the process.

I. Problem Definition & Research	II. Creative Exploration	III. Implementation
A. Initial Problem Definition • Client definition	A. Preliminary Ideas • Expansive, all realm of possibilities	A. Production Refinement • Cost to produce • Time to produce • Methods of production • Sales potential
B. Research • User Needs: -Function -Aesthetic -Economic • Market: -Assess current products -Competitive Analysis -Economic conditions	B. Design Refinement • User constraints: -Function -Aesthetic -Economic • Production Constraints -Cost to produce -Time to produce -Methods of production -Sales potential	B. Phase 1: Immediate Production • Changes in product or production that can be accomplished immediately
C. Working Problem Definition • Defined by industry client & university designer • Design criteria established	C. Prototype(s) Development • Meshing design criteria and constraints to develop workable ideas D. Evaluation of Prototype • Preliminary: by university designer • Final: by university designer and industry client	C. Phase 2: Improvement/Refinement • Further development that may be delayed

Figure 5. Textile product design process stages (LaBat & Sokolowski, 1999).

Overview of product development processes. There are many overlapping characteristics of product development processes among the design disciplines, with individual designers and companies developing preferred methods of approaching product development. As LaBat and Sokolowski (1999) discovered, most of the processes discussed in this section consisted of *analysis* in the form of problem definition, research, and the development of design requirements, *synthesis* or *creative exploration* in which possible solutions to the problem are explored, and *implementation* of the new product. However, due to the increased complexity of design problems and the high risks and costs associated with new design, most business and design professionals agree, “there is a need to improve on traditional ways of working in design,” (Cross, 2007, p. 45).

The creation of wearable products is inherently interdisciplinary because nearly every department within a company is involved in some manner (Ulrich & Eppinger, 2012). It is unclear which elements of the product development process are used, or whether the process becomes something entirely new when design and material companies begin design development together. Research is needed to understand how the product development process is used in an interdisciplinary environment consisting of wearable product designers and material developers.

Material Development and Wearable Product Design

Today, innovation in wearable products is being driven by new material development. Ashby and Johnson (2014) write, “changes in design…derive largely from the introduction of new materials” (p. 29). New materials are being introduced to the market at an incredibly fast pace, yet many designers have a tendency to revert to using materials they are familiar with when designing new wearable products (Bye & Griffin, 2015; Ashby & Johnson, 2014). Bramel (2005) elaborates on this concept in regards to the development and application of synthetic fibers:

> The study of the history of synthetic fibers has shown that new fibers are at the basis of most textile innovation, but they do not always lead to evolutions in

> garment design. All too often, new materials are simply copied and pasted to traditional garment shapes and assembled using conventional manufacturing techniques. Yet though there are plenty of so-called smart textiles, there are not so many smart garments. (p. 25)

This quote illustrates that a novel material does not guarantee an innovative product. Basing a product's features on the material choice alone "is one of this market's weaknesses," (Bramel, 2005, p.27). Innovative wearable products require a marriage of intelligent design and high performance materials.

Material innovation is driven by market demand, technology, functionality responses, environmental sustainability responses, and scientific development in textile finishes, structures, sensing textiles, smart textiles, and nanotechnology. Functional properties can be built into a material at nearly any stage of the material development process: molecular, such as advances in nanotechnology; fiber, where changes in composition and treatments such as finishes and texturing can result in innovative materials; yarn; material structure such as weave, knit, web, films, foam, etc; and fabric where treatments such as waterproofing, finishes, and composites can transform the material.

While innovative material development is occurring at a rapid pace, it can be risky from a business perspective. Horne (2012) elaborates:

> The manufacturer's nirvana is to develop and produce exactly what its customers want, when they want it – ideally with no risk of overstocks or inventory. The increasing heterogeneity of demand, a rapid change of preferences, and the resulting micro-segmentation of many product categories, however, prevent manufacturers from reaching this state easily. In many consumer goods markets, manufacturers today are forced to create suitable assortments for smaller market niches than ever before, as these markets frequently are the only way for growth and an escape from heavy price competition. In such a situation, new product development projects often cause enormous investments and are highly risky.

> While new products or product variants have to be developed and introduced at high pace, forecasting their exact specification and potential sales volumes is becoming more difficult than ever. (p. 176)

The risk associated with developing and producing new materials can inhibit innovation and development of materials in a company or manufacturer. Business collaboration and development between the manufacturer and the wearable product design company can continue to encourage new material development, while mitigating the risk for both companies.

When examining the application of new materials in wearable products, it is important to understand how designers currently source and use materials in the industry. In the apparel industry, designers typically source materials from material manufacturing companies. Manufacturers provide the designers with material specifications and samples, and designers evaluate the material's effectiveness for the product based on sensory evaluation such as the drape, texture, and appearance of the material, as well as past experience working with similar materials (Bye & Griffin, 2015). These sensory evaluation techniques are successful in most apparel applications of everyday clothing; however, difficulties arise for designers of more advanced wearable products. When wearable product designers are given the opportunity to use innovative materials they may avoid using the material because they are unfamiliar with its properties, the sensory evaluation may not align with their expectations, and too many changes may have to occur in current production practices to accommodate the new material (Ashby & Johnson, 2010; Bye & Griffin, 2015). Material application models may help wearable product designers make more educated decisions about material use and encourage the application of innovative materials in their designs.

Application of new materials in apparel. There are two models, Ashby and Johnson's (2014) Materials in the Design Process and Bye and Griffin's (2015) Wearable Product Materials Research model, which are relevant to the application of new materials for wearable product designers. Both of these models rely on the beginning stages of the product development process to provide design requirements for material selection based on user needs.

The Materials in the Design Process (Ashby & Johnson, 2014), Figure 6, was developed for product design. This model follows material selection throughout the product development process. Initially, all materials are to be considered by the designer. Once technical and design constraints are developed, the designer should narrow down the material choices to a small number to explore in detail. Next, the designer should test the materials based on their technical performance, evaluate the results, and narrow down the material options even further. Using the final selected 5-10 materials, the designer should create working prototypes and select one to two materials to work on manufacturing specifications and process, and to test in more developed prototypes.

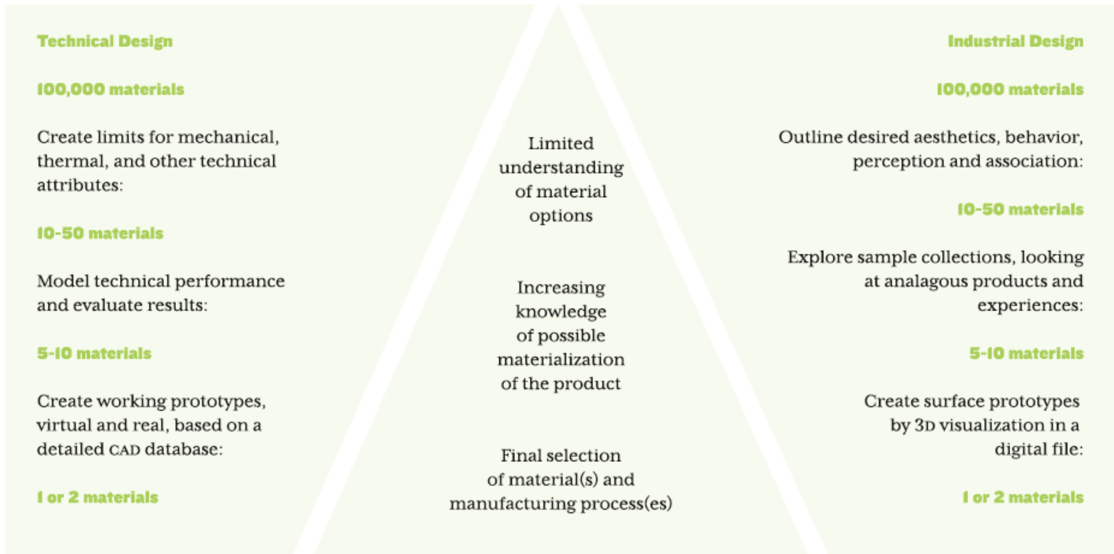

Figure 6. Materials in the Design Process (Ashby & Johnson, 2010, p. 39).

Bye and Griffin's (2015) Wearable Product Materials Research model supports material experimentation through a material selection process that encourages the designer to think about the application of the material and the user simultaneously (Figure 7). It was developed for designers to use with the product development process. This model begins with the selection of materials based on design requirements and user needs developed in the beginning stages of the product development process. Once potential materials are selected, the designer is asked, "Does the material bend and allow movement?". This is an important aspect of any material used in wearable products because the product needs to be worn on the human body, a surface that moves, bends, and changes shape. If the material cannot bend or allow for movement, the designer is asked if these elements can be manipulated through the design, pattern, joining or seaming method, material manipulation or cutting. If at any point the designer says no to a step, then the designer should select another material to move through the process. The second step is to determine if the material can hold adequate shape and structure based on the design needs. For the third step, the designer is asked if the material can be joined (sewn, welded, etc.) to self or other components using available manufacturing methods. The fourth step addresses the need for humans to be able to don and doff the designed product by asking if the material can support closures such as zippers, hook and loop tape, buttons, etc. The last step, and perhaps the most important step, is for the designer to determine if the material addresses user expectations and perceptual qualities needed for product success. All of these questions are easily addressed when a designer is familiar with the material, but this rational method can improve the selection of materials and encourage innovative material use through experimentation throughout each step of the model.

Ashby and Johnson's (2014) and Bye and Griffin's (2015) models provide a method for material selection for designers to use in conjunction with the product development process. These models, however, are relatively new and their effectiveness has not been tested in an industry setting. While these models are useful and wearable product designers should continue to improve their material application skills, these models do not place the material developers and the designers any closer together during the product development process. The advantage of interdisciplinary collaborations with material developers is a method that has been suggested to improve the application of innovative materials in wearable products. A deeper knowledge of how to promote improved material application through interdisciplinary collaboration is sought through a review of literature of individual and group creativity influences and factors.

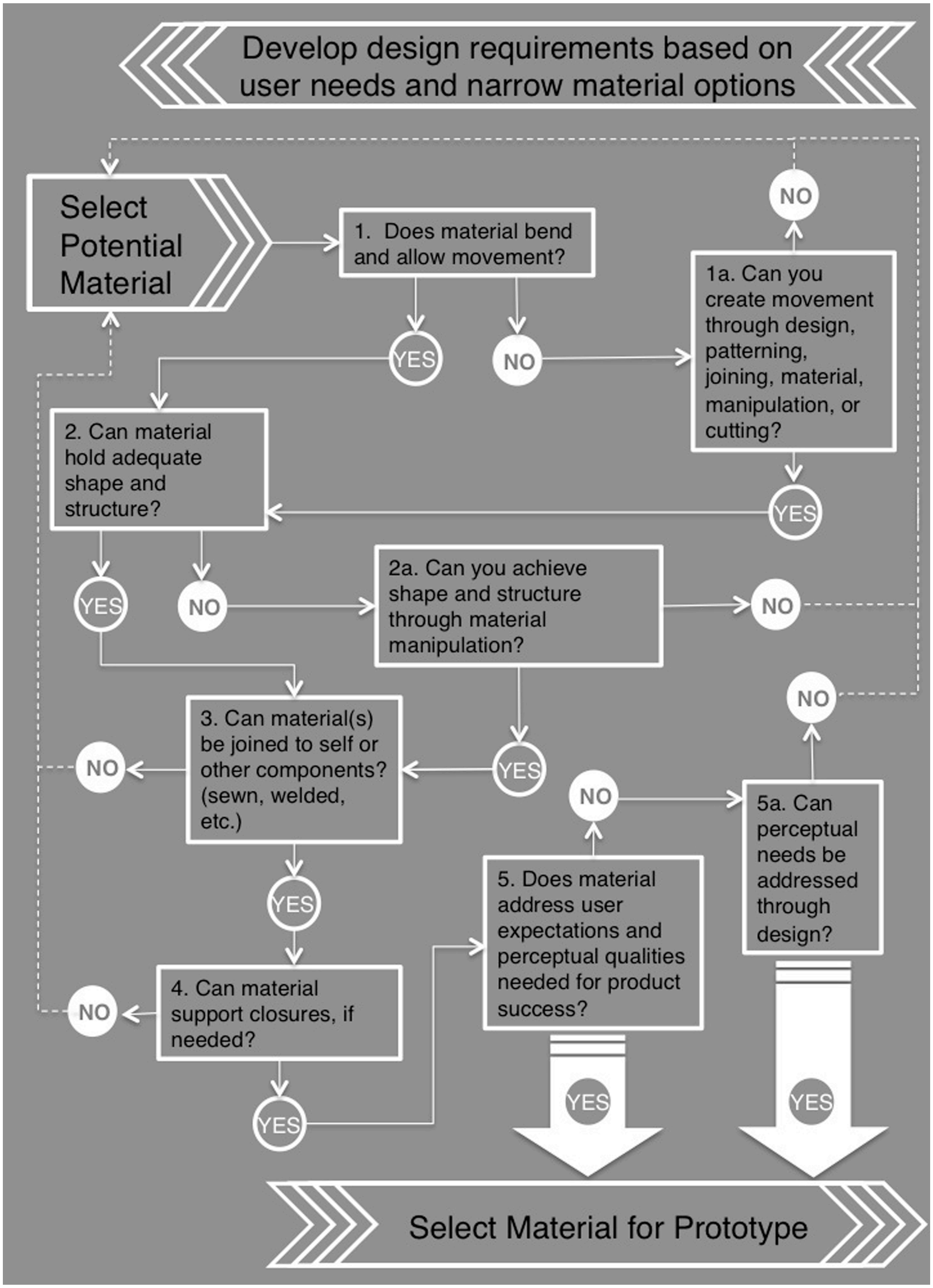

Figure 7. Wearable Product Material Research model (Bye & Griffin, 2015, p. 4).

Creativity and Innovation

Creativity is the generation of new ideas, while innovation is the development of a new idea, technology, or product that is adopted by society (Rogers, 2010; Paulis & Nijstad, 2003). A strong base understanding of the components of creative individuals and creative groups can help identify key components advancing innovative wearable product design in interdisciplinary teams.

Individual creativity. The meaning and theory of creativity has evolved over time, with each piece of new knowledge playing an integral role in how we evaluate creativity in modern research (Sternberg, 1999). Sternberg (1999) describes the different perspectives in which creativity developed in research as the mystical approach, psychodynamic approach, psychometric approach, cognitive approach, socio-personality approach, and the confluence approach. According to Sternberg (1999) and Csikszentmihalyi (1997), creativity was first associated with mysticism, religion, and pragmatism. The meanings that developed around creativity through these associations were typically concerned with developing methods to improve creativity in humans, as opposed to developing a clear *understanding* of creativity.

The first major development in the theory of creativity occurred with the psychodynamic approach to creativity, which began to dominate the field in the 1950s (Sternberg, 1999). Freud (1908, 1958) first wrote about creativity in terms of the "tension between conscious reality and unconscious drives," (Sternberg, 1999, p. 267). Thus began the development and study of creativity as a process of thought (Sternberg, 1999).

Concepts of creativity continued to develop in terms of classifying and generalizing creativity through psychometric and cognitive approaches. Psychometric approaches developed meanings of creativity through the idea that creativity could be measured through testing of creative thought in individuals. Cognitive approaches aided in the development of creative theory through research on systematic thought process in creative individuals. Major developers of conceptual meaning with a psychometric approach included Guilford (1962), who promoted the concept of divergent and convergent thinking as a method to classify, describe, and measure creativity, and Torrance (1974) who in a similar vein developed creative thinking tests to measure creativity. Divergent thinking and flexibility are still considered central elements of creativity and design (Bye, 2010). Many of the creative theory approaches developed in the psychometric and cognitive research are still widely used today as a basis for understanding and developing modern creative design processes.

Key researchers who developed creativity concepts from a social-personality perspective are Amabile (1983), MacKinnon (1965), and Barron (1968). While the social-personality approach has provided valuable insight into concepts of creativity, most of the key researchers studied the variables independently and rarely sought to understand personality traits, motivation characteristics, and the sociocultural environment in conjunction with one another.

While the social-personality approach developed creativity theory by combining diverse variables, the confluence approach begins to characterize and study creativity as complex, multi-dimensional, and reliant on environmental (personal, local, societal, global) systems working together to form creative outputs (Sternberg, 1999). Major researchers of the confluence approach to creativity development include Amabile (1983), Csikszentmihalyi (1988, 1996), and Sternberg and Lubart (1991, 1992, 1995, 1996).

The three dominate researchers in the field of confluence creativity development viewed and researched creativity from a variety of perspectives. Amabile (1983) looked at the interaction of intrinsic motivation, knowledge, and ability in a particular domain, and creativity-relevant skills such as cognition, problem solving, heuristics, and work style. Csikszentmihalyi, one of the most influential researchers in developing concepts in creativity theory, developed theory through a systems approach that emphasized the relationship between the individual, domain, and field (1988, 1996). Sternberg & Lubart (1991, 1992, 1995, & 1996) developed an investment theory of creativity that combines distinct variables related to the individual person and outside world

Csikszentmihalyi's creativity theory revolves around a person's domain, which consists of a set of symbolic rules and procedures. Fields act as gatekeepers to the domain and decide on whether to promote new ideas or products. The individual uses symbols of a domain, comes up with new ideas, or sees new patterns. Thoughts or actions change a domain, or can establish a new domain. Personality, skill, complexity of thought, social access, and convergent/divergent thinking methods are among many of the variables that can affect an individual's ability to create and/or promote a new product or idea.

The investment theory of creativity (Sternberg & Lubart, 1991, 1992, 1995, 1996) describes creative individuals as having the ability to pursue ideas that might not be in favor (buying low), and persisting in promoting their ideas until they are eventually accepted (selling high). The researchers developed the theory that creativity incorporates six distinct but interrelated variables (intellectual abilities, knowledge, styles of thinking, personality, motivation, and environment) in order to describe how the investment theory fully functions in the 'real world' (Sternberg, 1999).

Epstein (1999) and Csikszentmihalyi (1997) outline major creative competencies in their research. Both researchers discovered that creativity is essentially accomplished through a series of behaviors and that those behaviors can be both improved and learned through repetition. The four major creative proficiencies that Epstein outlines in his Generativity Theory (which are very similar to those that Csikszentmihalyi writes about) are: capturing and preserving ideas, seeking challenges, increasing knowledge and skills, and seeking change in both the physical and social environment. Epstein suggests ways in which individuals, businesses, and teachers can foster these skills through eight steps that involve encouragement of new ideas and knowledge, challenging others, creating a stimulating working environment and providing resources. The most efficient way to implement these ideas into wearable product design is through a design process. Most product development processes encourage in-depth research, capturing a vast amount of new ideas and synthesizing information, which can eventually lead to creative problem solving.

The individual creativity of wearable product designers and material developers is influenced by their personality, experience, culture, motivation, and cognitive skills (Sternberg, 1999). However, the presence of individual creativity is not directly correlated to group creativity due to social, organizational, and team process influences (Paulis & Jigstad, 2003).

Group creativity. Prior to the 1990s, researchers ignored studying creative collaboration because it was believed that individual creativity was superior to group creativity (Paulis & Nijstad, 2003). Initially, researchers of group creativity and innovation found that groups have a tendency to come to premature consensus, individuals in groups tend to share common rather than unique ideas (a problem called 'group think'), and groups can lower accountability and motivation of the individual, all of which can cause a drought of creativity (Janis, 1982; Stasser, 1999; Karau & Williams, 1983; Paulis & Nijstad, 2003). Despite these factors inhibiting creativity in groups, innovation in organizations provided a glimpse of hope to those studying group creativity and offered evidence that highly functioning groups could in fact be creative (Paulis & Nijstad, 2003).

In recent years, researchers have discovered that team context such as group diversity, organizational context such as culture, and team processes all contribute to the number and quality of innovations from a group (Paulis & Nijstad, 2003; Milliken, Bartel, & Kurtzberg, 2003; West, 2003).

Team context. From a team perspective, literature suggests that influences of innovation implementation in work teams are the challenging nature of the task, group diversity, and group tenure (Milliken, et al., 2003). The positive influence of group diversity on creativity and innovation is particularly important for supporting interdisciplinary teams in wearable product development.

Homogeneity, consensus, and majority views within a group can be problematic for creative idea generation (Nemeth & Nemeth-Brown, 2003). These elements of groups, also known as group think, have contributed to research that has shown individuals often scoring higher on creativity tests than groups (Nemeth & Nemeth-Brown, 2003). Dissent among group members, however, has been shown to stimulate divergent and creative thought in a group (Nemeth & Nemeth-Brown, 2003). One way to reduce group consensus and promote dissent among group members is to form groups from diverse individuals.

Cognitive-diversity is the result of an individual's knowledge, education, and background, and is a prime element of group diversity. Many researchers have argued that a diverse workforce, and more specifically groups composed of diverse individuals, can raise the number of perspectives in a group and reduce the chances of creativity inhibiting group dynamics (Nemeth & Nemeth-Brown, 2003).

In a review of literature on group diversity, Milliken, Bartel, and Kurtzberg (2003) found overwhelming evidence to support cognitive diversity in groups within organizations because it may "enhance task-related or cognitive performance, especially on tasks requiring creativity," (p. 44) (Austin, 1997; Bantel & Jackson, 1989; McLeod, Lobel, & Cox, 1996). Stasser (1992) found one reason promoting the concept of group diversity is because a high level of cognitive diversity increases the "potential range of perspectives and opinions members bring to the task," (Milliken, et Al., 2003, p. 45).

When group members bring differing perspectives and opinions to a task, it can create task conflict. Task conflict refers to disagreement among group members in how the task should be executed. Jehn et al. (1997, 1999) and Gruenfeld (1995) discovered that task conflict,

> …is thought to both encourage and legitimize the consideration of multiple alternatives. In addition to airing differences in perspective, task conflict or disagreements in opinion can serve to encourage each individual to give more careful thought and attention to his or her own viewpoint. (Milliken, et al., 2003, p. 45)

A central element of creativity is the generation of new ideas. The result of task conflict is an increase of the creativity output of a group, and in turn has the potential to increase the development of innovative products.

This research suggests cognitive diversity among group members, such as the functional and knowledge diversity of wearable product designers and material developers, is positively associated with divergent thinking and innovation (West, 2003). Stasser and Birchmeier (2003) reiterate this by stating, "clearly, one way of promoting more innovative decisions is to compose groups with diverse perspectives and knowledge," (p. 104). Thus, an interdisciplinary, diverse work group can enhance creativity and should be encouraged between material developers and designers of wearable products.

Organizational context. The culture for innovation in an organization and external demands are major influences of innovation implementation in work teams from an organizational context.

Support for innovation from an organizational context refers to the "expectation, approval, and practical support of attempts to introduce new and improved ways of doing things in the work environment," (West, 1990; West, 2003, p. 263). One crucial element of improving group creativity is organizational support and the culture for innovation (West 1998; West & Anderson, 1996). New ideas at the group level can be rejected, ignored, supported, or accepted. Supporting and accepting new ideas at the group or team level are shaped by individual and group behavior, and an organization's support for innovation can encourage the team to introduce new ideas without fear by encouraging risk taking and idea generation (Amabile, 1983; Kanter, 1983; West & Anderson, 1996; West & Anderson, 1998). In fact, the support of an organization "was discovered to be one of the most powerful predictors of team innovation," (West, 2003, p. 263). However, if a company has too many external demands on groups, such as funding capacity for research and development, and time-to-market constraints, group creativity may suffer (West, 2003). As it becomes more common for interdisciplinary teams of material developers and wearable product designers to work together, organizations must support and encourage their endeavors if innovation is to be achieved.

Team processes. Participation of team members, the development of shared objectives, reflexivity, and leadership contribute to the effect of team processes and the implementation of innovation in an organization.

Research has shown teams who have a high level of participation in making group decisions are less likely to allow dissent to affect the stages of the product development process, less resistant to change, and are more motivated to implement their innovations (Bowers & Seashore, 1966; Coch & French, 1948; Lawler & Hackman, 1969; West, 2003). A high level of participation in teams is directly correlated to the concept of developing shared objectives. Developing shared objectives within a team can "facilitate innovation by enabling focused development of new ideas," (West, 2003, p. 261). When a team's objectives are unclear, they lack the ability to produce focused ideas and filter new ideas with precision. Furthermore, if team members are not committed to the goals of their work, innovation can be inhibited (West, 2003). The importance of shared objectives was suggested through the research of Pinto and Prescott (1987), in which they studied 418 project teams. They found shared objectives can predict success at all stages of the product development process and are necessary to ensure persistence in implementing ideas if faced with resistance (Pinto & Prescott, 1987; West, 2003).

Elements contributing to the processes of groups can affect innovation implementation at a variety of levels beyond developing shared objectives and the participation of team members. Team reflexivity where in a team collectively reflects, plans and adapts to both the team objectives and the organization is one way in which group process contributes to creativity (West, 2003). Leadership within groups influences creativity and innovation through utilizing a reward structure and enticing intrinsic motivation in group members (West, 2003). All of these factors can affect the product development process at any stage and should be further researched in the context of wearable product design.

Innovation implementation in work teams. Several of the group creativity influences discussed in this section are summarized in West's (2003) Input-Process-Output Model of Group Innovation, Figure 8. This framework uses inputs as the team and organization, team processes as the mediator of the inputs and outputs, and the output as the number of innovations. It is important to understand how innovation occurs within groups from a variety of perspectives. West's (2003) model helps to contextualize the varied influences and relationships of group innovation. Furthering our understanding of how interdisciplinary teams, such as those consisting of material developers and wearable product designers, work through the design process and implement new innovative products is an important area of research that has yet to be fully developed (West, 2003).

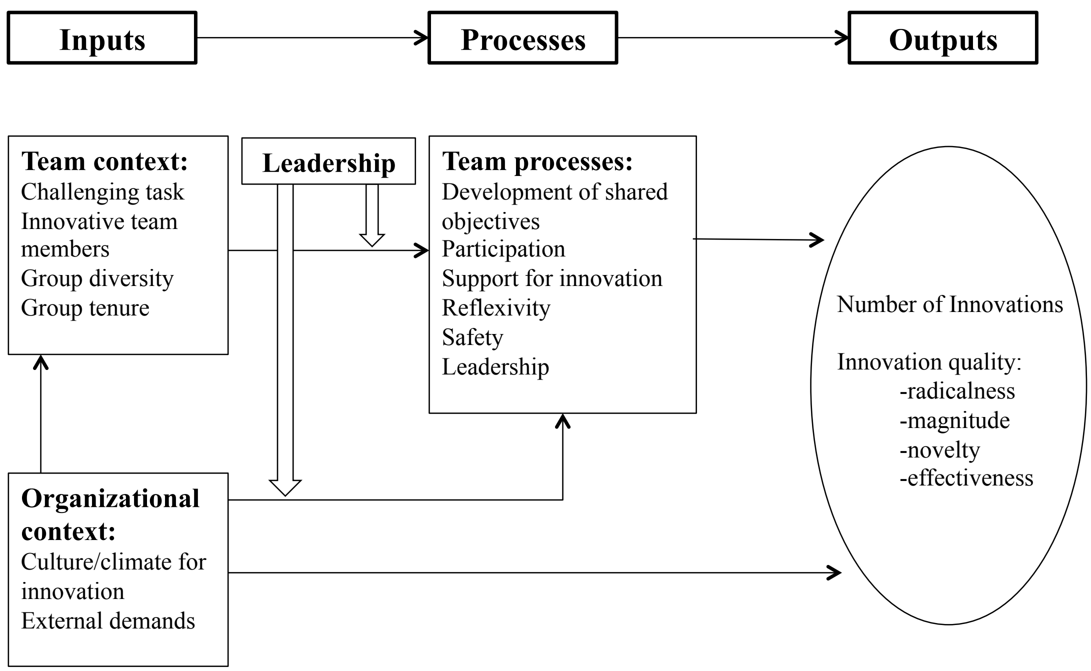

Figure 8. An input-process-output model of work group innovation (West, 2003, p. 246).

Interdisciplinary Alliances

Research has deemed interdisciplinary alliances between businesses one of the most important trends in industrial organizations of the past quarter century (Grant &

Baden-Fuller, 2004). In terms of product development, interdisciplinary alliances between businesses have been shown to have a strong effect on new product development, product innovativeness, and innovative performance (Kotabe & Swan, 1995; Baum, Calabrese, & Silverman, 2000; Lerner, Shane, & Tsai, 2003; Rothaermel & Deeds, 2004). There are two noteworthy theories that aid in the understanding of interdisciplinary alliances from the product development perspective: the knowledge accessing theory of strategic alliances (Grant & Baden-Fuller, 2004) and the exploration-exploitation model of organizational learning (March, 1991; Rothaermel & Deeds, 2004).

Grant and Baden-Fuller (2004) proposed the knowledge access theory of strategic alliances based on the premise that the, "primary advantage of alliances is in accessing rather than acquiring knowledge," (p. 61). The authors found that due to outsourcing and a divestment in 'non-core' activities, companies tend to engage with other companies to access resources outside their own boundaries (p. 61). Their proposed knowledge access theory of strategic alliances makes some basic assumptions about the knowledge of a company that are very relevant to understanding alliances between wearable product design companies/teams and material companies/teams. Those assumptions are:

1. Knowledge is the overwhelmingly important productive resource in terms of market value (Grant, 1996; Machlup, 1980).
2. Different types of knowledge vary in their transferability: explicit knowledge can be articulated and easily communicated between individuals and organizations; tacit knowledge (skills, know-how, and contextual knowledge) is manifest only in its application – transferring it from one individual to another is costly and slow (Kogut and Zander, 1992; Nonaka, 1994).
3. Knowledge is subject to economies of scale and scope. Since the costs of replicating knowledge tend to be lower than the costs of the original discovery of creation of the knowledge, it is subject to economies of scale. To the extent that knowledge is not specific to the production of a single product, economies of scale imply economies of scope. The extent of economies of

scale and scope vary considerably between different types of knowledge. They are especially great for explicit knowledge, information in particular, which is ‘costly to produce, but cheap to reproduce (Shapiro and Varian, 1999, p. 3). Tacit knowledge tends to be costly to replicate, but these costs are lower than those incurred in its original creation (Winter,1995).

4. Knowledge is created by individual human beings and to be efficient in knowledge creation and storage, individuals need to specialize (Simon, 1991,p. 127).
5. Producing a good or service typically requires the application of many types of knowledge (Kogut and Zander, 1992). (Grant & Baden-Fuller, 2004, p. 66)

These knowledge assumptions contribute to the premise that it is more advantageous for a company to enter into an alliance (or collaboration) that has a different set of knowledge and skill, than it is for the company to acquire the knowledge.

Based on the advantage of a company accessing knowledge as opposed to acquiring knowledge, Grant and Braden-Fuller (2004) proposed four basic propositions that make up their knowledge access theory of strategic alliances. The first proposition states that alliances between organizations are beneficial because of the costs associated with knowledge integration. Especially when an organization is developing products that require a vast range of knowledge types, it is more efficient for the organization to link with another specialized organization. Proposition two of the theory states that the larger the scope of an innovative product’s domain compared to the parent organization’s specific knowledge, the more likely that organization is to form alliances. Proposition three centers around the uncertainty of knowledge requirements in the future. A company is more likely to engage in interdisciplinary collaborations as a way to access and integrate different types of knowledge if the future of the product is unclear due to a high risk and uncertain market. Grant and Braden-Fuller’s (2004) final proposition of their theory states that there is a greater propensity for interdisciplinary collaborations between companies when early-mover advantage in technologically dynamic environments is strongest. All aspects of this theory could propel wearable product designers/companies and material developers/companies to enter into strategic alliances in order to create more innovative wearable products.

Beyond the motivation of why companies enter into strategic alliances, it is important to understand the role the product development process plays in their formation. Rothaermel and Deeds (2004) exploration-exploitation model of organizational learning expands upon Grant and Braden-Fuller's theory through examining alliances in an integrated product development path. The authors of this model emphasize that different stages of the product development process require different motives for creating strategic alliances. In this model, the authors differentiate the types of alliances that companies seek as exploration and exploitation alliances. An exploration alliance is when a company enters into an alliance during the research phase of the product development process in order to enhance discovery, innovation, and a product's chance of being placed into development. An exploitation alliance occurs during the development aspect of the product development process and enables the commercialization of a product. Figure 9, demonstrates how a company's exploration alliance predict products in development and how a company's exploitation alliances predict products on the market. The stage in which a wearable product company enters into an alliance with a material development company during the product development process will determine the type and characteristics of the alliance. A better understanding of when and why a wearable product company enters into an interdisciplinary alliance can inform how the product development process is being utilized in the two companies.

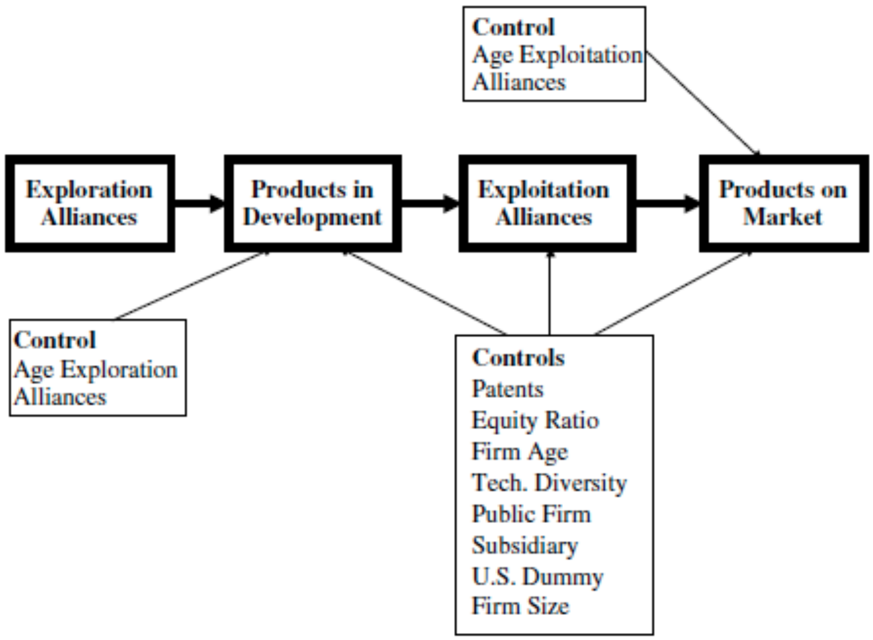

Figure 9. Firm allying and new product development (Rothaermel & Deeds, 2004, p. 202)

Summary

Literature related to product development processes, material development, individual and group creativity, and interdisciplinary alliances was reviewed in this chapter. Generic, engineering, and apparel specific product development processes were reviewed. Areas of material development and innovation were discussed, as well as current methods used for new material application within the apparel industry. The development of creativity theory and group creativity research related to group diversity, team processes, and organizational context were reviewed. Finally, interdisciplinary strategic alliance theories were discussed to form a stronger understanding of the factors contributing to material companies' and wearable product design companies' collaborative projects within teams and organizations. This overview of literature has provided the background for conducting this research.

Research Questions

The literature review contributed to the development of the proposed research. This research sought to answer the following questions:

1. How do interdisciplinary companies and teams work together during the development of new products?
    a. What was the interaction during the development of the sewn product?
    b. At what stage of the design process did they collaborate?
    c. Are there instances where the material and the design were developed simultaneously?
2. How does an interdisciplinary approach to design and material development impact the way in which product development is conducted (i.e. the processes used? Manufacturing and production?)
3. How does an interdisciplinary process of design and material development lead to the creation of new products?

CHAPTER III

METHOD

The purpose of this study is to understand the process by which wearable product designs are advanced in interdisciplinary teams: how team members engage in the practice of design and use the design process, how they interact to develop innovative products, and how products are brought to market through this interdisciplinary interaction. Literature was reviewed to guide the selection of the research method. The literature examination focused on the product development process and interdisciplinary teamwork in wearable product development with a specific emphasis on material innovation. This chapter describes the methods used for this research, which includes research approach and methods selection, data collection procedures, and data analysis procedures. Limitations of the research are discussed.

Prior to subject selection and conducting research, the University of Minnesota Institutional Review Board (IRB): Human Subjects Committee determined that the study was exempt from review and granted human subjects research permission. The study approval number is 1508E77568.

Case Study Approach and Methods Selection

Case study methods have been used in a variety of settings as a way to investigate organizational practices (Patton, 1990; Yin, 2014). A case study approach was selected for this research because it supports a holistic investigation of interdisciplinary product development in organizations using multiple sources of evidence (Yin, 2014). Yin (2014) describes three conditions relevant for selecting the case study method as: the research question, which should seek to explain how or why an event occurred/is occurring; the lack of behavioral control; and a focus on contemporary events. The research questions guiding this research seek to explain *how* the product development process is conducted through interdisciplinary collaboration, the research requires an in-depth examination of a contemporary phenomenon, and the research does not involve the manipulation of any social events. Furthermore, because of the dynamic nature of interdisciplinary product development, the case study method is considered effective in allowing the research to adapt to different types of evidence (Yin, 2014).

Case study research can focus on a single case study or multiple cases depending on the desired outcome (Yin, 2014). Because there is the potential for the design and product development process to be different between companies, designers, and material developers, the multiple case study approach was used. For this research, it was important to study the richness of each context, and to encourage accurate theory-building connections between the cases (Yin, 1993, p. 11). Central to this research design are purposeful sampling, triangulation, and systematic data analysis which allows 'patterns' of the phenomena and context between the organizations studied to be found amongst the data (Fox-Wolfgramm, 1997; Pickkari, Plakoyiannaki, & Welch, 2010; Yin, 2014).

Using methods adapted from Yin (2014), Eisenhardt (1989), Fox-Wolfgramm (1997), and Pickkari, et al. (2010) as the foundation for the data collection procedure, the sources of evidence collected for this research included focus group interviews, individual interviews, observation, a site visit, archival and patent documentation, and physical artifacts. This chapter covers the specific case study procedures used for this research:

- The phenomenon, context and units of analysis to be studied
- Case selection criteria
- Field and data collection procedures
- Pilot Study
- Methods of analysis for each form of data
- Synthesizing data using pattern-matching and theme forming techniques
- Incorporating methods to improve the validity of the findings

The following sections detail the case study research method on the interdisciplinary product development process between sewn product and material companies.

Phenomenon, context, and units of analysis. Specifying the phenomenon, context, and units of analysis is an important aspect of case study design and has been found to represent best practice in case study research (Pickkari, et al. 2010; Yin, 2014). The *phenomenon* to be studied was the product development process of sewn products among multiple companies in which a new sewn product was created using a new material application. The companies involved in the product development must represent different disciplines. The *context* to be studied was the condition under which the companies implement the product development process for the sewn product. Yin (2014) describes the unit of analysis as the linkage of a joint organizational effort. For this study, the *units of analysis* were the product development stage in which the various companies work together. In case study design, the phenomenon and context become the rationale of purposeful sampling (Pickkari, et al., 2010).

Criteria for selecting cases. The selection of cases for this research followed principles of replication logic, topical relevance, and exemplary outcomes as proposed by Yin (2014), Ginsburg (1989), and Pickkari et al.(2010). This research required an extensive data collection process, thus a small number of cases (n=3) was selected.

Replication logic requires every case to demonstrate the phenomenon (sewn product development and interactions between interdisciplinary companies) and context (companies implementing the design process for a sewn product) prior to case selection. One way to ensure replication logic in the cases is to select cases that already demonstrate exemplary outcomes (Yin, 1993; Ginsburg, 1989). Using the exemplary outcome rationale means that,

> …all of the cases will reflect strong, positive examples of the phenomenon of interest. The rationale fits replication logic well, because your overall investigation may then try to determine whether similar causal events—within each case—produced these positive outcomes. (Yin, 1993, p. 12)

By choosing cases that represented the exemplary outcome and replication logic, it was possible to develop a deep understanding of how the product development process was used and how the interdisciplinary companies interacted in a specific product development case, as well as determine the cause and effect relationship of the phenomenon and context being studied between the cases.

Potential cases were selected from the fields of sportswear and activewear, sustainability, medical wearables, protective wearables, and military applications. These categories represent areas of substantial breakthroughs in both material and sewn product design development. Once a potential product and company was selected, an initial inquiry was conducted to confirm that the product was developed through an interdisciplinary team containing both sewn product designers and material developers.

Thorough screening is needed to ensure that the cases demonstrate the established criteria (Ginsburg, 1989). Each potential case first demonstrated that a new application of material and a new product was developed. Patents were researched to determine this aspect of the criteria, as well as news and media releases available for the product. Once the potential case was selected, the company was contacted by email or phone, and another round of screening took place to ensure the phenomenon and context were exemplified.

In summary, the site selection criteria for this research included:

1. A product development process took place to create a wearable or sewn product.
2. The product was advanced through new material use or application, and through a new design.
3. Companies collaborated across disciplines to create the product.
4. The product represented advances in the field of sportswear/activewear, sustainability, medical wearables, protective wearables, or military products.
5. The individuals and company/companies involved in the creation of the product are willing to cooperate in this research.

Case Selection

The initial strategy of contacting companies for this research involved using personal connections and LinkedIn to make early contact through email to introduce the company leadership to the purpose of the research and the basic research process. After researching potential products for case study, individuals working at sixteen companies ranging from a Fortune 500 sportswear company to a Midwestern sewn product manufacturer were contacted. Next, informational interviews were conducted with individuals from seven companies. Nine companies declined participation in the research due to intellectual property concerns.

Once the potential products for case study research were narrowed down, two in-depth interviews, one by phone and one in person, were conducted with the central manufacturing and design company to determine if the products and companies fulfilled the selection criteria. These informational interviews lasted between 60 and 130 minutes.

The case studies for this research centered on individuals and companies involved in the creation of three sewn products incorporating phase-change materials: A flexible cooling vest; a sewn tent; and a foam bed. All products and materials were designed, developed, and tested prior to this research. The three products were at different stages of market entry at the start of the research.

While there is overlap between the case studies in terms of companies and material technology, three distinct processes were conducted for three different products. A defining feature of the research questions is "how" the product development process is conducted. Each case study features a distinct sewn product and the collaboration of different disciplines, companies, organizations, and industries. These distinctions caused the interdisciplinary product development process to vary greatly between products. Furthermore, Yin (2014) describes and explains that the unit of analysis for a case study can be described as an "event". Because three distinct processes (events) occurred to create three different cool products, the case study research was determined to be three case studies as opposed to one.

Pilot study. To refine the research procedures and to ensure appropriate content was obtained, a pilot study was conducted prior to the final case study research. Pilot studies and pre-studies are used to identify and clarify key issues, and are used as a tool "for assuring that the exploration is following some exploratory "theory," and not merely wandering through the exploratory phase," (Yin, 1993, p. 7).

A pilot study was conducted to test the focus group and interview questions, and refine the research content and procedures. The product and company were selected based on the established criteria. Several products made by companies in the United States were identified and key personnel were contacted by email. One company in the upper Midwest was selected for the pilot study due to their application of a new textile technology into a product design. A focus group between a product engineer with expertise in the new textile technology and a designer with expertise in wearable products were interviewed using the questions in Appendix A. The focus group was recorded, transcribed, and analyzed to ensure themes related to the research questions were obtained. Due to intellectual property concerns, the participants were unable to provide process documents. However, after the analysis of the focus group data, the participants were able to describe the product and process sufficiently so that conclusions could be made regarding the research questions.

Data Collection Procedures and Sources of Evidence

This research was planned and represented a system of 'explicit rules and procedures' (Frankfort-Nachmias & Nachmias, 2008). The major purpose of establishing a method is to help scientists "see" and to facilitate communication between researchers by making the methods explicit, public, and accessible. This case study foundation created a framework for replication and constructive criticism, therefore advancing the field of sewn and wearable product design.

In case studies, best practice research indicates the importance of including different sources of data (Eisenhardt, 1989; Fox-Wolfgramm, 1997; Pickkari, et al., 2010; Yin, 2014;). Common sources of data in case studies include in-depth interviews, observation, and archival records (Pickkari, et al., 2010; Yin, 2014). In recent years, innovative case study research has moved past traditional interview-based case study approaches to collect data from a diverse range of sources that include focus groups from an organization and photographs of physical artifacts (Piccari, et al., 2010). This case study research included patent and archival record examination, physical artifact examination, in-depth interviews, observations, and site visits as sources of evidence.

Research Time-Frame. The research was conducted over a 9-month time period. Products that fulfilled the case study criteria were identified by examining patent and company marketing material in August 2015. Individual personnel were contacted regarding research participation once IRB approval was obtained in September 2015. A company in the upper Mid-Western United States fulfilled the product and research criteria, and was selected for the pilot study. After the initial pilot study, recruitment continued from September 2015 through January 2016. During this time, seven informational interviews were conducted with potential subjects to ensure the product and company fit the case study criteria. In January 2016, three products were chosen for case study research. Central to each case-study was a sewn product manufacturing company and a phase-change material company. In total, seven companies were studied in relationship to the development of three sewn products. Those seven companies included the sewn product manufacturer, a cool product company, a bio energy material company, a bio energy material packaging company, a marketing company, a large material and chemical development company, and a military consulting company. The individuals and companies studied in the research, and the type of data collected is listed in Table 2. All individuals have been given pseudonyms, used throughout the research.

Company	Location	Role	Pseudonym	Data Collection
Sewn Product Manufacturer	Upper Midwest, USA	CEO/Owner	SPM-Owner	Interview, Focus Group
				Observation
				Site Visit
		Product Development	SPM-PDev	Interview, Focus Group
				Site Visit
		Vice President of Pet Division / Owner	SPM-VP Pet	Interview
				Site Visit
		Sourcing / Materials	SPM-Sourcing	Interview
				Site Visit
		Production Engineer	SPM-Engineer	Interview, Focus Group
				Site Visit
Cool Product Company	South Atlantic, USA	Owner / Former CEO	CPC-Owner	Interview
				Observation
		President	CPC-President	Interview
				Observation
		Controller	CPC-Controller	Observation
		Partner	SPM-Owner	Observation
		Partner	PCM-Investor	Observation
		Partner	MC-President	Observation
		Sales Representative	CPC-Sales	Observation
Bio-based Phase Change Material Company	Upper Midwest & South, USA	Investor/Owner	PCM-Investor	Interview
				Observation
Bio Energy PCM Packaging Company	South Atlantic, USA	Owner/CEO	CPC-Owner	Interview
				Observation
		Investor/Owner	PCM-Investor	Interview
				Observation
Marketing Company	Upper Midwest, USA	President/ Partner	MC-President	Interview
				Observation
		Creative Director / Partner	MC-Creative	Observation
		Account Manager	MC-Account	Observation
Material / Chemical Company	South Atlantic, USA	Development Manager	MCC-Development	Interview

Military Consulting Company	Upper Midwest, USA	Owner	Mil-Owner	Interview

Table 2. Individuals and companies studied in the research and the type of data collected for each company.

Equipment used in data collection. An audio recorder and digital camera were used to improve the reliability of the data collection. The audio recorder was used to record each focus group and interviews with the participants. The focus group and interviews were transcribed verbatim by transcription service company rev.com. The transcribed interviews were reviewed against the original recording to check for missing dialogue and errors. The camera documented the product and supporting evidence of material related to the interdisciplinary product development process that was approved by the participating company and interviewees. Of particular focus for photograph documentation were the manufacturing facilities and initial prototypes of the material and design that revealed the development of the product. Due to confidentiality concerns of some participants, it was not possible to include the photographs in the final research report.

Patent and archival records/document examination. Companies document a variety of everyday activities. Documents pertaining to the development of the sewn products and archival records were reviewed when available to aid in the understanding of how the companies operated throughout the development of the product. Product patents also provided insight into how a product was developed and gave a reliable time-line for different aspects of the product's development. Company documents, archival records, and patents enable transparency in the research and clarified information collected through interviews, observation, and site visits. Yin (2014) discusses the importance of these forms of documents as being capable of focusing the research with specific information in regards to processes and timelines. This research focused on company correspondence notes, news articles available to the public that highlight product details, archival records related to the product, material and design specifications (if permitted), and product patents. Access to this information was not always available from all of the participating companies due to confidentiality concerns. While the information does add to the overall knowledge of the product development, it is not essential to the success of the research because the overall focus is not on the product itself, but on the product development process and the interdisciplinary interaction between the companies.

Physical artifact examination. Physical artifacts were examined to facilitate familiarity with the material and innovations being examined through the product development process. For this research, the flexible cool vest, a sample of the sewn tent, and a sample of the foam bed were examined during the informational interview with the sewn product manufacturer. By examining the product prior to interviews, observation, and site visits, specific design related questions were developed and relevant product information was gleaned. When possible, the physical artifact was examined with the interviewee during the interview. Follow-up questions were asked about the product if specific, design related questions arose.

Whenever possible, design and material sketches, technical specifications, and prototypes were examined in detail, documented through written description, and photographed. These types of physical artifacts demonstrated different stages of the product development process and clarified and enhanced the meaning of interview or focus group data. The prototypes and technical specifications were examined during individual interviews with the sewn product manufacturer CEO and product developer. The interviews and examinations were conducted during a site visit to the sewn product manufacturer facilities, and during observation of the cool product company's shareholder meeting.

Materials and physical evidence were collected whenever possible; however, company confidentiality concerns prevented access to some product development evidence. Because this research was focused on the product development *process* that occurred, this limitation does not diminish the quality of data that was obtained. When available, this data, though not essential, added depth and reliability to other collected data.

Interviews. The primary source of evidence for each case study was collected through interview data. The primary interview participants were selected based on diverse perspectives of the product being studied and were not limited solely to the designer or material developer. According to Pikkari, et al. (2010), a varied selection of interview and focus group respondents ensures that data is collected from assorted viewpoints of the interdisciplinary product development process in each case. Interviews enable a glimpse into the routine activities of the teams and organizations of the case study (Schwartzman, 1993; Yin, 2014).

Interviews consisted of the primary person involved in the development of the sewn products at each company, as well as design, marketing, sales, finance, and manufacturing specialists who worked on the product. Because this research was focused on how the companies worked together throughout the product development process, it was important to get their perspectives on the process of working across companies as a team. Follow-up interviews were conducted to clarify key aspects of their roles and to delve deeper into their perspectives on interdisciplinary product development.

Individual interviews were also conducted with managers responsible for the project and other individuals who played a significant role in the process and implementation of the design. These individuals played a supporting role during the creative development of the product, or they played a role in the implementation and production of the product. The managers and 'supporting' individuals for the interviews were selected at the recommendation of the sewn product company CEO during the case study investigation.

Interview questions. Based on the research questions developed from the literature review, the interview questions focused around three themes of exploration:

1. The product development process and procedures used by the companies during the development of the sewn product being investigated.
2. Viewpoints of the interdisciplinary approach to design and material development and its impact on the way product development was conducted for the specified product.
3. Discoveries and organizational practices that allowed the interdisciplinary process of design and material development to take place, and eventually lead to the creation of a new product.

The initial interview questions were administered in a semi-structured interview format to allow for conversational flow. The interview questions can be found in Appendix A. When possible, the interviews took place in the setting in which the product was developed such as the sewn product manufacturing facilities, and in depth field notes were taken during the time spent in the company facilities.

Interview questions for individuals such as managers, supporting designers, and material developers were based on the supplementary interview questions found in Appendix B, and were directed specifically at the individual's role in the product development project.

Direct observation. Observations allow for a better understanding of the interaction and relationships developed over the course of the product development process. For this research, a shareholder meeting of the cool product company was observed in February 2016. The interactions of individuals from the sewn product manufacturer, the bio energy material company, the bio energy packaging company, the marketing company, and the cool product company were observed during this meeting. A confidentiality agreement was signed before observation, so nothing was audio recorded and no photographs were taken. In-depth field notes were written during the course of the six-hour meeting that described the interactions between the companies. During the meeting, current and future product development, marketing strategy, and finances were discussed at length. The observation of this meeting allowed for a holistic view of the interactions between the companies that developed the flexible cool vest, as well as some of the companies that were involved with the development of the sewn tent and the foam bed. After the meeting, two hours of reflective journaling and mind mapping took place to help build a deep understanding of the contributing roles of each individual and of the relationships observed during the meeting.   The meeting, field notes, and journaling helped inform many of the interviews. Specific interview questions were developed in an effort to capture a deeper knowledge of the interactions between individuals and companies during the development of the three products.

Site visit. A site visit was conducted at the sewn product manufacturing facilities in February 2016. This site visit included a tour of the facilities by the CEO/owner, in depth interviews with the CEO/owner, interviews with personnel involved in the development of the flexible cool vest, the sewn tent, and/or the foam bed, and observation of personnel performing their daily activities. Interviews were recorded, photographs were taken to document various stages of the products' development, documents were reviewed related to the product development of the three products, and in-depth field notes were taken throughout the site visit. Field notes included sketches of the manufacturing facilities, descriptions and sketches of artifacts pertaining to the development process of the three products, interview notes, and descriptions of personnel interactions.

Data Analysis Procedures

Data analysis took place through examining, categorizing, pattern-matching, and combining multiple forms of evidence. The data analysis process enabled the researcher to capture processes and outcomes of the phenomenon and context being studied, triangulate different types of evidence, and develop generalizable lessons to the sewn and wearable product design fields (Yin, 2014). Methods of data analysis, such as triangulation techniques, respondent validation, pattern-matching, and constant comparison of findings with theory were employed to improve the validity and reliability of this research (Pickkari, et al., 2010).

Triangulation is an important concept in the design of case study research because it helps establish the rigor and validity of the research (Richards, 2009). In this study, triangulation was completed through the use of word comparisons from the focus groups and interviews, the archival and patent documentation, the pictures of the wearable product and material development, and in-depth field notes describing the observations, site visits, products and the environment in which the product development took place.

Data was examined and reviewed numerous times throughout the collection and analysis process. Because of the volume of data that this research produced, the collected data was reviewed, thoroughly read, and categorized by the type of data obtained (archival and patent documentation, written documentation, physical artifact examination, and interview data). Once categorized, the data was organized according to the product development process and timeline of the sewn product development being studied in the cases.

Documentation data analysis. The documentation obtained throughout the case study research was categorized according to the following: 1) product information such as patents and news articles 2) public company information, and 3) correspondence between the companies related to the development of the product being studied such as design and technical specifications, sketch sheets, and meeting notes.

Documentation analysis prior to interviews informed interview questions and was a source of comparison to other forms of data obtained. The information from the documentation analysis was used to better understand the organization as a whole, and informed the understanding of how the interdisciplinary product development process took place within the organization.

Physical artifact data analysis. Physical artifacts and photographs obtained during the case studies were classified according to type and the stage of development the artifact or photograph represents in the design process. The physical artifacts were used to support the documentation data and the interview data through triangulation.

Interview data analysis. In order to ensure clarity between the interview data, the recordings were labeled and categorized. Next, each audio recording was transcribed by the transcription service Rev. Rev guaranteed participant privacy through bank-level encryption of recordings and confidentiality of the transcribers. The transcriptions were read and compared to the original audio recordings to verify accuracy of the transcription. The transcriptions were also compared to field notes.

Theme Forming and Pattern Matching. The data from each case study was analyzed, themes were formed, and patterns matched according to a "systematic procedure" presented by Bloomberg and Volpe (2008) and Yin (2014). This procedure requires all of the data to be reviewed and explored, including documents, transcriptions, field notes, and photographs in order to identify the big ideas or themes. The ideas and themes were categorized according to each stage of the interdisciplinary product development process being examined (Yin, 2014). The next step that Bloomberg and

Volpe (2008) recommend was to reread and examine the data. This step allowed either the acceptance or rejection of the themes found in the first round of data analysis. Once themes were solidified, the data was dissected and classified, in-depth coding was completed, and the data was placed into categories. Data summary charts and journaling was used in an effort to gain insight into the information that was discovered throughout the coding process. Throughout the theme forming and pattern matching, critical event and process analysis was employed (Yin, 2014). The analysis was completed for each individual case, by looking for themes and pattern matching across the steps of the product development process. Once the individual case studies were complete, the data was re-examined and reviewed for higher order patterns across the data, as well as similarities and differences between the cases.

Case study report. The products and companies chosen for this research overlapped in terms of the material technology used in each project and the central Sewn Product Manufacturing Company. The companies are described, and then the interaction of the companies throughout the development of each product was reported. The findings and themes of all case studies were then documented to show commonalities and differences in how companies use the product development process throughout their collaborations.

Limitations

Limitations of this research are the following:

- This research is based on case studies that have already been successful and require the participants to look back at the process of design and development.

This limits the data in some regards because it is not current and relies upon the memory of participants. However, Yin (2014), states that contemporary events that have occurred in recent past are acceptable as long as multiple forms of data are used to conduct the case study.

- Some of the data that documents the process, such as material technical specifications and exact design requirements, were not always accessible due to company confidentiality. While this information adds to the understanding of the timeline associated with the product development process, it is not the main focus of the research. Furthermore, multiple forms of data were available for all three case studies, including documents, so the lack of accessibility to a few documents did not have a major effect on the research.
- This research is limited to the product development process recalled by participants at a small number of companies. However, case study research does not seek to "extrapolate probabilities" or make "statistical generalizations" (Yin, 2014, p. 21). The goal of this research is to expand and generalize product development and interdisciplinary alliance theories which is possible with case study methods (Yin, 2014).
- While the Phase-Change Material was incorporated into the products in different forms (micro-encapsulated, liquid, macro-encapsulated), each product utilized the same material technology. Despite this, each product followed a different path to creation and demonstrated a distinct

interdisciplinary product development process that involved different people and companies.

CHAPTER IV

RESULTS

This research explored the interdisciplinary development of three sewn products. Eleven companies contributed to the development of the flexible cool vest, the cool tent, and the cool pad. This chapter describes the capabilities and expertise of the companies and key personnel, the interaction of the companies through the product development process of each product, and themes relating to interdisciplinary product development. The results are based on the analysis and synthesis of interviews, site visits, observations, and the examination of documents and physical artifacts.

Company and Personnel Descriptions

Eleven companies worked together in various capacities to develop three cooling products: the flexible cool vest, the cool tent, and the cool pad. Seven companies participated in this research. The Sewn Product Manufacturer and Bio-based Phase Change Material Company were central to the development of all three products. Figure 10 shows the relationships of the companies and the products that they developed.

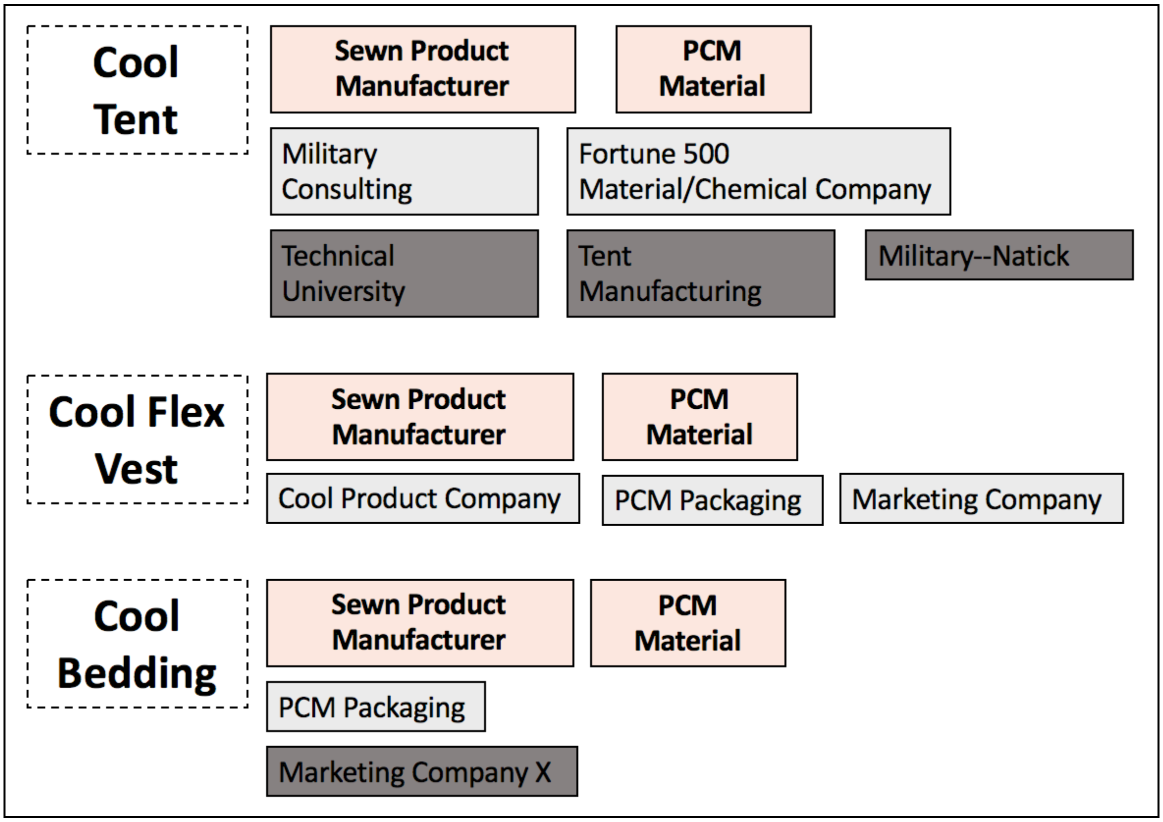

Figure 10. Relationship of companies to the development of the cool tent, flexible cool vest, and cool pad. Light orange boxes represent common companies among all three products. Dark grey boxes are companies/institutions that did not actively participate in the research (i.e. were not observed or interviewed).

Sewn Product Manufacturer. The Sewn Product Manufacturer is located in the upper Midwest and specializes in the production and development of sewn products in industries ranging from marine and medical to apparel and upholstery. Started in 1958, quality, diversity of both product and business, and responsiveness have been integral to the company's growth and success. The company began as a cut and sew business, and has grown to include customized product development, sourcing, importing, embroidery, computerized cutting, and large format printing. The parent company owns three unique brands, and currently inhabits an 80,000 square foot facility that includes dedicated space for manufacturing, shipping, upholstery, product development and design, and business.

The company has sustained growth through niche businesses and business opportunities, while maintaining quality and service for a diverse customer base. Technical expertise for a broad array of product lines such as gun covers and US Olympic ski-jumping uniforms have enabled the manufacturer's continued growth of new product development for sewn products. Industry partnerships with material companies ranging from the foam industry to a Fortune 500 company specializing in military material development have enabled the development of products ranging from wall padding for NASCAR to acoustic panels for the Smithsonian American Art Museum to the cooling products discussed in this research.

Five individuals were interviewed from the Sewn Product Manufacturer, all of which have over twenty years of experience with the business. Their roles as Owner, Product Development/Designer, Sourcing Manager, Production Engineer, and Vice President represent specific types of expertise in sewn product development and manufacturing. A site visit was conducted at the company's facilities on February 19, 2016. Observation of SPM-Owner was performed during a Cool Product Company partners' meeting of the owner on February 10, 2016. All interviews with company personnel took place on February 19, 2016. Additional interviews with SPM-Owner took place on January 22 and 29, 2016.

Bio-Based Phase Change Material Company. The Bio-Based Phase Change Material (PCM) Company is a specialty chemical company located in the upper Midwest and Southern United States. The company sells patented PCMs in a wide variety of temperatures for applications ranging from cooling vests and refrigerators to warming blankets and portable coolers. The PCM can be purchased in liquid or microencapsulated form. Both forms of PCM were used in the development of the sewn products for this research. The owner of the Bio-based PCM Company, PCM-Investor, is actively involved in promoting the Bio-based PCM material as an investor in in the Cool Product Company and the PCM Packaging Company. PCM-Investor was observed at the Cool Product Company's partner meeting on February 10, 2016 and interviewed on March 2, 2016.

Cool Product Company. The Cool Product Company was founded by a military veteran in 1995 and is headquartered in the South Atlantic United States. The company develops products that help manage body temperature in extreme environments. The company's first product was one of the first cool vests available on the market and was developed predominately for military and industrial applications. Over time, the company expanded its product line to include cooling vests for dogs and people with MS. All products made by the Cool Product Company have always been 100% American made.

During the course of the development of the flexible cool vest, the Cool Product Company split into two companies: The Cool Product Company and the PCM Packaging Company. The Cool Product Company brought on new partners to advance the cool vest business including SPM-Owner from the Sewn Product Manufacturer, the Marketing Company partners, and PCM-Investor from the Bio-based PCM Company. This allowed more focused, interdisciplinary product development for the vest. A new President, CPC-President, was hired to lead the development and sales of the flexible cool vest, as well as other products. While CPC-Owner, the CEO and original owner of the Cool Product Company, is still involved in the Cool Product Company, his engineering and PCM expertise have been re-directed towards the PCM Packaging Company. For this research, CPC-Owner, CPC-President, CPC-Controller, and CPC-Sales were observed at a partners' meeting on February 10, 2016. CPC-Owner was interviewed on March 2, 2016. CPC-President was interviewed on February 29, 2016.

Phase Change Material Packaging Company. In partnership with the Bio-based PCM Company, the PCM Packaging Company was developed to offer innovative containment and packaging solutions for the bio-based PCM. The company is headquartered in the South Atlantic United States.

Phase Change Materials can be difficult to contain because of their small molecule size and require customized approaches for various applications. Traditionally, the Bio-based PCM Company sold PCMs to customers in liquid form and it was up to those customers to design a method of containment. PCM containment often became a hindrance for companies who wanted to use PCMs as a solution to a problem, but did not have the capabilities to contain the materials in an efficient or effective manner. The Packaging Company grew out of a need to eliminate the containment obstacle for companies and to encourage the use of PCMs. The Packaging Company develops and sells macro-encapsulation devices that maximize surface area, efficiently transfers thermal energy, and charge PCMs quicker than current devices on the market. The devices are sold pre-filled with the bio-based PCM.

The PCM Packaging Company contributed to the development of the packaging for the flexible cool vest and the cool pad. CPC-Owner became an expert engineer and innovator in the field of packaging PCMs during his time as the CEO of the Cool Product Company. PCM-Investor has in-depth knowledge of the consumer need and overall market for phase change materials, and has provided financial backing for the packaging company. For this research, CPC-Owner and PCM-Investor were observed at the Cool Product Company's partners' meeting on February 10, 2016. Individual interviews with CPC-Owner and PCM-Investor took place on March 2, 2016

Marketing Company. The Marketing Company specializes in market analytics and brand development for businesses. Located in the Upper Midwestern United States, the company works in industries ranging from health and food services to sports and apparel. Through developing strong logo and brand identity, graphic and web design, print and broadcast marketing, as well as video and packaging design, the Marketing Company seeks to break down market barriers for their clients.

Initially, the Marketing Company worked on branding, print, and web design for an in-house brand of the Sewn Product Manufacturer, and separately for the PCM Packaging Company. Later, the Marketing Company was approached to do branding, graphic design, and web design for the Cool Product Company and they played a crucial role in the product development of the flex vest. MC-President, MC-Creative, the Executive Creative Director, and MC-Account, an Account Manager, were observed during a Cool Product partners' meeting on February 10, 2016. MC-President, was interviewed on March 17, 2016.

Material/Chemical Company. The Material/Chemical Company is a Fortune 500 company specializing in chemical and material development, and is located in the Southern Atlantic United States. Their material development centers on performance and workwear fabrics, protective fabrics such as materials with flame retardant capabilities, and industrial textiles for automotive and building industries. Their materials can be found in a range of industry and military applications including athletic uniforms, hunting fabrics, and medical scrubs. They have become one of the largest material suppliers to the military for clothing and gear.

The Material/Chemical Company collaborated with the Sewn Product Manufacturer, Military Consulting Company, and the Bio-based PCM Material Company to create the material for the cool tent. The Development Manager, MCC-Development, was interviewed about the company's involvement in the development of the cool tent on February 29, 2016. MCC-Development works in a division of the company that develops material applications and solutions for the military.

Military Fabric Consulting Company. The Military Fabric Consulting Company was formed to help individuals and companies bring products to the military. The Owner, Mil-Owner, has been working with the military for over thirty years, first as an officer and later as a contractor selling specialty fabric products for military use. His expertise in producing and selling products to the military was integral to the creation of the cool tent. The company is located in the Upper Midwestern United States. For this research, Mil-Owner was interviewed on February 26, 2016.

Case Study Product Development Process

This section describes the product development process for the cool tent, the flexible cool vest, and the cool pad. Interactions between individuals and companies are also described.

Cool tent product development process. Approximately nine years ago, the Sewn Product Manufacturer Owner, SPM-Owner, was approached by the Owner of the Military Consulting Company, Mil-Owner, as a possible vendor for a military product his company had created. At the time, the unique demands of SPM-Owner's product were outside of the capabilities of the Sewn Product Manufacturer. Despite this, SPM-Owner and Mil-Owner forged a friendship and kept in touch with one another.

Throughout Mil-Owner's career, he had been actively involved with a group of companies that cater to the defense industry. Approximately six years ago, the Small Business Administration (SBA) put out a Request for Quote (RFQ) to create clusters focused on helping small, innovative companies with new technologies find a foothold in the government and military. Mil-Owner's group secured a contract with the SBA and through this contract he was introduced to the Bio-based PCM Company.

At the beginning of this product's development, it was the height of the United States' War in Afghanistan. Mil-Owner was actively attending military focused conferences in which the military's energy demands and the need for energy efficiency were topics of conversation with a variety of academics, and middle and senior military officers. They were all seeking solutions to the military's energy demands.

With this knowledge, Mil-Owner approached SPM-Owner to partner in exploring the PCM technology in sewn products. Informal brainstorming sessions led to their idea of integrating the material into tents. SPM-Owner and Mil-Owner then went into partnership together and formed a new company with the intent of bringing their "cool tent" to the military.

After researching the need and brainstorming solutions, SPM-Owner began to test the PCM material in liquid form. He tested a tent option that used traditional construction and materials such as a heavy nylon and insulation with the addition of a layer of liquid PCM configured in plastic pouches approximately 1" x 2", with a ½" plastic seal in between each pouch. Their idea of incorporating the PCM material into the tent proved successful in initial testing. Without the use of any electricity, their cool tent prototype kept the interior temperature between 70 and 90 degrees Fahrenheit, with outside temperatures ranging from 40 to 120 degrees Fahrenheit (typical of the night to day temperature flux in Afghanistan).

The main purchaser of tents for the military is the U.S. Army Natick Soldier Systems Center (Natick). In order for SPM-Owner and Mil-Owner's tent to be accepted and purchased by the military, they knew that they needed a link to Natick. SPM-Owner, through his years as an Entrepreneur and Sewn Product Manufacturer, had developed a relationship with his state's senior US Senator. SPM-Owner called his Senator who was on the Senate Appropriations Committee, and the Senator was able to connect them to a person at Natick.

SPM-Owner and Mil-Owner met with senior personnel at Natick where they validated the need for energy efficiency and their interest in the technology and product. Natick signed a contract with SPM-Owner and Mil-Owner worth just under $100,000 to develop a tent using the bio-based PCM. With this contract, Natick established strict product criteria that led the next phase of product development.

With the new product criteria, SPM-Owner and Mil-Owner were charged with developing a cool tent using PCMs without increasing the overall weight of the product, with fire and flame resistant (FR) properties, and Berry compliant (created and produced in the United States). The criteria drastically changed their original cool tent idea and required them to partner with companies in order to fulfill their contract with the military.

The first challenge was the weight of the PCMs. In liquid form and over a large mass, the PCMs would significantly increase the weight of the product. There was a potential solution through micro-encapsulating PCMs and embedding them in/on the material, however current applications were not able to sustain a temperature for very long because there is difficulty in getting a large enough quantity embedded in/on the material. SPM-Owner, first, contacted a professor of chemistry at a local technical university to help solve the PCM weight problem, as well as incorporate FR properties into the material.

This interdisciplinary relationship eventually failed when the professor's team was not able to deliver a viable solution within a reasonable time frame. On his own, SPM-Owner was able to solve the problem of creating a material with enough PCMs on the surface to regulate the environmental temperature. Then, SPM-Owner began researching companies with experience working with the military and incorporating FR properties into material. He contacted numerous individuals at the Material/Chemical Company. Because they had a contract with Natick, he was put in contact with MCC-Development, a development manager for the military, and a chemist at the company. The Material/Chemical Company agreed to work with SPM-Owner and Mil-Owner on their material development pro-bono because they were interested in the PCM technology and they saw an opportunity for new business with the military and other business divisions through this material development. After nearly a year of trial and error, MCC-Development and the chemist were able to contribute to the development of a material that fulfilled all military requirements.

MCC-Development put SPM-Owner and Mil-Owner in touch with a company that produces tents for the military and they established a working relationship. Because of the company's experience creating tents that fulfilled military regulations, SPM-Owner and Mil-Owner had the company manufacture the new cool tent. Once the cool tent was successfully created, SPM-Owner and Mil-Owner delivered the product to the military for testing.

The cool tent product development took approximately two years longer to create than originally intended. During that time, the needs of the military changed and the war in Afghanistan ended. The tent is still waiting to be tested by Natick.

Figure 11 is an illustration of the product development process for the cool tent and highlights LaBat & Sukolowski's (1999) three stage product development process with the addition of interdisciplinary relationships.

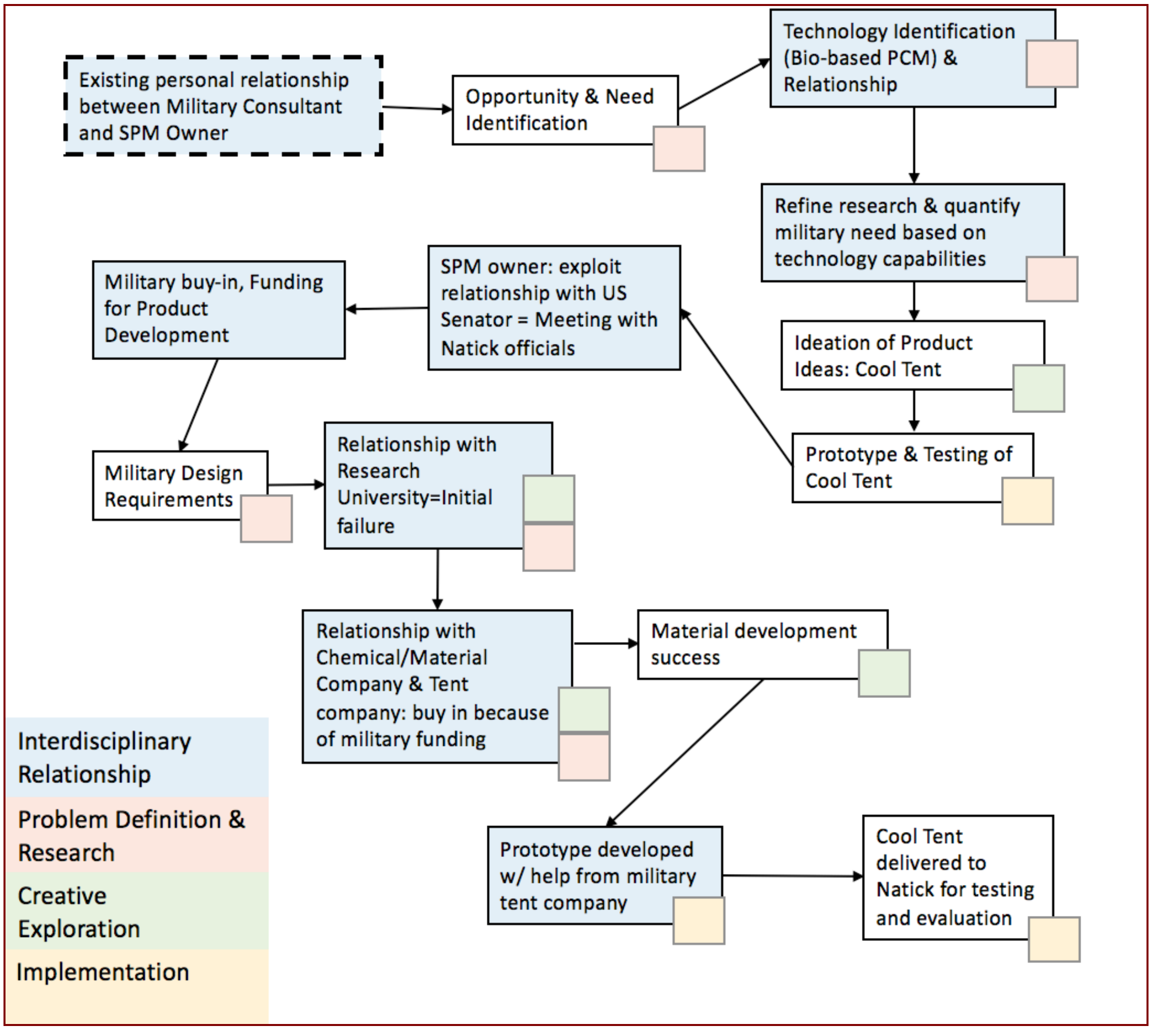

Figure 11. The interdisciplinary product development process of the cool tent.

The development of the cool tent required people from different backgrounds and expertise to collaborate throughout the product development process. The interaction of the people and companies changed over the course of the development of the cool tent depending on where the product was in the development process. Interdisciplinary relationships were apparent during all three common phases of the product development process: research, creative exploration, and implementation. The collaboration and relationships among companies and the military were integral to moving the product through each phase of the process and led the creation of the cool tent as a viable solution to the military's energy problems. Unfortunately, because the cool tent required substantial interdisciplinary development from initial concept to completed product, the needs of the military changed and the product missed prime market entry.

Flexible cool vest product development process. The development of the flexible cool vest involved the Sewn Product Manufacturer, the Cool Product Company, the Bio-Based Phase Change Material Company, the Phase Change Material Packaging Company, and the Marketing Company. At the beginning of the development of the flexible cool vest, all companies had worked with one another in some capacity. Similar to the cool tent development, all companies and personnel were physically located between 200 and 1600 miles away from one another.

The original cool vest was developed to withstand harsh industrial and military environments, and was made to endure impact and resist blunt force trauma. The main market for the cool vest was military and oil companies seeking to keep their employees cool. The original cool vest eventually reached individuals and markets outside of military and industrial applications, and became popular with individuals suffering from MS. However, the wearers desired a vest that was less conspicuous and more form fitting, that could be worn under clothing. Moreover, PCM-Investor and CPC-President saw a need for a form fitting cool vest in the health and medical markets.

During the development of the cool tent, the Sewn Product Manufacturer became acquainted with the Cool Product Company and began producing some of their products. This led to a relationship between SPM-Owner and CPC-Owner built on respect of one another's industry expertise and promoted idea exchange. Once respect of one another's expertise was established, CPC-Owner began to confide with SPM-Owner about a desire to 'update' the cool vest and expand the market. With the support of PCM-Investor and CPC-President, the CPC-Owner and SPM-Owner began to develop basic requirements for the redesign of the original cool vest. Starting with little more than a desire to create a form fitting vest that maximized the cooling capacity of the cool packs, SPM-Owner initially began working with his team to create a new vest prototype, while CPC-Owner set out to redesign the PCM packaging.

The development of the flexible cool vest relied heavily on the sourcing, design, and product engineering personnel at the Sewn Product Manufacturer. The company had little-to-no experience manufacturing stretch knit products, so it required sourcing expertise to locate made-in-USA spandex, design expertise, and production problem solving. Soon, SPM-Owner delegated the project to SPM-PDev, the lead designer and prototype maker of the Sewn Product Manufacturer, who has been working closely with SPM-Owner for over twenty years.

During the prototype development phase, CPC-Owner would give loose guidelines for the design of the vest. SPM-PDev would ideate and prototype a vest based on those guidelines, and send the prototype to CPC-Owner for evaluation. This process went through over twenty cycles over the course of one year. Eventually, SPM-Owner and the new President of the Cool Product Company, CPC-President, stepped in to speed up the development process and to help define the requirements of the new vest.

The involvement of the Sewn Product Manufacturing Company and Marketing Company led to the development of new requirements for the PCM containment packs. The new packs for the flexible cool vest needed to fit closer to the body and cover a larger surface area. The CPC-Owner, also an expert in PCM containment devices and owner of the PCM Packaging Company, ideated new solutions for the cool vest PCM packs. The CPC-Owner and his team developed new production technology to produce the cool packs for the vest, and re-designed the packs to cover a larger body surface area, lowered production cost of the packs, and made the packs with a new configuration of materials that allowed for distinguishable logo printing. A final flexible cool vest was prototyped and tested for usability by staff at the Sewn Product Manufacturer.

During the wear trials, it was discovered that it was difficult to insert the new packs in the flexible vest and the pack corners often got caught. CPC-Owner ideated and developed a machine to re-configure the PCM pack shape to eliminate this problem. After usability testing, the vest design was refined, a more robust stretch material was sourced, and a sizing system was developed.

Next, the production team at the Sewn Product Manufacturer developed an order of operations for the flexible cool vest. Prior to the development of the new cool vest, the Sewn Product Manufacturer did not have experience sewing stretch materials. A significant amount of time and research went into teaching personnel proper techniques for sewing stretch knit, adjusting their machines to handle the new type of work, and developing solutions to new production problems related to the material.

The Marketing team was involved with the rebranding of the Cool Product Company and researched new and emerging markets for the Cool Product Company. The Marketing Company worked closely with the Sewn Product Manufacturer on developing a new embroidered logo and the graphic design for a new printed option of the flexible cool vest.

The companies launched the flexible cool vest as a minimal viable product, with the intention of doing consumer research to continually improve the product. After a soft launch of the flexible cool vest, the marketing team held focus groups to understand consumer purchase motivation related to the new cool vest, performed competitor analysis, and analyzed the health and medical markets for key entry points. After rebranding the Cool Product Company with the slogan “built to endure,” the Marketing Company redesigned the Cool Product Company’s website, creating an online marketing campaign, and developed a marketing campaign directed at the health and medical markets to be used at select conferences and trade shows.

During the development of the flexible cool vest, the Cool Product Company underwent a re-organization. The company split into two companies: the Cool Product Company and the PCM Packaging Company. The Cool Product Company also sold some of its stake to the Sewn Product Manufacturer, the Marketing Company, and the Bio-based PCM Company, adding new owners.

Figure 12 is an illustration of the product development process for the flexible cool vest and highlights LaBat & Sokolowski’s (1999) three stage product development process with the addition of interdisciplinary relationships.

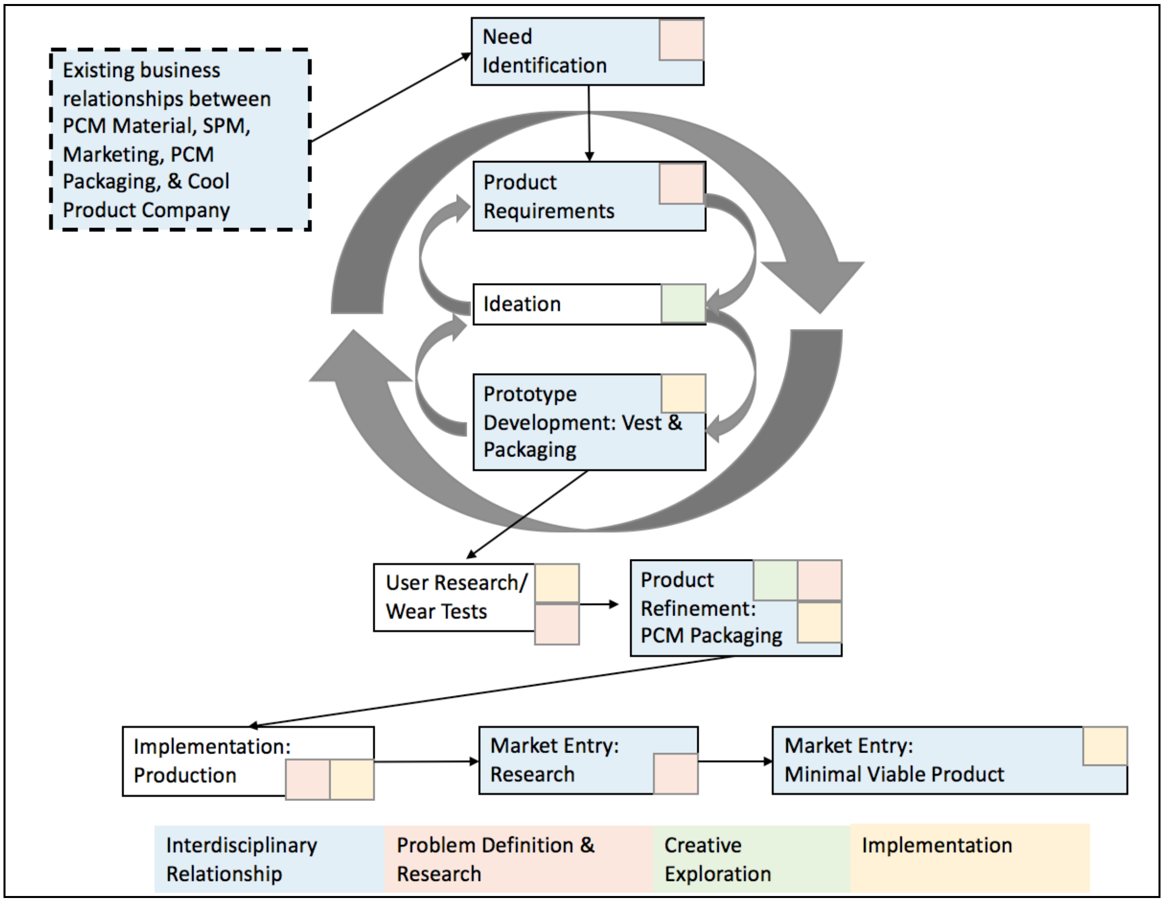

Figure 12. The interdisciplinary product development process of the flexible cool vest.

The development of the flexible cool vest relied heavily on the owners of all companies involved to make decisions and delegate tasks to their personnel. Each phase of the development process relied on a different type of interdisciplinary relationship and collaboration style. This product development process depended on both the Sewn Product Manufacturer and the Cool Product Company/PCM Packaging Company to develop new production processes for the product. The addition of Marketing into the product development cycle reduced market barriers and improved the adoption chances.

Cool sleep pad product development process. Throughout his time working with PCMs, SPM-Owner saw many opportunities for the material to be used in different products. With early access to new sphere containment devices from the PCM Packaging Company, he was able to explore different ways of incorporating the devices into sewn products. Part of SPM-Owner' existing business is in upholstery and pet bedding. Expertise in these two businesses allowed SPM-Owner to see opportunity in a variety of industries. One need that he and CPC-Owner, also the PCM Packaging Company Owner, discussed was that for better cooling products in the mattress and bedding industry. This industry has many products claiming to have cooling properties, but marketing has made the cooling claims of these products seem more capable than they are in reality. SPM-Owner and CPC-Owner both knew that PCMs could provide a cooling solution in a market filled with gimmicks.

First, SPM-Owner began researching different materials and foams that could easily integrate the PCM sphere containment devices. He asked SPM-Sourcing to source a variety of foams in different shape configurations and weights. This led to a period of creative exploration in which SPM-Owner and his designer SPM-PDev ideated and developed different 'cool pad' prototypes. The creative exploration and the prototype development happened simultaneously because the act of making prototypes was integral to exploring different cool pad possibilities.

After some basic user testing of the cool pad prototypes, SPM-Owner met with CPC-Owner and proposed working together to get the product to market. CPC-Owner has extensive experience working with lawyers to develop patent applications, so he applied for a patent on the product. SPM-Owner began working with a marketing and branding company (different from the company discussed in the the Flexible Cool Vest development) and hired them to do in-depth market research to develop a plan for market entry, as well as brand the cool pad product.

Currently, SPM-Owner has been refining the cool pad product and developing manufacturing solutions to reduce the construction steps and improve the overall cooling of the product. CPC-Owner and SPM-Owner are working closely with the marketing company and hope to launch the product soon.

Figure 13 is an illustration of the product development process for the cool pad and highlights LaBat & Sokolowski's (1999) three stage product development process with the addition of interdisciplinary relationships.

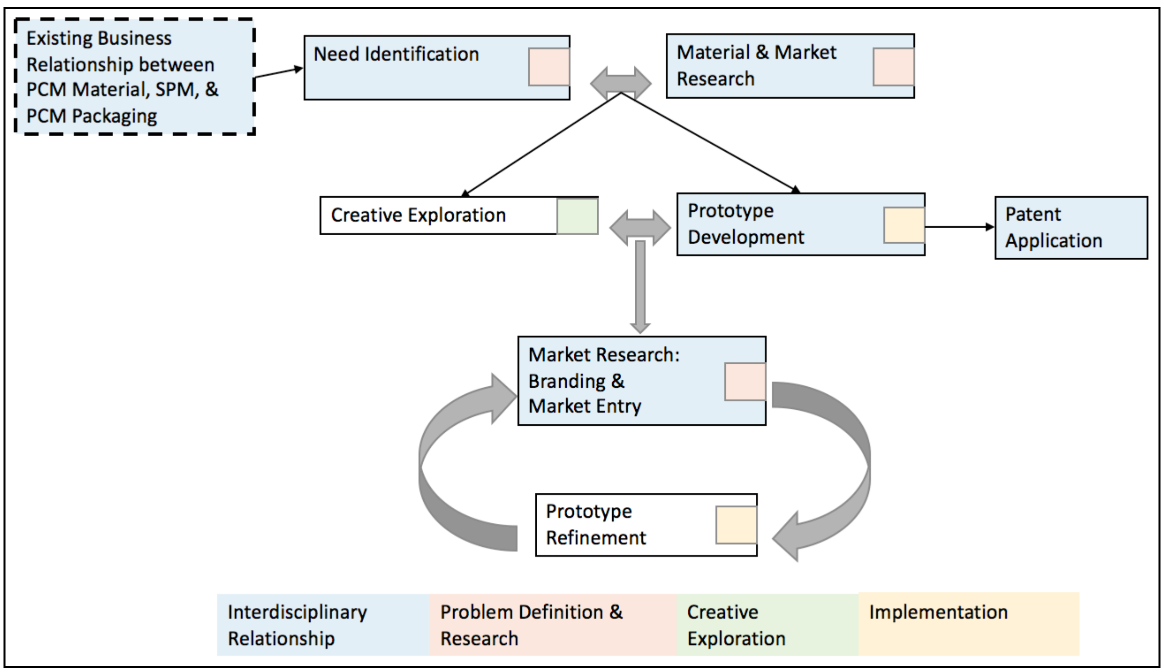

Figure 13. The interdisciplinary product development process of the cool pad.

The development of the cool pad relied on the relationship and trust that SPM-Owner and CPC-Owner have been building over the past five years. A relationship built on an appreciation of one another's talents led to an interaction that promoted idea exchange throughout the product development process. With knowledge of one another's experiences, task delegation and roles were clearly defined early in the process. Market entry and branding were carefully considered with the help of experts because they were viewed as crucial elements in the product's success.

Interdisciplinary Product Development Themes

This section summarizes themes related to interdisciplinary product development. The themes have been divided into two areas:

1. The product development process and how it was conducted in interdisciplinary teams.
2. The interaction of the companies and teams, and how the interdisciplinary process led to the creation of new products.

Themes surrounding how the product development process was conducted in interdisciplinary teams were organization and communication, flexibility and experimentation, and stakeholder support. Themes that surfaced when examining how the interdisciplinary product development process can lead to the creation of new products were expertise, collaboration and trust, and flexibility and experimentation as part of the business model.

The product development process in interdisciplinary teams. An interdisciplinary approach to design and material development impacts the way in which product development is conducted. These include: the organization of the development process and communication among interdisciplinary team members; the need for a great deal of flexibility and experimentation through each phase of the product development process; and the importance of gaining early stakeholder support of the research, new technology, and final product.

Organization and communication. The development of all three products required team members to develop systems to organize and focus the project, as well as learn new ways to communicate and listen to individuals with different expertise.

From the material sourcing point-of-view, organization and communication were very important to keep the development projects and business on track. SPM-Sourcing has been working with SPM-Owner for over twenty years and typically has to juggle orders for the company's core business as well as several new product development projects during his daily routine. At the beginning of the cool tent, flexible cool vest, and cool pad projects, SPM-Sourcing worked with vague specifications. This resulted in trial and error, requiring time to clarify the ideal material for the product. Organization was important to ensure he knew what he was ordering and from which vendor throughout the development process. Without some organization of the development process, SPM-Sourcing said it was extremely difficult to keep track of what he had ordered and the decisions related to each of the material choices. In the past, time and energy would be wasted during the development process ordering duplicate materials, or not ordering all the material options originally requested by SPM-Owner.

As more details and specifications became available while working on the three cool products, SPM-Sourcing examined each possible material against the new specification and presenting the best options to SPM-Owner. He had to make sure that once a material was selected, he could get it from the vendor. Building vendor relationships was a challenge because vendors tend to have a distrust of start-up projects and do not want to invest time in low quantity orders. Communicating with the vendors from the outset about the nature and uncertainty of the project was important for SPM-Sourcing because it was a way to build trust.

Finally, organization and communication of specifications played a role in terms of certifying whether or not the material would be compliant with government and/or military standards. Throughout the development process, SPM-Sourcing continually compared the material requirements against industry regulations to confirm that the final material would pass all necessary certifications or testing. SPM-Sourcing's knowledge of materials allowed him to ask the 'right' questions of SPM-Owner related to government regulations as the specifications were being developed. Being able to clearly transfer and communicate his knowledge of material regulations was very important to developing material specifications that were industry relevant. Furthermore, communicating and foreseeing potential issues related to material regulations helped reduce potential road blocks later in the development process.

Learning to communicate between diverse partners was integral to the development of each cooling product. Particularly, communication was important when developing product requirements and focusing the scope of the project.

In the development of the cool tent, communication was identified as a critical factor in the failure of the initial material development with the university researcher. SPM-Owner, Mil-Owner, and his team thought that they were communicating their expectations and the requirements for the material, however the researcher was unable to deliver a successful product. SPM-Owner believed that this was due to a lack of transparency in the researcher's work and because the time-sensitive nature of the project was not understood. Ultimately, SPM-Owner had to sever ties with the university researcher and subsequently developed a successful relationship with the Material/Chemical Company.

The development of the Flexible Cool Vest was challenging because there were too many ideas and no clear direction in the beginning, which resulted in miscommunication between teams. At the start of development of the flexible cool vest, The Cool Product Company restructured its business and brought on the Marketing Company and the Sewn Product Manufacturer as partners. MC-President said:

> It was a very new company, so there was a lot of discussion on things, opportunities, fears, and everything else. Everything seemed like an opportunity. Focus was definitely something that was needed in this company.

CPC-President, the President of the Cool Product Company, also noted the lack of focus of the company and the product development of the flexible cool vest. He described an early interaction of the group at a product meeting:

> When I first met with the group, it was a lot of fun, but there were nine people in the room. I remember sitting back at one point so, I'm not even talking, and there were five conversations going on simultaneously with just the remaining eight people in the room--which meant some people were in more than one conversation. There's no lack of ideas, but my mission is to grow the company, so I had to figure out how to focus. It's exciting to see all the ideas that are there, but it's also hugely distracting.

Organizing the people in the group and developing a clear direction for the flexible vest was a challenge for everyone involved. CPC-President was challenged to develop clear roles and paths of communication between the team members. In doing so, he had to ask himself, “who gets the direction as to what to try to develop, who makes the decisions along the way, and who decides when a certain attribute is locked in.” The challenges of organizing the team, decision making, and product requirements were felt by everyone during the early stages of the product development process. CPC-President pointed out that one of the difficulties in collaborating, working through the design process with broad design requirements, and too many people giving direction is that, “things can get lost in translation.”

SPM-PDev had difficulties translating the constantly changing design requirements throughout the development of the flexible cool vest. As background, SPM-PDev and SPM-Owner have a long history of working together and have developed an efficient system of designing new products even when no specifications and very few design requirements are available. This level of communication developed over twenty years and has resulted in the ability to finish one another’s sentences. They have a clear understanding of ideas even when very little has been communicated because they have learned to “speak the same language” (SPM-PDev). Typically, SPM-PDev and SPM-Owner have clearly defined roles in the development process with SPM-Owner leading the process with a concept, sometimes accompanied by a sketch and sometimes not. SPM-PDev would then create a prototype. Next, SPM-Owner would offer suggestions for functional improvement of the product, and SPM-PDev would offer aesthetic, economic, and practical manufacturing considerations. For the cool vest development, SPM-PDev was given concept direction from CPC-Owner, typically over the phone or through email. SPM-PDev translated this direction the best he could, made a prototype, then sent it back to CPC-Owner for evaluation. It would typically take several weeks or even months to receive feedback on the prototype. The direction for the next prototype was typically very different from the first set of directions. Often, SPM-PDev felt like he was starting from phase one with each new prototype, instead of each prototype getting incrementally better. SPM-PDev mentioned that there was a lot of miscommunication between CPC-Owner and himself, which was caused by their inefficient communication and different backgrounds. Eventually, SPM-Owner stepped in to communicate and translate the Cool Product Company's design requirements to SPM-PDev. Once roles became defined and lines of communication between the companies were clarified, the development process moved much faster and resulted in a successful new product.

Lines of communication, task delegation, and clearly defined roles were characteristics of the cool pad development due to the companies' and team members' experience working with one another on the flexible cool vest. Many of the same people who worked on the development of the cool vest worked on the development of the cool pad. The development process of the cool pad was faster and more efficient because of the clear communication between the companies and an understanding of how members of each team worked through the process.

Experimentation and flexibility. Despite the need for organization and clear communication, a tremendous amount of flexibility and experimentation was required of each company and person involved in the development of the new cooling products. The challenge of maintaining organization and clear communication amid changing product requirements was a statement echoed by most of the participants interviewed. CPC-

President stated, “until you start to see finished products, sometimes, it's hard to pre-think ahead all of the requirements that a product needs.” Partnering with companies that encourage experimentation throughout the product development process and have flexibility in their daily work flow was fundamental to the creation of the cool products. CPC-President illustrated this point by stating:

> When I visited the [Sewn Product Manufacturer], [SPM-Owner] and I had a discussion in the morning. We had a vest sample completely done by end of day. If it was not for the nature of that relationship, that might've been two, three, four weeks with an external supplier if you will. The visualization really helps. You both learn a lot. You’ve got something to look at something that’s tangible towards the end product. His team are wearing the vest, testing out the cooling effect and things like that. There’s hand-on experimentation.

Because SPM-Owner and his team make experimentation and flexibility a priority when working on new products, it not only improves the design outcome, but in some instances it can make the process more efficient and aids in face-to-face communication.

The development of new products is not without set-backs and challenges. Most of Mil-Owner’s experience in recent years has enabled him to bring companies together for the purpose of bringing new technologies and products to the military. In terms of understanding the interdisciplinary product development process, he says, “It isn't a road map of boom. It's very rarely you'll get a straight path to something.” The companies and personnel interviewed for this research discussed how flexibility and experimentation during the product development process allowed them to move past the problem and continue to develop the product. Mil-Owner, who contributed to the cool tent development, stated:

> You embrace the challenges and don't feel defeated through it because in time, that's how you grow. I don't care if it's an individual or if it's a project or whatever it is, it is. You show me a project that's never had setbacks or challenges and I pretty much guarantee that it won't work long-term. It may get to certain stages but you've got to have that. That's what builds character. That's what builds strength through...It's hard. I mean some of it is just wisdom as you're growing older of saying, "It'll work. Faith. It'll work. Faith. It'll work. We'll figure it out." The big part of [the cool tent development] was the numerous Flame Retardant material failures that we had. Perseverance, experimenting, working through the problem…and "We'll figure it out. We'll figure it out," led to a successful outcome.

Many of those interviewed echoed this statement, emphasizing that without experimentation and flexibility at every phase of the product development process, the projects would have most likely ended in a half-finished state.

SPM-VP Pet discussed an organic process throughout the cool pad development that deviated from the systems that were in place for the development of their core sewn product divisions. CPC-President also discussed that the process for the flexible cool vest required flexibility and perseverance.

> Actually, there are cycles to each of them, but they overlap each other. You might get close to the end and find yourself coming back to the beginning. It's not a linear process. It can be conceptually, but it's not in practice. It really follows the practical path of human interaction, right. You talk. You do. You learn. You revisit. You talk some more. It's just how things happen. If it's a process and if it's an output that you already know then, a lot of that's nailed down and you're just tweaking and refining. Some of that will be happening going forward now, but when you're really launching into something completely different than anybody has done, even though you might say, "Hey, it's just a vest. What's the big deal?" With the technology, that imposes constraints that aren't easy to work through.

Despite knowledge and experience working through the typical product development process, the interdisciplinary teams in these case studies had to move beyond their everyday routines in order to find solutions to the problems faced throughout the development process.

Specific occurrences of flexibility and experimentation occurred during each case study. The cool tent development relied heavily on developing interdisciplinary relationships to move past stalled progress. SPM-Owner had to be flexible with the methods he used to develop these relationships, and his team had to continually develop new development processes, such as testing and production techniques, every time they began working with a new company or institution. The flexible cool vest development required personnel of the Sewn Product Manufacturer to experiment and develop new methods of communicating, have flexibility and patience through the ideation and sample making process as product specifications changed frequently, and experiment with new manufacturing techniques to produce products with stretch material. The cool pad development required team members to follow a more organic product development process. Specifically, the team members had to be flexible with continually changing product specifications, experiment with very foreign materials and PCM packaging, and then efficiently integrate these materials into different types of foam.

Company systems developed over time to aid daily work flow require flexibility through the development process of a new product. When discussing the interdisciplinary product development process, CPC-President emphasized the need for a loose process that allows for experimentation at the beginning and incorporating systems after the invention. This allows personnel and companies to not be bogged down with distractions. He says:

> I've been on the research side of things, too, and medicine, and you got to give some freedom to some folks. It's difficult, if you're asking people to be innovative and you're overloading them with all kinds of systems and reporting and stuff, it takes the joy out of it anyway. You're spending so much time on that, you're not

> really thinking a whole lot about the product. You're not putting your best time in on the product itself.

Furthermore, when you allow freedom and experimentation during the design process, it can result in new opportunities. The development of the PCM packaging while creating the flexible cool vest led to a very important discovery. CPC-President explains,

> We've got a basic set of parameters we're trying to meet, which was thinner packs, greater comfort, bigger surface cooling area, and using that stretch fabric to make it work. Let's see what that looks like. In the process of thinking through the packs, we came across this wonderful discovery. When CPC-Owner initially worked on those vests, he had to invent a film that would handle those packs and it's a full barrier film so nothing comes out of that. The new pack is now hermetically sealed, it's odor free, it’s thinner and covers more body area. Now, you've created not just another cooling pack, but you've created a cooling pack that is different from everybody else's. That then begins to open up other markets like healthcare because that's exactly what they need: something that's hermetically sealed, odor free, and can be easily sanitized. In terms of this application into our Flex Vest, they were developed in tandem. Now, as a result of that sealing technology with this new barrier film, for the first time, we were able to put our logo on it

To allow for flexibility during the design process, many of the participants recommended the importance of balancing this flexibility with long term planning in order to keep some control over the development process. For example, one goal that CPC-President put into place for the flexible cool vest was to do a soft launch of the vest for the Summer 2015 season. This allowed the company to receive customer feedback early in the development process. It also took the pressure off those involved to have every detail and process designed to ‘perfection’ because they would have a full year to continue development on the vest before the major launch of the product for Summer 2016. Long term planning allows for the serendipitous discovery that is important when incorporating new materials and technology. Also, long term planning encourages business goals to be integrated into the product development process.

Stakeholder support. Embedded in each of the cool products' development was the need to gain stakeholder support and buy-in from industry during each phase of the process, as well as the demand to develop a plan to market and communicate the product. Phase Change Materials are a relatively new technology in sewn products. Because of this, not only did the companies need to develop ways to communicate the technology to potential collaborators and business partners, but they also needed to develop marketing methods to make the product accessible to customers.

Stakeholder support was a key component in mounting interdisciplinary relationships throughout the cool tent development. From Mil-Owner's understanding of selling products to the military and forging a relationship with the Bio-based PCM Company, to SPM-Owner' ability to call his US Senator to connect him to Natick, to securing Natick's funding support, these relationships were crucial to moving the product forward through the development process. Each relationship acted as a building block to the next phase of the material and product advancement. MCC-Development, a Project Manager at the Material/Chemical Company, and Mil-Owner discussed the importance of military support in the company's decision to work on the project pro-bono. Mil-Owner said,

> The real reason that [the Material/Chemical Company] was excited is they knew the military was interested. The military is a huge current customer and they want to keep them as a future customer. So they want to be responsive, they wanted to [collaborate]. The other huge reason is they saw the commercial potential of PCM in another one of their biggest industries, mattresses and bedding.

MCC-Development works in a business unit that was established to specifically cater to the end use market of U. S. military and government agencies. He echoed Mil-Owner that having military support was crucial to being able to get their foot-in-the-door at his company. He elaborated on why he and his company began working with the Sewn Product Manufacturer and the Military Consulting Company.

> I would say that from a company perspective, they're supportive of the decisions that are made at a business unit level. From my specific role, I think it's important for us to understand what technologies are being made available and what people are working on. Certainly the benefit to us is, in the long term, if we assisted in developing the technologies and providing feedback there's always going to be an opportunity, if a solution is adopted by the market, to participate. I think it's resetting the curve on a regular basis as much as possible. We recognize that all innovation doesn't come from inside the company. We're always willing to look outside the company for new innovations that we could take advantage of and be successful with.

MCC-Development saw the prospect of contributing to the cool tent material development as a possible competitive advantage and a long term business opportunity because of the unique PCM technology. Additionally, he was encouraged that Natick had put their support behind the project. Once the material was developed with SPM-Owner and Mil-Owner, MCC-Development helped develop a relationship between SPM-Owner and a business that produces tents for the military.

Industry buy-in also played a role in the cool pad development. During market research, SPM-Owner and SPM-VP Pet reached out to people in the bedding and seating industry and pet bedding industry to obtain a sense of need. This early support across industries allowed them to develop clear product channels for their cool pad, as well as gain access to potential customers through their relationships with these industry leaders.

As illustrated, each interdisciplinary relationship was not only important for the actual phase of product development, but it typically helped build relationships needed later in the process. SPM-Owner believes that his sewn product business' success and diversity of expertise is a direct result of building relationships across a plethora of industry.

Developing customer understanding and support were central elements of the development process for the flex cool vest and the cool pad, specifically marketing. At early stages in each product development process, marketing companies were involved in creating new product branding, as well as the development of marketing materials to improve customer understanding of the phase change material. SPM-VP Pet readily admits that one of the biggest challenges that the cool pad faces is marketing the new product to customers and explaining the technology. She says,

> I think the hardest thing is getting or explaining it to customers, and getting them to understand the technology and the science behind it. Right now, we always have [SPM-Owner] who can explain anything to anybody, but we are at the point now where we need those selling materials that [our marketing company] is developing to say, "this is the technology." I'm a very visual woman. If you hand me a hand out, I'm going to read it and be like, "duh, I get it." I think we need more than SPM-Owner just talking, because a lot of people see the spheres and they don't always get it. I think that's been a challenge and luckily SPM-Owner has been able to explain it all the way, but some people are just not getting it right now.

Beyond developing tools to explain the product to customers, SPM-Owner, CPC-Owner, and SPM-VP Pet discussed the need to create a brand around the cool pad that sets it apart from other products in the industry. SPM-VP Pet continued her thoughts on the cool pad development and said,

> I'm excited we're going to actually have a name behind it and it doesn't look just homegrown anymore. It's such a cool product that we need a brand behind it now. I think that's been the biggest challenge, getting people to understand it and know why it's so much better than what's out there now.

Creating any new product requires a keen understanding of the end-users. When creating a new product that incorporates a new material technology, sometimes it’s not enough to have a creative, new product that fulfills a need in the market. The product also has to be understandable and accessible. Brand development and marketing continue to play an essential role in the development of the cool products.

The development of new products by interdisciplinary companies and teams. The three case studies presented in this research demonstrated how companies work together to produce new advanced sewn products. Building relationships and working together based on the company’s expertise contributed to the successful development of new sewn products. Idea generation and efficiency of business were seen as two of the dominate reasons why working across disciplines was successful from a business perspective. But the benefits of working in interdisciplinary teams do not come without investment from the companies involved. It requires a substantial amount of collaboration and trust, a business culture that promotes flexibility and experimentation, and money and time to ensure the new product is successful.

Expertise. Diversity of knowledge between companies contributed to idea generation, as well as more efficient business and product development practices for the companies involved in the development of the cool products. For the cool tent, interdisciplinary product development created competitive advantage for the Material/Chemical Company, as well as provided momentum to move the cool tent through the product development process. For the cool pad, SPM-Owner' ability to see the big picture and deep knowledge of foam and sewn products created an opportunity to partner with the PCM packaging company to create a product with the potential to revolutionize the industry. The flexible cool vest benefited greatly from creating an interdisciplinary team to redesign their cool vest.

Compiling a team from diverse perspectives led to many creative advances in the flexible cool vest. Many of the interviewees discussed past experience with being too insular in terms of developing a product. PCM-Investor, who contributed to the development of the flex vest from the Bio-based PCM Company and the Cool Product Company, described why it was important to gather a diverse group of people to brainstorm for the cool vest:

> There's like an inertia of thinking, "When you get into this mode, it stays in that mode." It felt kind of like we needed someone to break that mold a little bit and look at the vest and company differently. I knew that the possibility of taking a very mundane product, like a vest, and looking at it differently could make it a light year ahead of another product.

The original cool vest, while successful in many regards, needed to be rethought in order to serve a wider consumer market.

Complimentary knowledge proved to expand creativity among the companies, according to SPM-Owner, PCM-Investor, CPC-Owner, CPC-President, and MC-President. Brainstorming in a large group with diverse knowledge helped move the flexible cool vest forward in unexpected directions (SPM-Owner, MC-President, PCM-Investor). The pack development was one area that developed specifically because people in the room during a product meeting were asking new questions: Can we do this cheaper? Can we make this more flexible? Can we change the shape? Can we cover more body surface area? The pack from the original cool vest had not changed for nearly ten years. It was developed for an application that required the packs to be very sturdy and puncture proof, however, , the shape was not efficient in terms of covering body surface area. The diversity of individuals in the room allowed for productive brainstorming. PCM-Investor explains:

> I love the diversity, and getting people with different ideas and bringing them together. Then, with that experience each individual has a unique skill set to tackle different problems. When you're having a product meeting, then you want different people with different skill sets to be there to throw out ideas on what can and can't be done, so you're not thinking up something in a vacuum that you're never able to really manufacture it because you don't have that individual in the room. It's just more efficient.

Idea generation with a diverse group led to the development of practical solutions because people with the correct expertise were able to consider the possibilities of the idea based on deep and specific product knowledge. The group asked new questions that inspired CPC-Owner to develop a pack that was significantly cheaper, more flexible, smaller, a different shape, and covered more body surface area. PCM-Investor continued his thoughts on why it's important for product companies to work in interdisciplinary teams, specifically why the manufacturing component is crucial when working with new technologies:

> A lot of people can come up with ideas, but getting it from point A to point B--I think sometimes there's so many ideas out there, but actually being able to make those ideas a reality is the tough part. The ideas aren't the difficult part, making it happen is, and CPC-Owner's the kind of guy that can make it happen. I kind of see CPC-Owner as a key and critical component. Just his knack for looking at something and, because of his manufacturing mind or the engineering mind, he's thinking of it as, "Okay, well we can't do it this way. We have to do it this way." He can come up with an idea and also make it happen. He has the background and

> the experience with the material, and engineering on how to manufacture it--so he's kind of the one that brings it all together.

This product knowledge and expertise also promotes efficiency in both business and the product development process because individuals can offer realistic solutions to problems based on experience in their field.

Division of labor according to expertise and diversity of knowledge between the companies created a more efficient business model. A change of business model and the split of the Cool Product Company into two companies, the Cool Product Company and the PCM Packaging Company, allowed for more innovation and technical progress in the flexible cool vest and the cool pad. CPC-Owner explains how reorganizing his companies, bringing on new owners with specific expertise, and reducing his management load allowed him to devote more time to his particular skill set.

> We decided that a lot of my time was being wasted devoted to management, human resources, insurance, taxes, ordering stuff. You name it. Just the running of the business. You can hire people to do that, but you can't really hire people to do what I do. We just decided we would do a reverse merger or reverse split. We bumped Vessel out and made it it's own separate company. It hasn't really been a transition from what I was doing before into what I'm doing know--It's been the discarding of a bunch of things that I didn't need to be doing that were already in addition to what I'm doing now, which frees me up mentally and physically to be able to go and pursue the things that I know that SPM-PDever a lot. Here's an example that's come up this week: I'm working on this piece of metal that's going to contain some PCM. It's a very simple thing. In order to create this piece of metal, I have to visit a company in Toronto. Then afterwards, I have to go to West Virginia. Then after that, I have to go to Chicago to two different places, and then I have a visit to Mexico. All of those things have to happen before I gain anymore knowledge on this particular project that I'm doing. When I was running the whole business and doing all that stuff two things happened. One is, I didn't have the time. Two is, I couldn't focus my mind on those things in order to get them all in the right order and marrying everything up together because I was busy sitting here doing HR and payroll and accounting and all those other kinds of things that go with running a business. Diverting all of those things, off loading the baggage

> so to speak, has enabled me to focus more on the things that I'm doing, I can be freed up, and create better progress.

The efficiency that the interdisciplinary relationships and business restructure allowed CPC-Owner to focus and empowered the group members. MC-President, the President and Partner of the Marketing Company, explained each primary member's contributions to the development of flexible cool vest.

> Here's one of the benefits of this group coming together is CPC-Owner is so good at what he does, and he's a brilliant man. CPC-Owner is an engineer and he's constantly innovating and tinkering. He's not a brilliant marketer, and he'll admit that too. He wanted this group to come together so other people can things off his hands, and he soon trusted the Marketing Company with the graphics and communications and design. He keeps an eye on it because he has to feel confident at all times, but it's freed him up to do more of the engineering and product development.
>
> PCM-Investor, his skillset is considered in finance, even though I know he's more than that. He's sort of the macro-business management aspect of it. He put in place CPC-President, who has been a phenomenal role in the growth of this organization over this year--I don't think we would've hit the sales figures we did this year without CPC-President. He's ideal. It was perfect, and PCM-Investor put him in place because he knew CPC-President from a previous project. SPM-Owner is brilliant in terms of innovating from the soft-product side and understanding the best way to manufacture a product, as well as ways to improve the functionality of the vest design.
>
> So everybody's got a pretty defined skillset that is different than everybody else and is empowered to use that skillset. So I think that's one of the reasons innovation's happening with them.

The development of the flexible cool vest reflects the importance of a creating a team with diverse perspectives and the benefits that working across disciplines can have on both the product development process and the core business.

The development of the cool tent also demonstrated the benefits of incorporating a diversity of perspectives. Seven distinct companies and institutions spanning four industries worked together to develop the cool tent. Developing diverse interdisciplinary relationships was the sole focus of several steps in the cool tent creation (figure 11). Each relationship and perspective helped solve development problems. The additional perspective and buy-in from the military helped create clear product requirements, as well as brought funding to the project. The expertise of the Material/Chemical Company was crucial to the development and success of the PCM application on material. Their expertise also highlighted the need to be forward thinking in terms of changing industry regulations. The company knew that several fire and environmental regulations were set to change within the next five years. They helped develop material requirements and created a material that would pass industry regulations in the near future. Without the variety of expertise from the companies and institutions, the cool tent might not have been able to move past many obstacles in the development process.

Diversity of perspectives, especially in terms of marketing the technology to a new consumer, was integral to the development of the cool pad. As discussed, early stakeholder support for the cool pad and a sound understanding of the material technology was crucial to move the development of the cool pad from prototype to market. The expertise of a marketing company and the development of a plan to easily communicate the product features added value to the cool pad product.

Collaboration and trust. Creating interdisciplinary relationships takes time and energy to develop methods to work together and build enough trust in the partner to work with them through development challenges and setbacks. SPM-Owner played a critical role in developing relationships and fostering an environment of collaboration and trust for all three cool products. In interviews, he emphasized the importance of developing quality interconnections that reach beyond business with collaborators who are passionate and enthusiastic about their work. Finding a personal connection and commonalties outside of work with business partners and developing a personal relationship are core principles that he and many of his business partners found to be important in terms of interdisciplinary product development success. CPC-Owner echoed many of the sentiments that SPM-Owner described as being core components of interdisciplinary product development.

> All of those people, they're excited, they're enthused, they're digging it. It's cool. I will only work with people that I like. People that I mesh with. People that I can deal with. I don't care if I'm passing on opportunities. You know what, I only have so many more mornings that I'm going to wake up. I'm not going to work with them in pain. I don't care how much extra money that might put in my bank account. I'm not going to do it. Whenever I choose somebody like CPC-President, or working with the Marketing Company people, those are all really super great people. SPM-Owner who is fantastic. I want to work with people who I can really, honestly say I love that person. They are so great and I'm so grateful they're in my life. If I don't feel that way, I normally pass. I normally do something else. That's just the way, at my age, I've decided to live my life.

Many of the people interviewed hypothesized that when you generally like the person who you’re working with, it makes collaborating with them through the product development process much easier. One repeated aspect of collaboration was the idea that if you had a positive personal relationship with your business partner, it made the individual more invested to work through inevitable challenges and collaborate to problem solve. Mil-Owner discussed his relationship with SPM-Owner and why the tent project was able to move past many setbacks during the development process.

> Expertise is important, particularly in the case of the [cool tent] PCMs, Flame Retardants, and sewing. But, the overriding thing is the capability of working with others, collaboratively, and not necessarily accepting no when things don't work. Asking, "how do we find our way around this, how do we do that?" I think the greatest attribute in all of this is the sense of collaboration. Of saying, "I know I don't have all of the answers, how do I get those answer?" I'd say that for a lot of entrepreneurs, that's one of the greatest faults is they think they've got to have all the answers. When you talk about a skill set, expertise is important but the real capability in getting this done is not that you've got some genius that understands this, but how is it that you can collaborate all this out. I'll give SPM-Owner all the credit of being able to bring--Had we not been able to get the [Material/Chemical Company] and [Tent Company] in this, it never would have gone anywhere.

SPM-Owner continued that developing relationships takes time and energy. He often devotes time during his work day and on the weekends to develop relationships with people outside of business such as going on a long bike ride. This encourages personal trust and makes collaboration in business easier.

Interestingly, SPM-Owner, CPC-Owner, and Mil-Owner all discussed how over time they have been able to develop tools to help them judge another person or business's potential to collaborate. These tools were developed because they all had been deceived or taken advantage of in business at one time or another. SPM-Owner discusses the importance of trust in business relationships.

> You usually know pretty quick--is that somebody that I want to do business with? And ask yourself if that somebody is someone I want to be associated with. I've been fooled in my life and it's hurt me badly. It's usually because I get suckered into something and I want to believe the best of them and that isn't necessarily what's there. This is human nature, so being able to trust is the paramount aspect of all of this.

In the case of the three products, building trust has also meant acceptance in un-equal contributions of work towards the development of the product. Even if the business relationship or partnership is equal, the effort and time spent developing the product is typically not evenly distributed. SPM-Owner emphasized this aspect of being in the product development business, and particularly the concept of valuing expertise and trust over pure work output because it is impossible to have equal contribution throughout the whole development process. An example of this was that the Chemical/Military Company worked on the material development for free because the relationship and long-term benefits outweighed the possible short term capital gain and they had the resources to contribute to the development.

Developing trust between companies requires everyone involved to be willing to take a risk for the sake of building a relationship. The development of all the cool products required an investment of time, and in some instances, money to get the project off the ground. The individuals and companies involved in the development of the cool tent had to risk time and resources at every step of the product development process, which required a tremendous amount of trust and confidence in the product from the beginning. The cool pad development required the Sewn Product Manufacturer and the PCM Packaging Company to invest heavily in patenting and marketing before either company saw a return on their investment. Especially in terms of the business agreements that were formed for the flexible cool vest development, incoming companies such as the Sewn Product Manufacturer and the Marketing Company had to prove their expertise, trustworthiness, and value before being considered a partner. For both SPM-

Owner and MC-President, that meant working without a contract for a period of time. SPM-Owner and MC-President had to place an incredible amount of trust and faith in CPC-Owner and PCM-Investor from the Cool Product Company. MC-President describes the process of becoming a partner in the Cool Product Company and the risk that he had to take to gain trust and prove his company's expertise.

> This may sound a little reckless in some respects, but, in April, there were like 2 or 3 months of conversations about, "Yep, we all want to do this. We all want to become partners." We had a relationship with them, and they got involved early on, and there is something really credible and good about these guys. One of my partners [at the Marketing Company], as a thinker, was instrumental in seeing the opportunities and pushing these conversations along early on, but, when it got to a tactical level, it was just difficult.
>
> In April, it was hot season. CPC-Owner's like, "I got stop talking about this and start doing things." And so, we said, "We're in. We're going to do this all as well. We're diving in, we're going to start contributing our time, we'll get to the details of the contract and everything else later." That contract didn't get signed until August/September. We had already put in a couple hundred thousand dollars in time and effort, and I had no problem doing that because SPM-Owner had done the same thing, right? CPC-Owner and PCM-Investor were giving up a significant piece of their company I thought to pursue this opportunity with us. I was stunned at how fast the trust was there and how much trust was put on the table, both physically and financially. Trust had to be gained across the board. Every single player. It's there, and that felt really good.

For all of the case studies, risk was a central aspect of developing a relationship with another company and played a role in creating a culture of collaboration and trust.

Business culture. A nimble business model and a culture of innovation set the tone for an employee's internal motivation and a business's external motivation to collaborate through interdisciplinary product development. SPM-Owner spoke at length about the importance of allowing time to experiment and build relationships, which are two key factors contributing to interdisciplinary product development. A company's openness and a lack of bureaucracy were characteristics of all seven companies discussed in this research. These business culture characteristics contributed to the successful development of new products because at the core of each business are flexibility and experimentation. CPC-President had this to say about the companies collaborating and working together to develop the flexible cool vest:

> As companies achieve scale, you get bureaucracy that creeps in. The ability to pivot, change directions, rethink, start over gets diminished because the other party's saying, "Hey, that all costs time and money. I've got to get approval for this, that, and the other thing." Whereas SPM-Owner is saying, "I'm a partner in the company." He has a stake in the Cool Product Company. He says, "I'm committing to that R&D for you guys." We're not on the clock. We're not being charged for that. He gets his return as the product gets sold into the market place. In a company with a lot of bureaucracy, there’s a lot of clock watching and billing. So many people get involved in checking a few cents here. It's not very value added. If we developing this vest bureaucratically, I'm not even sure we'd have the first vest, to be honest.

He continues to discuss the importance of culture and strong people in each organization.

> You've got to have a little bit in your culture. CPC-Owner is at heart an engineer and an innovator so, he's on the pack side. I think I could push him to do a lot of things yet that we haven't really thought to explore. As long as he has a reason, if I can tell him there's a market for it. He's got a reason to go forward. That's in his core. That is what he does best is innovate. If I tap into that, I've got a really strong asset.
>
> SPM-Owner is, how shall I say, a consummate entrepreneur. He's a connector so he knows everybody. He can grease a lot of skids to get things moving. Once he's grasped a basic idea, he's impatient to just make it happen. Let's see something. I think that SPM-PDevers a lot. Both CPC-Owner for his team and SPM-Owner for his team, they're setting a culture of being action oriented. Let's do it. If you've just thought of it, you can conceive of it, let's see it.

A business culture of being nimble, flexible, and action oriented propelled the development of the cool products forward. With the exception of the Material/Chemical Company, all of the companies involved in the product development of the cool products were small and had the ability to move quickly when the product needed to change focus. The leaders of the organizations, SPM-Owner, CPC-Owner, Jim, and PCM-Investor, led by example and enabled their staff to and to be flexible with how they approached and solved a design or production problem.

Time. The concept of time is important to the successful development of new products between companies and interdisciplinary teams. Developing a new product inevitably takes time, but it also takes time to build connections between companies and to develop the 'right' relationships, as well as time to learn about the new technology or material application. All of the individuals interviewed mentioned the need for time and resources due to the complexity of the products that they were attempting to create. MC-President said, "…if you're developing a new product for market, there's an inevitable discovery process that you have to allow for because you won't know that all ahead of time." Time is a very valuable and expensive resource in most companies. This need for time and resources to create the products was counterbalanced by the fact that all of the companies involved had other sources of income. David explained,

> It's the one critical factor here for small companies. When they're trying to do breakthrough technology, they want to protect their core business, and that consumes almost all of their resources. There's very little left over for that breakthrough development, even though they may see it, but they just can't get to it. By having some financial support pour into this, which is where PCM-Investor fits in. He has enabled us to break free of meeting the bottom line day to day, long enough to go ahead and introduce the new products. For a small business, that's almost a luxury they never have, and that's a constraint on getting innovation into the marketplace.

The companies involved in the creation of the cool products were all respected and established in their fields. The development of the cool products was not the sole source of their income. Therefore, they could spend time during the development phase and did not have to worry about keeping their businesses afloat. Financial support and resources available to the companies working on the cool product development, such as the funding from Natick and from PCM-Investor, the owner of the bio-based PCM Company, helped alleviate some development constraints. All companies were able to contribute ample company resources in the form of personnel time, materials, and equipment to the creation of the cool tent, flexible cool vest, and cool pad.

Summary

An overview of the product development process for the cool tent, flexible cool vest, and cool pad was presented, as well as descriptions of the seven companies involved in the interdisciplinary development of the cool products. Interviews, observation and site visit notes, and product development documents were examined and themes regarding the interdisciplinary product development process were formed. Themes that surfaced were organization and communication, flexibility and experimentation, stakeholder support, the importance of diverse expertise, and collaboration and trust.

CHAPTER V

DISCUSSION

This chapter presents the analysis and discussion of the interdisciplinary product development for the cool tent, flexible cool vest, and the cool pad. It is presented according to the research questions posed at the beginning of this study. Those research questions were: How do interdisciplinary companies and teams work together during the development of new products? How does an interdisciplinary approach to design and material development impact the way in which product development is conducted? How does an interdisciplinary process of design and material development lead to the creation of new products?

For the analysis, participant interviews, observation notes, product development documentation, and literature were investigated and synthesized to gain insight into the interdisciplinary product development process of the cool products. Included in this chapter is a comparison of the development process for the cool products; an evaluation of how the companies and teams involved in the development of the cool products interacted, collaborated, and created; an evaluation of how an interdisciplinary approach to the cool products impacted the way in which product development was conducted, with a special emphasis on the processes found in literature and the inclusion of interdisciplinary relationships; and an evaluation of how interdisciplinary product development led to the creation of the cool products specifically examining how and why interdisciplinary collaboration occurred for the cool tent, flexible cool vest, and the cool pad. Finally, this chapter presents an analysis of the application of new material and technology into newly designed cool products.

Comparison of Cool Tent, Flexible Cool Vest, and Cool Pad Interdisciplinary Product Development

The complexity of the product development process for the cool products was affected by the number of companies or institutions involved, the number of industries involved, whether the design and manufacturing companies had experience working with the new material or technology, and whether the interdisciplinary relationships were established prior to the development of the product. These factors play a role in the type of product created and the length of time it took to get the product to market. Table 3 compares the interdisciplinary product development of the cool tent, flexible cool vest, and cool pad. The number of interdisciplinary companies involved in the creation of the three products ranged from four to seven, and the number of industries involved ranged from two to four. The design and manufacturing companies that contributed to the development of the cool tent had no previous experience working with the PCM technology or material application. The Sewn Product Manufacturer, the Cool Product Company, and the PCM Packaging Company had some experience working with the PCM technology prior to beginning the development of the flexible cool vest. All companies involved with the development of the cool pad had experience working with the PCM technology. Interdisciplinary collaboration occurred during all phases of the product development process for all of the cool products. Prior to development, no interdisciplinary relationships had been established for the cool tent. Some relationships were established prior to the development of the flexible cool vest. All interdisciplinary relationships were established prior to the development of the cool pad.

Product	**# of Companies or Institutions**	**# of Industries**	**Material/ Technology Experience (from design and manufacturing perspective)**	**Product Development Phase: Interdisciplinary Relationship**	**Type of Innovation**	**Time to Market**
Cool Tent	7: no working history	4 (material, product, government, research/ university)	No	No established business relationships prior to development; All PD phases	Transformative	2.5 years
Flexible Cool Vest	5: some working history	2 (material and product industry)	Yes, some	Some prior established relationships; All PD phases	Incremental	1 year
Cool Pad	4: working history	2 (material and product industry)	Yes	Prior established relationships, All PD phases	Transformative	TBD, Prototype w/in 6 months

Table 3. Comparison of cool tent, flexible cool vest, and cool pad interdisciplinary product development

The time to market and the type of innovation achieved during the development process of the cool products varied greatly. The cool tent took two and a half years to develop. It is a transformative product because it has the capacity to completely change the way the military heats and cools tents, can reduce the military's energy needs and save money due to reducing the need to heat and cool the tent, and the material developed could have applications beyond the product. The flexible cool vest took one year to develop and exhibits incremental innovative change because the overall shape of the garment did not change dramatically. Regardless, these incremental improvements in PCM material packaging and overall vest design have enabled the product to enter new markets, such as healthcare. The cool pad was developed over six months and is a transformative product because it brings a completely new cooling technology to the bedding industry. The cool pad also has the capacity to transform human seating and bedding, as well as pet bedding. While the total time to create the prototype was shorter than the cool tent and flexible cool vest, the interdisciplinary relationships were established prior to the development of the cool pad and members of the development team had over three years of experience working with the PCMs.

Obstacles involved in interdisciplinary product development, such as learning to communicate knowledge and organizing the product's development across disciplines, as well as the effort involved in gaining stakeholder support are major factors contributing to the complexity of the interdisciplinary product development process. A logical assumption can be made based on the three cool products' development that the more companies, institutions, and industries involved in the creation of a product the more complex the process becomes. More companies, institutions, and industries involve more types of expertise and knowledge in the development process, present difficulties developing common and shared goals across the disciplines, and require more stakeholder support to motivate the companies to work together. A comparison of the development process of the cool tent, flexible cool vest, and cool pad demonstrates this assumption. The cool tent had seven companies and four industries involved in its creation, none of the relationships had been established prior to the beginning of the process, and no one from design and manufacturing had experience working with PCMs. The cool tent development process (figure 11) compared to the flexible cool vest and the cool pad (figures 12 and 13), contained more process steps and less flow. The cool tent product also took longer to create: over two and a half years, compared to one year for the flexible cool vest and six months for the cool pad. The complexity of the cool tent material development was more than the flexible cool vest and the cool pad, but much of the material complexity was dictated by the companies and industries involved. Amongst these three case studies, the more companies and industries involved in the creation of the product, the level of material/technology experience, and whether interdisciplinary relationships were established prior to product development affected both the time to market and the complexity of the development process.

Interaction and Collaboration of Interdisciplinary Companies During the Development of New Products

Interdisciplinary collaboration occurred before the start of the cool product development process, during every phase of the process, and continued after the development process as many of the companies continued to work together on the development of new cool products (figure 11, 12, and 13). The companies and individuals working on the cool products sought out different types of knowledge and expertise through interdisciplinary collaboration as a method of problem solving. This is apparent as the individual cool product development processes are examined (figures 11-

13). Looking at the location of the interdisciplinary relationship of each cool product process, the relationships can be found during each major phase of the development process. The interdisciplinary relationship is continually relied upon and relationships are sought out throughout the process.

The interaction between disciplines and companies, as well as the process of development continually evolved for each cool product. Especially for the cool tent and flexible cool vests, the interaction between companies and process was messy at the beginning and tended to smooth towards the end of the development after the teams learned to break down communication barriers and developed effective forms of communication. The interdisciplinary interaction and collaboration of companies during the development of the cool products is strongly affected by the types of knowledge sharing required of individuals. Over time, the interdisciplinary interaction changed. This is demonstrated in the development of the cool pad product where the collaborators had prior working experience and knowledge of the material and technology. Less time was spent developing the relationships, methods of communication, and the learning curve to apply the PCM in the design and production was reduced due to previous working experience.

Analysis of data regarding communication among team members highlighted Grant and Baden-Fuller's (2004) assumptions of how different types of knowledge transfer among team members. Based on the research of Kogut and Zander (1992) and Nonaka (1994), transferability and communication of tacit knowledge is much more difficult than explicit knowledge. During the cool tent and flexible cool vest development, each phase of the development process relied on a different type of interdisciplinary relationship and collaboration style. An example of the communication difficulties arose during the creative exploration phase and prototype development of the flexible cool vest. CPC-Owner had difficulties communicating with SPM-PDev because CPC-Owner's expertise is strongly based on skills and know-how developed by working with PCMs for over twenty years. Similarly, SPM-PDev's design and product knowledge was not easily transferrable or communicated to CPC-Owner (especially over phone or email) because it's specialized. In interdisciplinary product development, the type of expertise being communicated requires the development of new methods of communication and clear tasks that can be understood by people with different skill sets. These new methods and task clarity encourage team members to effectively communicate in different knowledge languages.

Impact of an Interdisciplinary Approach to Design and Material Development

Many factors influence the way in which interdisciplinary product development is conducted. Learning to communicate across disciplines, developing stakeholder support, building trust between companies and team members, the culture of the company, and the resources of the company provide a foundation for and impact the product development process. An analysis of common product development processes compared to the development process for the cool products is presented.

Comparison of Product Development Processes. LaBat and Sokolowski's (1999) product development process and Ulrich and Eppinger's (2012) generic product development process were analyzed and compared to the interdisciplinary product development process of the cool tent, flexible cool vest, and the cool pad to gain a clear understanding of how the addition of interdisciplinary relationships influenced the development process of the cool products.

LaBat & Sokolowski three stage design process. LaBat and Sokolowski (1999) examined product development processes in design disciplines and found that the processes all contained a problem definition and research phase, a creative exploration phase, and an implementation phase. The three case studies examined for this research contained elements of these product development phases. Figure 5 provides an overview of LaBat and Sokolowski's three stage development process and figures 11-13 provide an overview of the product development process for each case study using LaBat and Sokolowski's broad design stages as a basis for the models with the addition of interdisciplinary relationships. While the characteristics of LaBat & Sokolowski's design process were common among the case studies, the product development processes were not linear. Each case study showed elements of circular and continuous development, as well as significant process iteration between stages as discussed in Koberg and Bagnall's (1981) and Watkins and Dunne (2014) design process models.

The cool product case studies diverge from LaBat and Sokolowski's textile product development process model in the specific steps described for each stage. Most significantly, the problem definition during the research phase, design refinement during creative exploration, and production refinement during implementation were heavily influenced by the addition of interdisciplinary collaboration. The concept of problem definition occurring only during the first stage of the process is an accepted feature of LaBat and Sokolowski's product development process, as well as most generic design, engineering, and apparel processes discussed in the literature review (Ulrich & Eppinger, 2012; Cross, 2007; Watkins, 1988; Koberg & Bagnall 1981). The interdisciplinary product development processes of the case studies clearly demonstrated that the problem definition was continuously redefined and renegotiated with the addition of interdisciplinary companies throughout development. For example, the cool tent problem definition was significantly altered with the addition of the military as a stakeholder, and was re-defined again when the Material/Chemical company joined the team. The goals of the product changed as stakeholders and interdisciplinary partnerships developed. Similarly, the development and addition of design requirements and design refinement occurred during every phase of the product development process as opposed to one specific stage as proposed in LaBat & Sokolowski's design process and several other common design process (Ulrich & Eppinger, 2012; Cross, 2007; Watkins, 1988; Koberg & Bagnall 1981). While LaBat & Sokolowski's design process does include circling back and reiterations, the extent to which the design requirements were reiterated and the process stage that it occurred diverged greatly. The addition of interdisciplinary partnerships during each phase of the development process, as well as the unknown nature of a new material and product, affected how and when design requirements were created. Finally, production refinement occurred throughout the design processes as opposed to specifically during the implementation phase. The continual change in design requirements as interdisciplinary partnerships developed caused production refinement to occur earlier and more often during the design process. Often a new production method needed to be developed before the product could be be designed or reconfigured. Examples of production refinement occurring throughout the product development process as opposed to only during the implementation phase include: the development of new cool packs and new machinery to create the cool packs for the flexible cool vest during creative exploration, the selection of stretch material for the flexible cool vest and a manufacturing facility with little stretch knit experience during the research and creative exploration phases, and experimentation with the production methods for foam and cool product integration for the cool pad during the creative exploration phase.. Broad application of the three phases in LaBat and Sokolowski's model can be seen in the cool product development, but the stages tend to blend together and overlap significantly making it difficult to attribute common features to a single stage.

Ulrich and Eppinger's Generic Product Development Process. Ulrich and Eppinger's (2012) product development process assumes that marketing, design, manufacturing, and business development occur within a single organization, as opposed to decision making and process occurring across multiple organizations. While elements of their process such as planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up can be found in all three case studies, the order in which they occur and the specific details of each step varied greatly in the development of the cool products. Many of the elements that differed between the cool product development and LaBat and Sokolowski's (1999) product development model were found to be true when comparing Ulrich and Eppinger's generic product development model. Each stage in the generic model includes clearly defined roles for each department or development area as outlined in Table 1. Specifically, marketing, design, and manufacturing have detailed tasks for each phase and little to no overlap in terms of their responsibilities. The case studies demonstrated when a new discipline/company began working on the cool product development, it took time to clearly define roles and establish clear lines of communication. Even if the companies had established relationships prior to the start of development, they exhibited flexibility in their function as a member of the larger team and developed new skills as necessary to develop the product. As the cool products developed, the roles of each company became clearer, more defined, and some similarities can be found in the tasks outlined in Ulrich and Eppinger's model. However, clear role delineation did not occur until close to the end of the development. Fortunately, the inclusion of interdisciplinary collaboration and flexibility during the process led to opportunities for creative exploration and innovative discovery which could have been lost if the process was too structured.

Problem identification and design requirements in common product development processes. A clear understanding of the capabilities of the material technology (in this case, phase change materials) and the basic design problem encouraged interdisciplinary design solutions for the cool tent, flexible cool vest, and cool pad. Unlike common product development processes, clear design requirements were not as imperative at the beginning of the process. In fact, the flexibility of companies to re-negotiate and redevelop design requirements encouraged more thoughtful design and development. The practical design requirements posed by the military and the addition of future-directed, strict environmental requirements by the Material/Chemical company during the development of the cool tent ensured that the product was created in a manner that would lengthen its lifespan in the military and enhanced overall innovation.

The interdisciplinary design processes of the cool products exhibited loose design requirements during the early stages of the development process. Design requirements built as companies collaborated and moved through the design process in all three cool products. Additionally, requirements were developed based on the expertise of partners in the process. Often, those partners entered into the development process at different stages.

The method of developing design requirements throughout the interdisciplinary product development process was different than most of the product development processes discussed in the literature review. Typical design processes place the creation of specifications and design requirements at the end of the research phase. In the case of the cool product development, when trying to create something completely new with a team that speaks different design languages it took time and iteration to develop design requirements that were understandable and agreeable to everyone on the teams.

Interdisciplinary product development process. Interdisciplinary relationships were integral to the development of the cool products. An examination of the development characteristics of each cool product (figures 11, 12, and 13) exhibited the common phases featured in LaBat and Sokolowski's (1999) product development process, as well as interdisciplinary relationships. Interdisciplinary relationships materialize before, during, and after product development, and can occur in conjunction with the common design process phase or on their own. The cool tent development (figure 11) demonstrated that forming interdisciplinary relationships can become a development phase in its own right and can move both the process and the product in new directions. Figure 14a combines the common features of the LaBat and Sukolowski's (1999) design process, *problem definition and research, creative exploration,* and *implementation,* with interdisciplinary relationships. The figure prominently places the interdisciplinary relationship at the center of the process. Regardless of where the product is in the development process, the interdisciplinary relationship is the catalyst that allows the product to move between problem definition and research, creative exploration, and implementation. The interdisciplinary relationship can also be a stage of the process. Despite the differences in the development of the three cool products, the addition of interdisciplinary relationships throughout the product development process created new opportunity for innovation in each product.

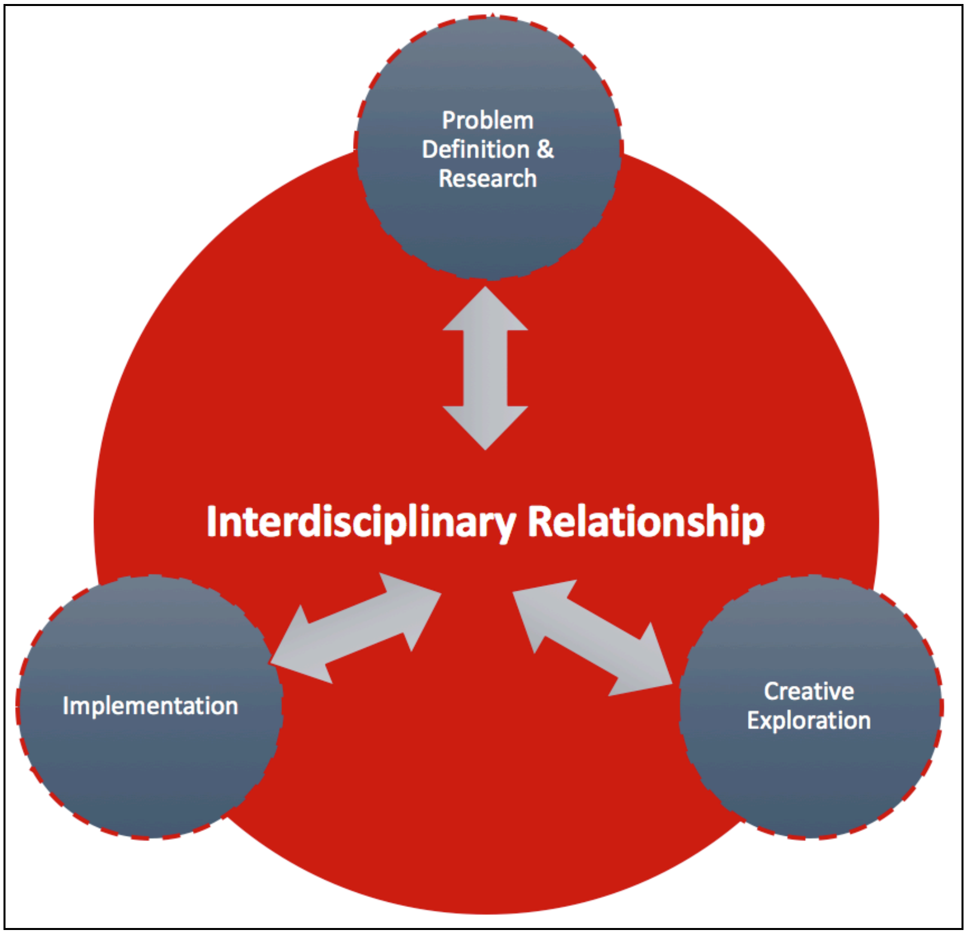

Figure 14a. Relationship of LaBat and Sokolowsk's (1999) product development process stages and interdisciplinary relationships.

Interdisciplinary relationships influence the product development process before, during, and after a product's created, as illustrated in figure 14b. Relationships, whether business or personal, can influence the start of the development process. The relationships at the beginning of the process affected the direction of the product for each of the cool product case studies. For the cool tent, the personal relationship between the SPM-Owner and Mil-Owner was the catalyst for incorporating the PCM technology into a sewn product. The relationships prior to the flexible cool vest became a catalyst for redesigning the product for a new market. For the cool pad, the relationships that were forged during the development of the flexible cool vest enabled early access to new containment devices from the PCM Packaging Company which facilitated the ideation and development of the product.

During the interdisciplinary product development process, the interdisciplinary relationship is both a catalyst and a stage or step of the process. As demonstrated in the cool product case studies, the development process can easily move between and among different stages throughout the process. The red dashed line that connects the various stages is symbolic of how the interdisciplinary relationship influences each development stage and helps move the product to the various stages. The central red shape is symbolic of how the development of interdisciplinary relationships can become a distinct stage of the process and the grey arrows indicate that the relationship can move the process in a variety of directions in order to develop the product. The interdisciplinary relationships after the development of the product can continue and lead to a series of new products developed among the interdisciplinary teams.

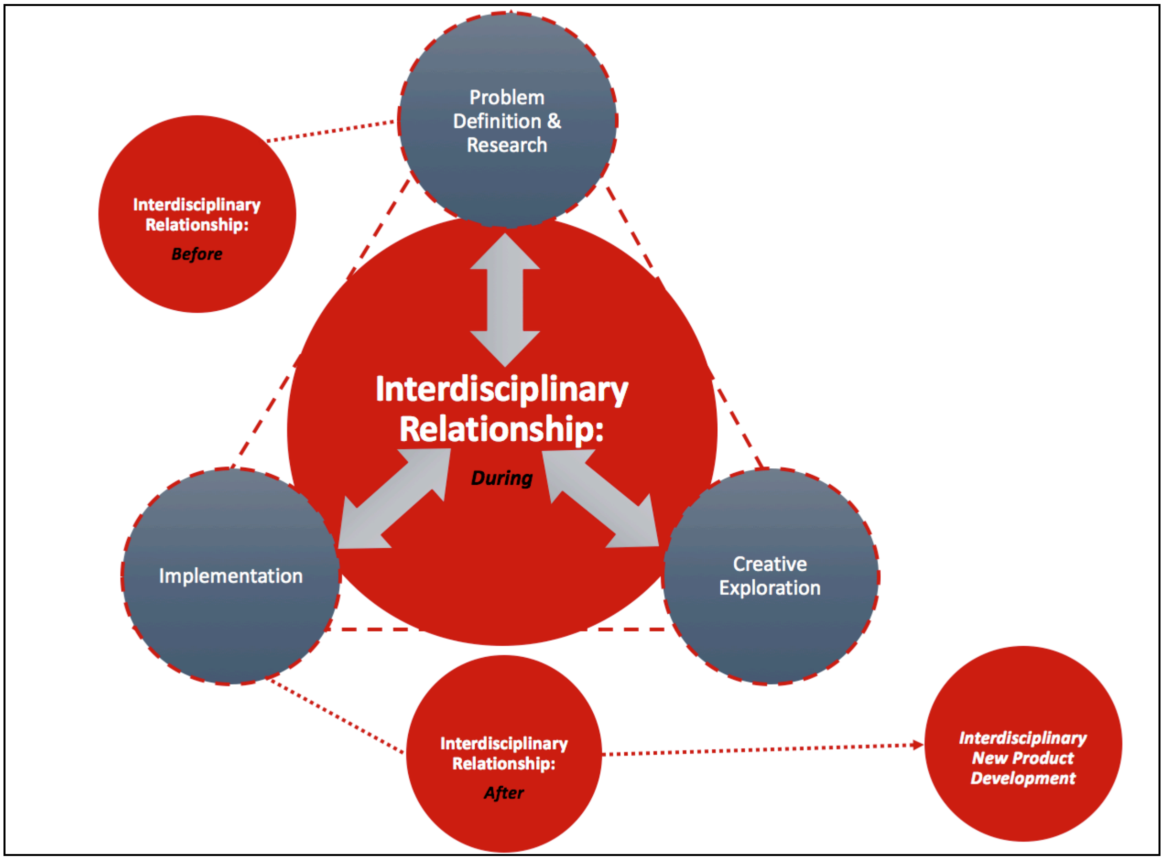

Figure 14b. Relationship of LaBat and Sokolowsk's (1999) product development process stages and interdisciplinary relationships, with the addition of before, during, and after influence of interdisciplinary relationships.

Figure 15 is a model of the *inputs*, *process*, and *outputs* of the interdisciplinary product development used in the three case studies. The *inputs* and influenced and affected one another throughout development, as characterized with a dashed line between them. The *inputs* and *process* combine to produce the *output*, symbolized with a solid line.

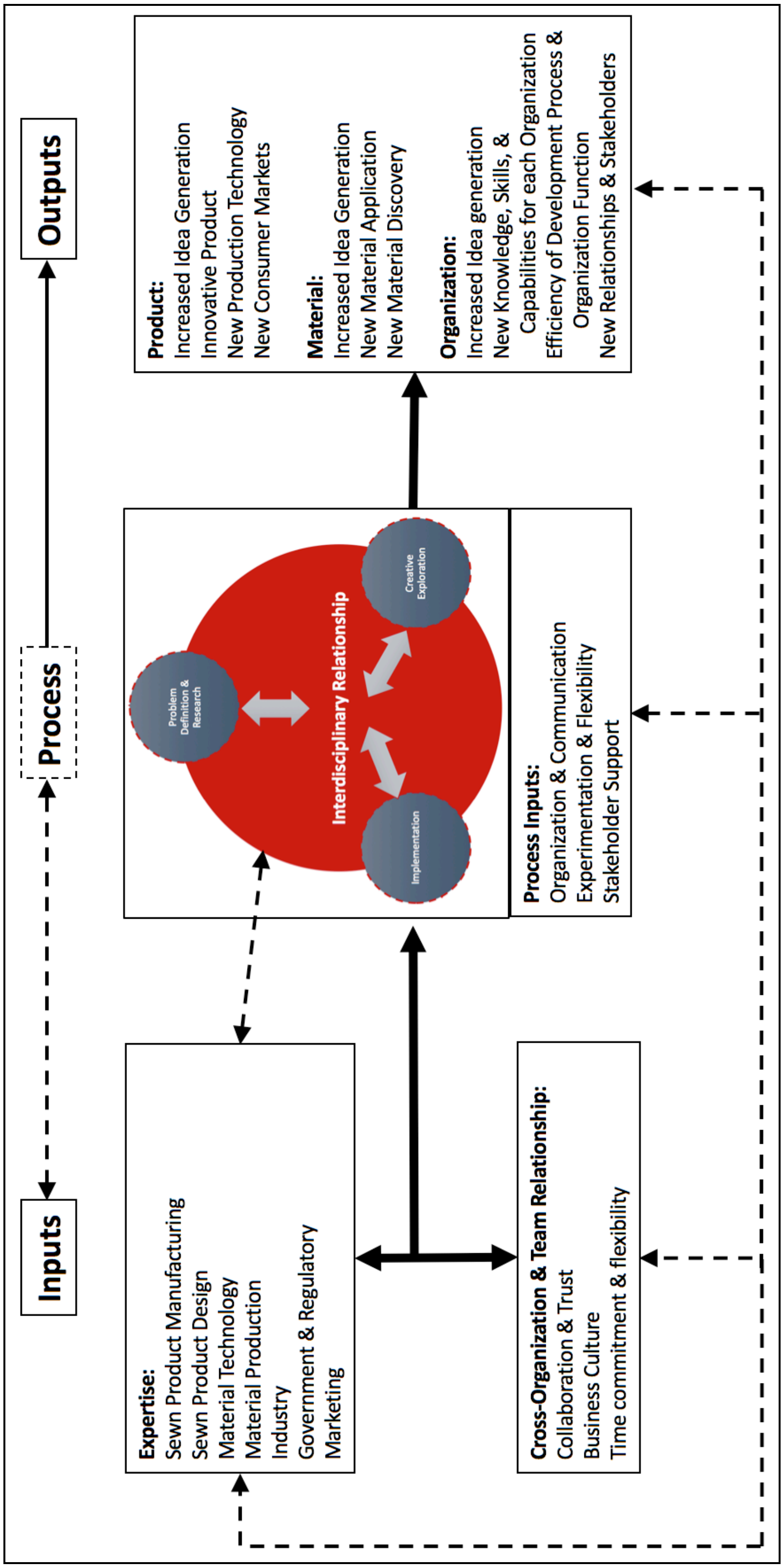

Figure 15. Interdisciplinary Product Development: *Inputs, Process,* and *Outputs* Model.

The *inputs* of interdisciplinary product development include expertise, and cross-organization and team relationships. The companies involved in the three case studies represented expertise in sewn product manufacturing, sewn product design, material technology, material production, various industry, government and regulation, and marketing. The dashed line connecting expertise to the *process* is symbolic of expertise as an input throughout the process and also indicates a feedback loop that supports the evolution of expertise involved in the creation of the product. Cross-organization and team relationships were built on collaboration and trust, an adaptable business culture, and a commitment of resources in the form of time and flexibility. These variables greatly influence stages and inputs of the overall process.

The *process* in figure 15, an adaptation of figure 14, is influenced by a distinct set of inputs. The *process inputs* of organization and communication, experimentation and flexibility, and stakeholder support influence the way in which the interdisciplinary product development process is conducted. Organization and communication affect the continual development of design requirements, the way in which tacit knowledge is communicated between teams and team members, and the organization of the product variables. Stakeholder support was found to be an integral process input in creating new interdisciplinary relationships throughout the product's development.

The *outputs* of interdisciplinary product development include benefits to the product, material, and organization. The product outputs include increased idea generation, an innovative final product, the development of new production technology, and entry into new consumer markets. The material outputs of interdisciplinary product development include increased idea generation, new material application, and new material discovery. The organization outputs include increased idea generation, new knowledge, skills, and capabilities for each organization; efficiency in terms of the development process as well as the organization's function; and new relationships and stakeholders as a result of participating in the development process. The outputs provide an important feedback loop, characterized by the dashed line, back into the inputs and process inputs for future interdisciplinary product development.

New Product Development through an Interdisciplinary Process of Design

An interdisciplinary process of design and material development led to the creation of new products through expertise. Interdisciplinary expertise led to efficient idea generation and the creation of knowledge, as well as contributed resources to support the development of new products. An analysis of the data indicated that creating resources through interdisciplinary alliances was one of the most important factors in new, realistic idea generation and implementation. Specifically, the reasons behind the acquisition of certain types of knowledge and the point at which the relationships were formed during the development of the cool products demonstrated how the new products were developed in an interdisciplinary process of design. The findings from this research were compared to Grant and Baden-Fuller's (2004) knowledge access theory and Rothaermel and Deeds (2004) exploration-exploitation model in order to glean a better understanding of why the companies collaborated to create the products, and how the time in which they began collaborating reflected the company's motivations for creating alliances/interdisciplinary collaborations at each phase of the development process.

Grant and Baden-Fuller knowledge access theory. Grant and Braden-Fuller's (2004) knowledge access theory developed basic propositions for why companies collaborate when creating new products. The basic premise behind this theory, which focused on companies in the bio-technology field, is that companies collaborate and create strategic alliances with one another as a way to access knowledge for the purpose of creating new products. The knowledge access theory comprises four basic knowledge propositions that predict why a company enters into alliance with another company to create a product. Table 4 outlines Grant and Braden-Fuller's four knowledge propositions and the motivation behind the companies involved in the cool product development to enter into an alliance. The first knowledge accessing proposition, knowledge integration, motivated the forming of alliances to develop all three cool products. It would have been too expensive and time consuming for any one company to integrate the knowledge and skills to create the cool tent, flexible cool vest, or cool pad. No single company, institution, or government entity had the knowledge or resources to develop the cool products prior to the strategic alliances forming.

Grant & Braden-Fuller's Knowledge Proposition	Description: Strategic Alliance was beneficial because…	Cool Tent	Flexible Cool Vest	Cool Pad
#1	Knowledge integration was too expensive	X	X	X
#2	Product's knowledge domain was much larger than the parent organization's specific knowledge	X	X	X
#3	The future of a company's current product is unclear due to a high risk and uncertain market. Strategic Alliance and interdisciplinary collaboration allows company to access and integrate different types of knowledge			
#4	Early-mover advantage in technologically dynamic environment is strong	X	X (into healthcare market)	X

Table 4. Knowledge Access Theory (Grant & Baden-Fuller, 2004) strategic alliance motivation in the cool tent, flexible cool vest, and cool pad development.

The cool products' knowledge domain was much larger than any one of the organizations' specific knowledge, the second proposition of Grant and Baden-Fuller's knowledge proposition theory. All three products needed a variety of skill sets and interdisciplinary knowledge bases in order to create the new cool product. The cool tent development needed military, material/chemical, and specific tent manufacturing knowledge, along with the product development expertise of the Sewn Product Manufacturer in order to be developed. The flexible cool vest required manufacturing knowledge of both the wearable product and the cool packs/PCM materials, in conjunction with industry specific marketing and consumer insights in order to create a new and innovative cool vest. The cool pad product required domain knowledge in PCM material, PCM packaging, foam material and glue, and sewn product manufacturing.

The third proposition of Grant and Baden-Fuller's knowledge accessing theory was that the future of a company's current product is unclear due to a high risk and uncertain market. Strategic alliances and interdisciplinary collaboration allows a company to access and integrate different types of knowledge. This proposition did not hold true for any of the cool products in this research. The development of the cool products represented a new product for the companies involved, however while the market for the products was not entirely clear it did not deter the companies from collaborating. All the companies had strong businesses outside of the cool product/s that they were developing, so the market risk was not a major factor in forming partnerships.

The fourth proposition of the theory highlights the benefits of early-mover advantage in a technologically dynamic environment. Phase change materials are a relatively new technology in the sewn product industry and the market for advanced sewn products is growing at a fast rate. By entering into strategic alliances to develop the cool products, it enabled the product to be developed on a 'near future' timeline. The cool tent was developed for military application. The military's strength as an organization relies heavily on innovative technology; therefore, the companies involved in the cool tent development knew that they had an early-mover advantage if they created a successful product because the material technology had the capacity to revolutionize how the military cools large spaces. The development of the flexible cool vest enabled entry into a new market that is seeking advanced wearable products, healthcare. The development of the cool pad offered early-mover advantage into a bedding market seeking higher tech solutions due to a saturation of cooling gimmicks. The interdisciplinary relationships and alliances formed during the development of the cool products appear to follow the majority of the propositions of Grant and Braden-Fuller's (2004) knowledge accessing theory.

Rothaermel and Deeds' (2004) exploration-exploitation model of organizational learning. Rothaermel and Deeds (2004) exploration-exploitation model examined the different stages of the product development process and motivations for creating alliances/interdisciplinary collaborations at each phase. With a focus on the bio-technology industry, the authors examined when alliances formed in relation to the product development process and for what purpose. An exploration alliance is formed at the beginning of the product development process, during the research phase, and in order to improve discovery and innovation. An exploitation alliance is formed during the implementation phase of product development to enable commercialization. Figures 14 through 16 show the companies and organizations involved in the development of each cool product, when the alliance was formed in relation to the model, and the type of alliance the companies formed. The cool tent development (figure 16) and the flexible cool vest development (figure 17) required both exploration and exploitation alliances to create a product for their respective markets, while exploration alliances propelled the development of the cool pad (figure 18). When discussing exploration and exploitation alliances in new product development, Rothaermel and Deeds' research treated the types of alliances as either-or occurrences in new product development. Either a company enters into exploration alliances to develop a product or a company enters into exploitation alliances. The cool tent development and the flexible cool vest development required both types of alliances. This shift in the understanding of alliances forming during the product development process from ‘either’ to ‘either’ or ‘both’ could be due to the difference in industries being studied. The original study was focused on the bio-technology industry and it is possible that the type and number of industries involved in the creation of the product affects the types of alliances being formed during the product development process.

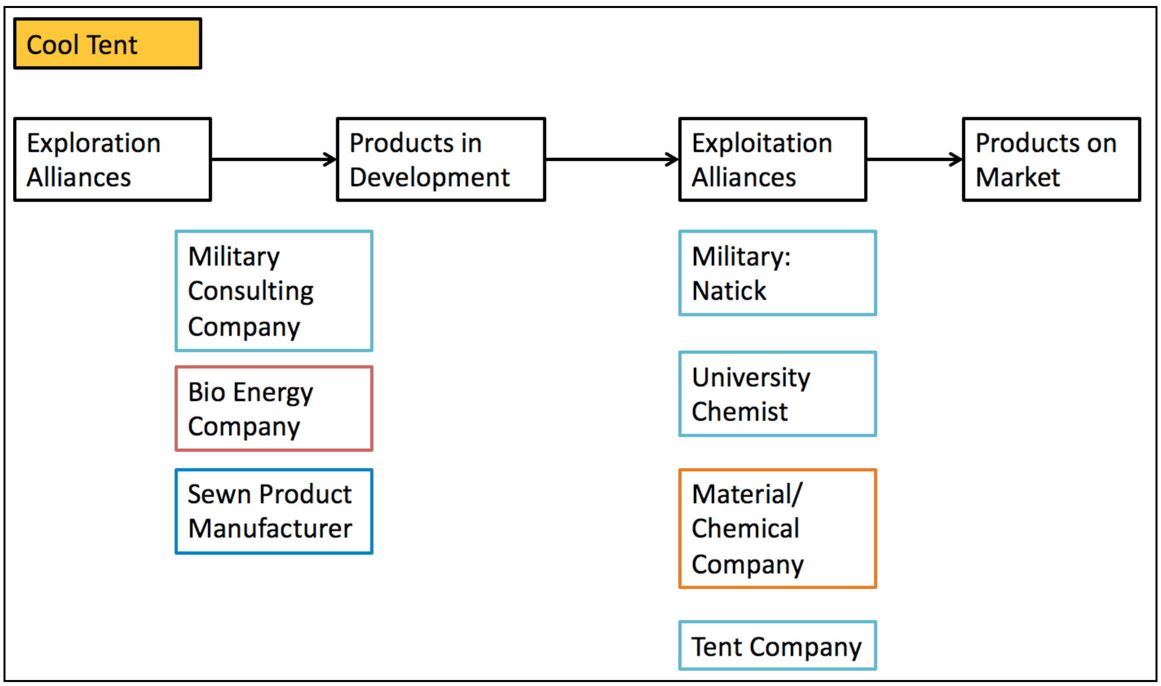

Figure 16. Exploration and exploitation alliances in the cool tent development.

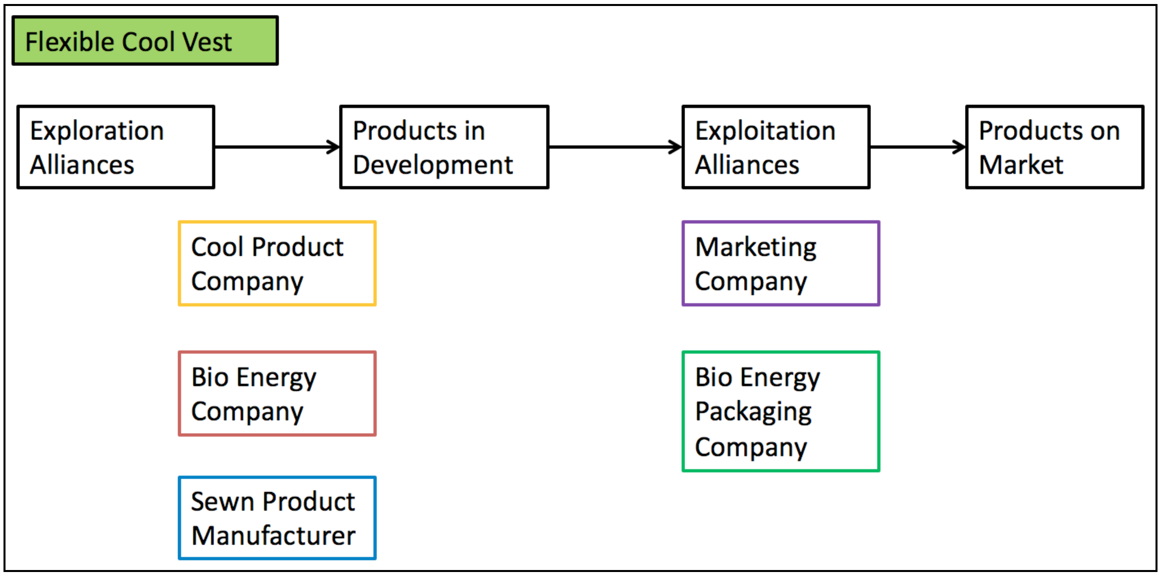

Figure 17. Exploration and exploitation alliances in the flexible cool vest development.

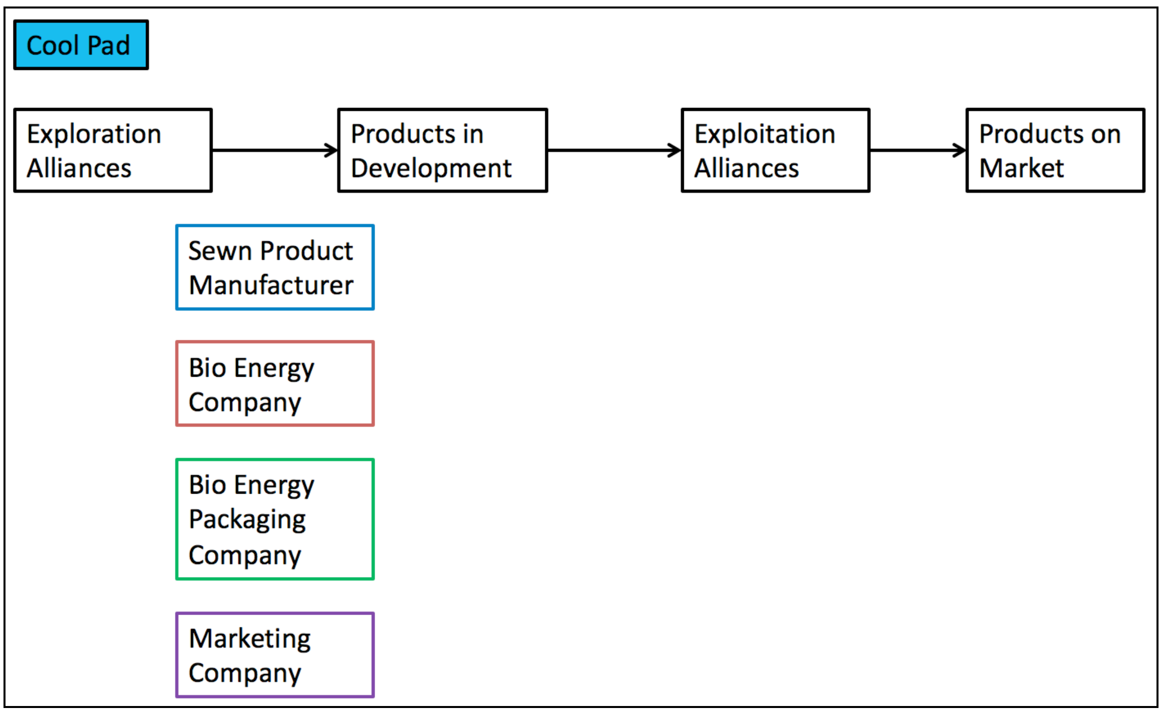

Figure 18. Exploration and exploitation alliances in the cool pad development.

Material and Technology Drive Interdisciplinary Product Design

The initial focus of this research was to understand the mechanisms of interdisciplinary product development that encourage material and design to be developed simultaneously. In this research, there were many instances when the cool products' material and design were developed in tandem, especially during the development process of the flexible cool vest. The collaboration between the material company Yulex and design company Patagonia to develop the first bio-based rubber for wetsuit application, the development of the Nike's FlyKnit® shoe, or Speedo's LZR Pro and LZR Elite competition swimwear led me to believe that the most important interdisciplinary relationships were between design and material development.

This research began with a substantial focus on material and design development, but the case study research and data analysis revealed that the product development process relied on many diverse disciplines to create the product. Sales, marketing, design, manufacturing, and government all played critical roles in the creation of new material, technology, the application of the new material, and product direction. In the development of the three cool products, the interdisciplinary collaboration that occurred was much more complex than the interaction of only designers and material developers, and entailed disciplines ranging from marketing to chemistry.

During the development of the cool products, the design direction and physical product design was highly dependent on the development and capabilities of the phase change material and technology. The phase change material and technology development transformed the features and capabilities of the end product design. The material development drove the design development, and the product function and design itself was heavily reliant on the material technology.

However, the case studies also clearly demonstrated the benefits of bringing diverse disciplines together to brainstorm and push the development of the material and technology in new directions. Designers, marketers, sales, and a range of other disciplines helped expand the possibilities of the material development and end design. Furthermore, the input at beginning stages from designers and production specialists encouraged a smoother implementation of the new material into the product and increased the functional properties of the new product. While the material technology was a dominate driver of the functional improvement, diverse disciplines working together provided the framework for the successful material application and implementation into innovative final product designs.

Summary

Analysis of data collected from seven interdisciplinary companies involved in the development of the cool tent, flexible cool vest, and cool pad resulted in a comparison of the cool products' interdisciplinary product development. The evaluation of the interaction and collaboration between the interdisciplinary companies demonstrated that elements of interdisciplinary collaboration occur at every stage of the design process and forms of communication had to be altered in order to work across disciplines. An assessment and comparison of the interdisciplinary product development processes of the cool products to LaBat and Sokolowski's (1999) and Ulrich and Eppinger's (2012) product development processes showed clear similarities and contrasts between the processes. Common features of the interdisciplinary product development process were presented and assessed. A comparison of strategic alliance theories provided a basis for the analysis of how the interdisciplinary process of design and material development led to the creation of new products.

CHAPTER VI

SUMMARY, CONCLUSION, AND RECOMMENTATIONS

The purpose of this research was to explore the interdisciplinary product development process for wearable and sewn product design. Interviews, observation, a site visit, and design development documentation provided the basis for the analysis of interdisciplinary product development in three case studies. This chapter contains a summary of the research, conclusions, and recommendations for future research.

Summary

This research was an exploratory study of the product development process of a cool tent, flexible cool vest, and cool pad between companies and institutions from different disciplines. Eleven companies worked together in various capacities to create three cooling products. The design process of the cool tent, flexible cool vest, and cool pad all featured the development and integration of phase change material technology into the product.

Data was collected from interviews, observation, a site visit, and documentation related to the product development process of the cool products. Themes that surfaced surrounding how the product development process was conducted in interdisciplinary teams were organization and communication, flexibility and experimentation, and stakeholder support. Themes regarding how the interdisciplinary product development process can lead to the creation of new products were expertise, collaboration and trust, and flexibility and experimentation as part of the business' culture.

Analysis of data collected from the seven companies resulted in a comparison of the cool products' interdisciplinary product development process. The evaluation of the interaction and collaboration between the companies demonstrated that elements of interdisciplinary collaboration occur at every stage of the design process, and forms of communication had to be altered to work across disciplines. An assessment and comparison of the cool products' interdisciplinary product development processes to LaBat and Sokolowski's (1999) and Ulrich and Eppinger's (2012) product development processes showed clear similarities and contrasts between the processes. Features of the interdisciplinary product development process were presented and assessed. A comparison of strategic alliance theories provided a basis for the analysis of how the interdisciplinary process of design and material development led to the creation of new products.

Conclusions

As consumer demands for advanced wearable products increase, companies are going to be required to seek out new opportunities to develop products that feature new and improved technologies and materials, create innovative design, and surpass current product offerings. An interdisciplinary approach to the development of materials and products is a way for companies to access new types of knowledge and create strategic alliances to solve more complex design problems and to enable early-mover advantage. The case studies in this research offered a glimpse of the changes that occur when diverse teams and companies work together on material and design development. A clear understanding of how the product development process changes as multiple companies work together, common issues that arise as diverse companies and teams form, and how interdisciplinary alliances improve product innovation at various stages of the product development process are crucial as wearable and sewn product companies seek to advance their product offerings.

The purpose of this research was to understand the process by which wearable product designs are achieved in interdisciplinary teams. This research demonstrated that when wearable and sewn products are developed in interdisciplinary teams, the process is dependent on the industries, companies, people, and product components involved. Each additional element added to the design process increased the complexity. Comparing the cool products' development processes to processes found in literature highlighted the fact that the interdisciplinary development always varied. No two processes were the same and the process was always non-linear.

As broader implications are considered as to why the processes of the cool products varied from one another and those found in literature, the crux lies in the companies and industries that make up an interdisciplinary team. Each discipline, company, and individual defines design differently and their approach to solving problems varies based on experience. A company can create loose boundaries around the development process to facilitate communication and create order across the company.

However, each company has a set of rules that dictates how they approach a design problem. Furthermore, each discipline's training and knowledge create a culture around acceptable methods of creating and problem-solving. When interdisciplinary teams are created, new rules need to be created and boundaries negotiated. This creates an uncertainty in managing what the development process looks like from the beginning of a new product, and has to be readjusted as new collaborators enter the process. These ideas are reflected in the themes that emerged in this research. Flexibility, both as part of the business culture and the process, communication across disciplines, and building trust surfaced because they represent methods of coping with the uncertainty of new product development process.

The ability of a company to successfully enter into an interdisciplinary alliance relies on the company's knowledge. All of the companies involved in this research had decades of experience navigating product development in their respective fields and industries. Deep knowledge and experience contribute to the company's ability to create and build trust between potential collaborators, as well as forming strong relationships. A company's experience also creates legitimacy when seeking stakeholder support. Without experience and domain knowledge, there's no benefit to another company collaborating through the development process. Companies interested in interdisciplinary product development need to be able to demonstrate that they add value to the development process. Communicating this value and proving their worth to another company is an important step in developing interdisciplinary relationships.

These case studies demonstrated the benefit of having diverse industries and fields represented throughout the design process. However, there is a natural tendency to try to compartmentalize and make expected connections between disciplines. We have to ask ourselves: What does it truly mean to be interdisciplinary? Design is interdisciplinary, but we do not have a firm grasp on how to facilitate design development across companies, disciplines, and industries. "Interdisciplinary" design courses are being taught at universities ranging from Harvard to Nova Scotia. However, even these majors and courses are limited in their scope. Pairing traditional disciplines such as architecture and engineering, or visual communication (graphic design) and interactive design does not allow for the combination of diverse knowledge to solve problems. This type of compartmentalization will eventually begin to limit and slow creation. Companies need to move past the natural connections between material development and design, and bring in disciplines like marketing, biology, chemistry, kinesiology, medicine, manufacturing, government or regulating entities to solve pressing issues facing the wearable product industry and beyond.

As we enter a new era in our capacity to create and consume, we need to broaden our scope of thinking, build connections, and bring disciplines together. Solving wicked problems like climate change or water supply should not be limited to experts in the field. Reaching across disciplines and collaborating to solve problems allows the creation of new knowledge, processes, and products. When discipline boundaries are crossed, the boundary itself begins to blur, overlaps are created, and gaps in knowledge are bridged resulting in a greater capacity to build viable solutions to complex problems.

Recommendations for Future Research

As interdisciplinary product development becomes more prevalent in the wearable and sewn product industries, research is needed to develop strategies for creating a more fluid development process among newly formed interdisciplinary teams. A deeper understanding of specific communication barriers between interdisciplinary teams and challenges to developing interdisciplinary relationships is necessary to reduce obstacles facing companies. Research and the development of processes to encourage interdisciplinary interaction can support the development of sophisticated wearable products that serve the wearer in ways that improve protection, safety, health, and enable everyday functional well-being.

An examination of the interdisciplinary material, technology, and design development in different wearable product industry segments, such as medical wearables, sportswear, or the personal protection industry, can lead to insights into the development process and broader applications of the research. Case study research in the different product segments can enable analysis of the interdisciplinary product development process and then can be compared and contrasted to determine best practices in interdisciplinary wearable product development.

Wearable products being developed for the medical and protective industries are heavily regulated by both industry and government. The development of the cool tent demonstrated the need to include the government as a stakeholder early in the development process to create a product that fulfilled both their strict requirements and needs. Often, it takes years for products to be approved for medical application.

Research examining products that were developed collaboratively with government and regulating entities for healthcare or industrial applications could provide insight into best practices and reduce time to market.

The extent to which interdisciplinary product development is occurring in the wearable product industry is unknown. How many wearable products are being produced in an interdisciplinary manner each year? What disciplines are involved in the product development process? Survey methods, with questions developed from case study research, can help gain insight into the changes occurring in wearable product development and can lead to a deeper understanding of the types of products being produced using interdisciplinary teams.

Finally, an examination of interdisciplinary product development across industries would lead to a broader understanding of interdisciplinary collaboration. LaBat and Sokolowski (1999) found that there were common elements in the design process across disciplines. Examining the interdisciplinary development of hard goods versus soft goods across an array of industries could provide a wealth of knowledge and possible common elements across the broad spectrum of interdisciplinary product development.

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APPENDIX A: INTERVIEW QUESTIONS

1. In what way do designers and material developers work together during the development of new products?
    a. What is the current interaction?
    b. Has this interaction changed over time?
    c. At what stage of the design process do they collaborate?
    d. Are there instances where the material and the design are developed simultaneously?
2. How does an interdisciplinary approach to design and material development impact the way in which product development is conducted (i.e. the processes used? Manufacturing and production? Etc.)
3. In what way does an interdisciplinary process of design and material development lead to the creation of innovative products?

The following includes the proposed focus group interview questions:

- How did the idea for this start?
- At what point did you (the designer/team and the material developer/team) start working together?
    - What prompted this relationship?
- Did you both play a role in developing product requirements or were those developed prior to your collaboration?

    - -Did each team/person have product requirements related to their specific role? i.e. did the material developer develop requirements for the material and the designer develop requirements for the basic design?
- How did you collaborate throughout this process? Was your collaboration more or less active during specific periods of the project?
- Was the material or product design developed first? Or were they developed simultaneously?
- Did you have to change some of your typical methods of working through the development of a product order to accommodate working together?
- Did you feel as if one team led the other, or were your roles equal?
- Is it common for you to develop products/materials together, or do you typically work separately?
    - Have your methods changed over time?
    - If there has been a change, what do you think facilitated the change?
- Do certain aspects of product development have to change in order for you to develop products together?
    - Manufacturing/production?
    - The process itself?
- Do you think your collaboration helped improve the end product?
- What challenges did you experience during this collaboration?
- Are there any changes that you will make to how you collaborate on future projects?

- Are there any other colleagues who were particularly supportive throughout the project?
- How did management support this project and your ability to work together?
    - Was funding difficult to acquire?
    - Was project approval difficult or easy?
    - Was it difficult to work out Intellectual Property agreements between yourselves or your organizations?

APPENDIX B: SAMPLE INTERVIEW QUESTIONS FOR SUPPLEMENTARY INTERVIEWS

The following are sample interview questions for supplementary interviews:

- What was your role in this project?
- What were your contributions?
- Did your typical product development process change due to the designers and material developers working together?
- Do certain aspects of product development have to change in order for you to develop products together?
    - Manufacturing/production?
    - The process itself?
- Do you think your collaboration helped improve the end product?
- What challenges did you experience during this collaboration?