Design & Analysis of a 21st Century, Scalable,

Student-Centric Model of Innovation at the Collegiate Level

by

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A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Approved November 2020 by the
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ARIZONA STATE UNIVERSITY

December 2020

ABSTRACT

The Luminosity Lab, located at Arizona State University, is a prototype for a novel model of interdisciplinary, student-led innovation. The model's design was informed by the following desired outcomes: i) the model would be well-suited for the 21st century, ii) it would attract, motivate, and retain the university's strongest student talent, iii) it would operate without the oversight of faculty, and iv) it would work towards the conceptualization, design, development, and deployment of solutions that would positively impact society. This model of interdisciplinary research was tested at Arizona State University across four academic years with participation of over 200 students, who represented more than 20 academic disciplines. The results have shown successful integration of interdisciplinary expertise to identify unmet needs, design innovative concepts, and develop research-informed solutions.

This dissertation analyzes Luminosity's model to determine the following: i) Can a collegiate, student-driven interdisciplinary model of innovation designed for the 21st century perform without faculty management? ii) What are the motivators and culture that enable student success within this model? and iii) How does Luminosity differ from traditional research opportunities and learning experiences?

Through a qualitative, grounded theory analysis, this dissertation examines the phenomena of the students engaging in Luminosity's model, who have demonstrated their ability to serve as the principal investigators and innovators in conducting substantial discovery, research, and innovation work through full project life cycles. This study supports a theory that highly talented students often feel limited by the pace and scope of their college educations, and yearn for experiences that motivate them with

agency, achievement, mastery, affinity for colleagues, and a desire to impact society. Through the cumulative effect of these motivators and an organizational design that facilitates a bottom-up approach to student-driven innovation, Luminosity has established itself as a novel model of research and development in the collegiate space.

DEDICATION

To my loving wife, Lauren, who inspired me to begin this pursuit and never stopped believing in me. This work would not have been possible without you.

To my parents, who have sacrificed throughout their life to support me. I will forever be grateful for your love and encouragement.

To the students of Luminosity, the most kind and talented group of individuals that I have known, this work is dedicated in honor of your selfless efforts to change the world for the better.

ACKNOWLEDGEMENTS

I would like to acknowledge Arizona State University for the countless opportunities it has provided me throughout my academic journey. Thank you to my committee chair, Dr. Vaughn Becker, and my committee members, Dr. Derrick Anderson and Dr. Nancy Cooke. Your support was instrumental in the completion of my dissertation research. Thank you to Dr. Michael Crow and Dr. Sethuraman Panchanathan, who gave me an opportunity to pursue a mission that very few others would have believed in. I will always be grateful for your guidance and trust.

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CHAPTER 1

INTRODUCTION

Innovation, defined by the transformation of ideas into services, solutions, and products (Baregheh et al., 2009), is at the heart of the human condition. Society has survived the world's challenging environment through the discovery, use, and dissemination of knowledge and tools (Boyd & Richerson, 1988). This pattern is observable throughout history, and is no different today, except that the challenges facing society are mounting in quantity and becoming more complex (Homer-Dixon, 2011). These challenges demand more advanced and innovative solutions, and thus new systems of human education and ingenuity are needed to adequately address the problems of the 21st century.

It is often assumed, and with good reason, that the world's research universities and institutions of higher education are leading the charge to innovate and address society's most pressing challenges. However, the design of these institutions may not be fully sufficient in meeting all the challenges to satisfy this expectation. The modern university is a descendant of the early medieval universities (Vauchez & Pedersen, 1997), which becomes evident each year when an institution's faculty gather to confer degrees in robes and antiquated hats - a traditional remnant of the past. Although much has changed over the centuries, many features of the medieval model have been retained (Scott, 2006). At their core, universities are legal entities that confer degrees, produce knowledge, and oversee curricula, examinations, and commencements (Haskins, 1927). Furthermore, today's universities continue to revolve around a faculty-centric system, which originated in the northern medieval universities (Cardozier, 1968). The faculty-centric culture of today's university research structure stems from its medieval roots and was likely inspired by the popular apprenticeship model of the time. In this model, faculty serve as the masters of knowledge and lead 'students apprentices', whether it is within the context of research labs or the committee oversight of doctoral candidates. Faculty are given the authority to oversee the direction of research and innovation. However, the faculty-centric model has not always been the sole management structure implemented within universities. The southern medieval universities during the 13th century, inspired by the University of Bologna, allowed their institutions to be fully controlled by the students (Cardozier, 1968). At Bologna, students established the rules and regulations that applied to themselves, as well as the faculty, servants, and landlords of the University (Cardozier, 1968). By 1500, this student governance model was replaced in favor of faculty driven institutions (Scott, 2006).

It is not yet well understood if the current top-down faculty approach to educating, researching, and innovating are effective at motivating all students within this generation. The current generation of college-aged students have grown up in a world where learning has become more democratized through the use of technology (Bullock & de Jong, 2014; Dankbaar & de Jong, 2014; Rosenberg & Foshay, 2002). High-quality educational content is prevalent throughout the internet, is commonly free of charge, and provides educational learning opportunities that can extend beyond what is available at a single university. For example, students can take M.I.T. courses online for free (Abelson, 2008). This adaption of technology suggests that students may become less reliant on traditional learning modalities – especially within specific populations, such as self-driven, exceptionally talented, and highly motivated students.

The possibility exists that the faculty-centric model of university research is limiting students' ability to engage in the full process of innovation. This may be an unintended consequence of the organizational design of universities, in which faculty are incentivized to pursue grant funding and peer-reviewed publications. In many research opportunities, faculty are the primary investigators and students play a supporting role. Often the pursuit of grant opportunities can run counter to innovation in that they can be pre-defined, narrow in scope, and may not allow for open-ended innovation. In cases where grant opportunities are applied, or innovative in nature, students, especially undergraduates, are rarely given the responsibility to lead these efforts. Within the diversity of collegiate students, both at the graduate and undergraduate level, it is fair to assume that there are high-performing students capable of conducting substantial research and development work. If this assumption holds, universities are missing an opportunity to utilize their students to produce innovative solutions to address 21st century challenges. Thus, today's universities may benefit from new organizational models that are effective in motivating and leveraging high-performing students in the full lifecycle of discovery and innovation.

The Luminosity Lab, at Arizona State University, is a prototype for a new model of collaborative, student-driven interdisciplinary research teams. Within Luminosity, exceptional students are hand-selected from all areas of the university and brought together to fuse youthful spirit, academic prowess, and business acumen. These students work together to produce system-level projects that are capable of having large-scale societal impact. Building upon concepts from systems engineering, the lab employs the use of a view model to analyze current and future systems from various viewpoints (i.e. enterprise, functional, computational, engineering, technology, services, standards, etc.). By leveraging the strengths of systems thinking, strategic design, and agile methodologies, the interdisciplinary team is positioned to tackle systemic challenges in domains; such as, healthcare, energy, education, and global climate. This model of interdisciplinary research has been piloted and tested at Arizona State University with participation from over 200 students, representing more than 20 academic disciplines, across 4 academic years. The results have shown successful integration of interdisciplinary expertise to identify unmet needs, design innovative concepts, and develop tangible, research-informed solutions without the involvement of faculty.

Luminosity's model has been greatly influenced and designed around the organizational concepts of 'Great Groups' and 'Skunk Works'. Ben Rich, the longtime leader of Lockheed Martin's Skunk Works believed that, "A successful Skunk Works will always demand a strong leader and a work environment dominated by highly motivated employees… Given those two key ingredients, the Skunk Works will endure and remain unrivaled for advancing future technology (Rich & Janos, 2013)". This dissertation explores The Luminosity Lab through a proof of concept and qualitative analysis to discover: i) Can a collegiate, student-driven interdisciplinary model of innovation designed for the 21st century perform without faculty management? ii) What are the motivators and culture that enable student success within this model, and ii) How does Luminosity differ from traditional research opportunities and learning experiences?

CHAPTER 2

LITERATURE REVIEW

Introduction

Despite being closely related, notable differences demarcate the concepts of research and innovation. University research is a formal, standardized approach to yielding generalizable results or internal validity, in which the study may or may not benefit the subject (Morreim, 2005). Research relies on the scientific method to pose questions and conduct studies to test formal hypotheses, with the primary intent of generating contributions to the body of scientific knowledge. Unlike research, innovation lacks a formal and agreed upon definition - carrying many meanings within the contexts of industry, government, and education (Faunce, 2012). Baregheh et al. (2009), through a review of literature and content analysis, provide an integrative definition of innovation. Their analysis concludes that innovation is “the multi-stage process whereby organizations transform ideas into new and or improved products, services or processes, in order to advance, compete and differentiate themselves successfully in their marketplace (Baregheh et al., 2009).” Although the results of basic research may lead to, or inform the development of a tool, product, or service that will benefit society, the aim is often the journey itself and the discovery of new information first and foremost. Alternatively, innovation and applied research maintain a clear focus on producing a deployable service or product that will benefit an organization or group of individuals. Whereas research seeks novel findings, this is not always the case with innovation.

Innovation can simply be the integration of existing tools and information to develop something that will provide value.

Given these definitions, this study seeks to understand a collegiate model of innovation rather than basic research, and aims to explore the processes, designs, and motivations that help to cultivate successful organizations that produce innovation. Historically, innovation has played a different role in industry than it has in institutions of higher education. Within corporate environments, innovation is considered essential to providing the competitive advantage needed for the company to grow and survive (Zahra & Covin, 1994). Internally, both entities have inherent incentives to innovate to better their operations, processes, and competitive advantage. Thus, an important distinction between academia and industry is that innovations are often the work outcome of industry which lead to marketable, profit-generating services or products. Universities, especially research-universities, do not have the same desired outcome, rather the focus of universities is primarily to generate two things: educated students and new knowledge through research and publications (Chan, 2016; American Council on Education, 1949).

Industrial environments have been home to much of the early and ongoing research around the motivation of employees. Motivation is regarded by many scholars as the most critical factor in influencing the success of individuals and organizations (Appleby, 2013; Grammatikopoulous et al., 2013) and a breadth of studies on motivation exist due to its potential benefits within the education system and the workplace (Keleş, 2010). As a result of its utility to various fields of importance, there exists a large diversity of definitions and explanations for motivation (Çeliköz, 2010). A definition well suited for the purpose of this review is an old one provided in 1976 by Lyle Yorks who described motivation as, “those forces within an individual that push or propel him to satisfy basic needs or wants” (Yorks, 1976). Management theorists spearheaded the early studies on motivation, attempting to present a universal model of motivation (Mawoli and Babandako, 2011).

Review of Motivational Theories

Process-Based Theories. Frederick Taylor, a pioneer in Scientific Management, believed that work consists of many non-interesting tasks, and that incentives were the primary factor in motivating workers (Taylor, 1914). Taylor promoted a concept, commonly referred to as the stick-carrot approach. Taylor believed that motivated workers should be given an incentive for conducting work (the carrot), and that penalties should be imposed on workers who underperformed on their work (the stick) (Taylor, 1914). Taylor’s notions around Scientific Management were rather simplistic (Katzell, 1990), and treatment of humans was regarded rather impersonally, with humans in the workforce being viewed similarly to components of a machine.

Bearing similarities to the stick-carrot approach, is Skinner’s 1953 Reinforcement theory. B.F Skinner, a pioneer of Behaviorism, promoted one of the earlier theories of motivation through his thoughts on reinforcement (Skinner, 1953). His theory stated that positive behaviors leading to positive outcomes are repeated and those leading to negative outcomes are not repeated (Skinner, 1953). Thus, from the viewpoint of workplace motivation, employee behaviors that are positive should be rewarded through positive reinforcement and negative behaviors should be negatively reinforced.

Vroom’s Expectancy Theory (ET) was another model dealing with human motivation (Vroom, 1964). The theory assumes that human behavior stems from conscious decisions and that humans act in a hedonistic way, making choices is to maximize pleasure and minimize pain (Vroom, 1964). ET as defined by Vroom in 1964 was later expanded upon by Porter and Lawler (1968) and others (Pinder, 2014). ET proposes that an individual is motivated to the degree that they believe that "(a) effort will lead to acceptable performance (expectancy), (b) performance will be rewarded (instrumentality), and (c) the value of the rewards is highly positive (valence)" (Lunenburg, 2011). Although ET shares similarity to Taylor's notion of 'strong performance leads to strong rewards', it differs from other motivation models in that it is a process theory, comprised of various cognitive factors that represent differences in motivation between individuals (Lunenburg, 2011; Suciu et al., 2013).

A more human-centered approach was achieved in the 1920's through the Hawthorne Studies. The Hawthorne Studies were a series of studies conducted at the Hawthorne plant of the Western Electric Company by Elton Mayo. Mayo was the pioneer of the Human Relations school of thought, in which the underlying ideology was that workers should be listened to, treated with respect, and seen as worthy contributors. The studies, conducted by Mayo, isolated women employees into separate groups and analyzed their productivity levels relative to changing factors such as lighting and working conditions (Sandhya & Kumar, 2011). The study concluded that workers could be motivated by improved communication with employers and by having their needs met at work (Sandhya & Kumar, 2011;). This budding theory, centered upon understanding and satisfying employees needs to motivate them, was a pivotal moment in motivation theory and led to many emerging theories around need (Fallatah & Syed, 2018).

Need-Based Theories. Frederick Herzberg promoted a theory known as motivation-hygiene theory in which motivation was broken out into two factors: motivators and hygienes (Herzberg et al., 1957). Motivators, also known as satisfiers, were factors such as achievements, recognition of achievements, and sometimes the job itself that motivated the employee (Fallatah & Syed, 2018). Counter to this were hygiene factors or dissatisfiers, which demotivated employees and included poor working conditions and environments (Miner, 2005). Herzberg, Mausner, Peterson, and Capwell (1957), derived this theory upon reviewing over 2000 job satisfaction studies and observing that variables leading to satisfaction differed from those contributing to dissatisfaction (Sachau, 2007). Herzberg's theory challenged the existing and basic assumptions about what satisfied and motivated employees (Sachau, 2007).

McClelland's thoughts on Human Motivation were originally specified in his 1961 book, The Achieving Society. Known as the Principal Theory of Motivation, McClelland believed that there were three primary needs that fuel human motivation: needs for achievement, needs for power, and needs for affiliation (McClelland, 1961). The need for achievement represents individuals who strive for accomplishment, are driven to excel and succeed, and who enjoy receiving feedback (McClelland, 1961; Ramlall, 2004). The need for affiliation reflects those who desire to be close with others and who make effort to develop friendships and maintain associations and interpersonal relationships. (Smits et al., 1993). The need for power represents those who enjoy control over their environment and having influence on others; these individuals yearn for leadership roles (Moorhead & Griffin, 1989).

Clayton Alderfer proposed a theory of motivation composed of three needs: existence, relatedness, and growth (ERG; Alderfer, 1969). The existence needs are concerned with the basic human requirements such as water, food, pay, and working conditions (Alderfer, 1969). Relatedness needs involve relationships with others such as family, co-workers, friends, and enemies, and can be satisfied through inter-relational sharing of thoughts and feelings (Alderfer, 1969). Growth needs represent one's desire for self-development and self-improvement. Alderfer proposed his theory as a direct alternative to Maslow's Hierarchy of Needs and through empirical analysis contended that there was more support for his theory than Maslow's (Alderfer, 1969).

In 1943, Abraham Maslow published, "A Theory of Human Motivation", a paper which outlines what is popularly known as Maslow's Hierarchy of Needs (Maslow, 1943). Maslow proposed five basic human needs in an order of importance. Starting with Maslow's most fundamental need and proceeding in order, the needs outlined in 1943 are: Physiological, Safety, Love, Esteem, and Self-Actualization. Physiological needs, which are the most basic needs that need to be satisfied before any other needs can be adequately met, are needs such as food, water, shelter, and sleep. Safety needs include financial security, health, wellbeing, personal security, and emotional security. Love needs relate to human needs to belong, and includes friendships, intimate relationships, and family. Maslow breaks the need of Esteem into two versions, one relating to a respect from others, and the other relating to self-respect. The final need, Self-Actualization, relates to the recognition and realization of one's full potential. Maslow believed that all other motives needed to be mastered prior to Self-Actualization, and therefore, Self-Actualization can be viewed as the penultimate goal to be desired and sought after.

In 1954 Maslow extended his model to include two additional needs: Cognitive Needs and Aesthetic Needs (Maslow, 1954). The cognitive needs represent one's need for curiosity and understanding, and relate closest to an individual's attainment of knowledge, whereas the aesthetic needs are concerned with human need for beauty and symmetry. Maslow acknowledged that inclusion of aesthetics was uncomfortable to the scientific world, yet he believed it was difficult to ignore, and posed the question, "What, for instance, does it mean when a man feels a strong conscious impulse to straighten the crookedly hung picture on the wall" (Maslow, 1954, p. 51).

Later in his life, Maslow's writings began to include an additional need he referred to as self-transcendence and considered this need to extend beyond self-actualization within his hierarchy (Maslow, 1969; Koltko-Rivera, 2006). Self-transcendence is representative of an individual who puts individual needs aside and who strives to pursue a cause beyond the self and to surpass the boundaries of the self through 'peak experience' (Koltko-Rivera, 2006). Although Maslow postulated additional considerations to his five-need model, such as those stated above, his model is commonly reflected as his conventional five need hierarchy from 1954. Although there are some who believe Maslow's hierarchy should be updated to reflect his later thoughts (Koltko-Rivera, 2006), others concluded that Maslow never finalized a coherent theory of self-actualization, nor did he integrate the concept of self-actualization in a meaningful way with self-transcendence (Daniels, 1982).

Maslow's Hierarchy of Needs has been the subject of much criticism and a common line of critiques focus on Maslow's concepts of deprivation/domination, gratification/activation, and self-actualization (Fallatah & Syed, 2018; Wahba and Bridwell, 1976).

Deprivation/domination refers to Maslow's notion that a deprivation in a certain need would lead to a greater desire for that need, and that deficient needs would develop dominance. Ten studies that were conducted between the years 1961 and 1973 tested the deprivation/domination proposition and a) found partial support when self-actualization was the primary need level, and b) found no support for the proposition when applied to social, esteem, and security needs (Wahba & Bridwell, 1976; Berl et al., 1984).

Closely related to deprivation/domination is Maslow's proposition of gratification/activation which suggests that when a need is satisfied, it activates the next higher-level need. This proposition was analyzed from two separate viewpoints. In the first, the proposition was operationalized as: while a need achieves higher levels of satisfaction, the importance of that need is lowered and the importance of the next level of need increases. A study conducted on this viewpoint was inconclusive, with some studies finding no correlation between satisfaction of a need and the importance of the next level of need (Berl et al., 1984). However, two separate studies that were each conducted twice and one year apart both rejected the gratification/activation proposition (Wahba and Bridwell, 1976). The first of these studies, Hall and Nougaim (1968) interviewed 49 AT&T managers, and similarly, Lawler and Suttle (1972) conducted the second study by soliciting information from 187 lower level managers. In the second viewpoint of gratification/activation, the proposition is operationalized as: average satisfaction levels of needs should generally decrease as they move up through Maslow's Hierarchy of Needs. Twenty-three studies conducted between 1962 and 1973 concluded that self-actualization and security were, on average, the lowest satisfied needs, and the that social needs had the highest levels of satisfaction; furthermore, no pattern was found among the remaining needs (Berl et al., 1984). Thus, the findings were counter to Maslow's proposition of gratification/activation, however Wahba and Birdwell (1976) cautioned that the study of the proposition operationalized in this manner is not a true test of Maslow's theory.

Lastly, a common line of criticism involves Maslow's thoughts on Self-Actualization. Confusion around self-actualization stem from Maslow's pragmatic remarks that most normal people have needs that are partially satisfied and partially unsatisfied, and that a more realistic approach would be to track percentages of satisfaction across the hierarchy (Maslow et al., 1970). This notion casted doubts on the concept of self-actualization, with confusion around attaining a percentage of self-actualization and other preceding needs, when these needs were supposed to be fully met before self-actualization can be achieved. The confusion stemming from Maslow's own statements led to beliefs that the concept was poorly defined and based on 'wishful thinking' (Fallatah & Syed, 2018). Maslow is further criticized for his lack of scientific approach in formulating his concept of self-actualization (Littrell, 2011; Neher, 1991; Wahba and Bridwell, 1976). When formulating the concept of self-actualization, Maslow highlighted highly successful individuals such as Abraham Lincoln and Albert Einstein, and these predetermined selections contained bias and a low sample size (Littrell, 2011; Neher, 1991). Cultural concerns exist due to Maslow's placement of Self-Actualization at the top of his hierarchy, as it is indicative of an individualist culture; which may resonate with citizens of countries such as the United States, but likely not within cultures that prioritize collectivism (Hofstede, 1984). However, this line of critique was somewhat alleviated with Maslow's late thoughts on self-transcendence, in which individuals extend beyond the needs of the self.

Cognitive Theories. There are many cognitive theories that complement and enhance the understanding of motivation. Motivation is believed to be aided by a strong sense of self-efficacy (Bandura, 1997). Bandura (1997) describes self-efficacy as an individual's perceived abilities to set and achieve desired goals. Self-efficacy helps individuals maintain control over their motivations and is believed to be strengthened through inspiration from social models, mastery of experiences, social persuasion, and the reduction of stress reactions and negative emotional proclivities (Bandura, 1997). Building on Bandura's work, Zimmerman (2000) introduces the similar, yet distinct construct of self-regulation (Schunk & Zimmerman, 2007). Self-Regulation is defined as the self-generation of an individual's thoughts, feelings, and actions, which are adapted to the attainment of the individual's desired goals (Zimmerman, 2000). Thus, self-efficacy represents an individual's belief in attaining their goals, while self-regulation represents an individual's strategy for achieving these goals.

Goal-Setting Theory provides support for increased motivation through the setting of goals and suggests that specific and stimulating goals can help to motivate an individual toward the achievement of their goals (Locke, 1968). An energizing function was identified that found that higher goals often leads to greater invested effort (Locke & Latham, 2002). Therefore, goal setting can influence task performance and is an important factor in promoting motivation.

Weiner's Attribution Theory focuses on three aspects, in which behavior is observed, is attributed to internal and external causes, and is determined to be deliberate (Weiner, 1985). In this model, achievement is attributed to effort, ability, task level, and luck (Weiner, 1985). Weiner's work, which focuses on learners, outlines how learners form causal beliefs and holds that learners are affected by their external environment. Weiner defines three dimensions of behavior, which are locus of control, stability, and controllability (Weiner, 1985). The locus dimension relates to whether the cause of the event is perceived by the individual as an external or internal cause. The stability dimension relates to whether the cause of the event is stable across time. Lastly, the controllability dimension relates to whether the cause of the event is perceived by the individual to be within their control.

Cognitive Evaluation Theory outlines two systems of motivation, one that is intrinsic and one that is extrinsic (Deci & Ryan, 1985). Extrinsic motivators refer to external rewards coming from the environment, such as promotions, pay, or feedback. Intrinsic motivators refer to internal motives such as a sense of achievement, purpose, and competence, which can lead an individual to fulfilling their inner potential (Deci & Ryan, 1985).

Motivation 3.0. The early models of needs and motives focused more on the extrinsic motivation of manual workers, especially those within a manufacturing context. Coined by Daniel Pink (2011), Motivation 3.0 promotes intrinsic needs over extrinsic ones, and views intrinsic motivation as more relevant to knowledge works and work environments focused on innovation and discovery. Peter Drucker, the father of modern management, claimed that the most important task of management for the 21st century would be to increase the productivity of knowledge workers, and that these knowledge workers, if productive, would be the most essential asset of a business or non-business entity of the 21st century (Drucker, 1999). A 2011 study found that the top five motivating factors for knowledge workers were: meaningful work, belief in mission, public service, opportunity to advance, and relationship with coworkers (Frick, 2011).

Daniel Pink (2011) countered decades of science findings in motivation by claiming that motivation comes from internal factors rather than external ones. Pink claims that the three elements of true motivation are autonomy, mastery, and purpose, and explains how each can be used for perpetual motivation (Pink, 2011). Autonomy is described as the freedom individuals have in choosing what they work on and who they work with. Mastery refers to the drive of improving at something important to the individual. Purpose is an individual's drive to produce or work towards something bigger than themself.

Pink was not alone in highlighting a theory of intrinsic motivations. For example, Self-Determination Theory had been previously introduced, which established three human needs of competence, relatedness, and autonomy (Deci & Ryan, 2000). These needs break down to innate needs of being able to achieve things, the freedom to pursue things, and the need to relate to other individuals. Certain organizational constructs have been successful in leveraging intrinsic factors of motivations to create dynamic, cohesive, and unique cultures that are favorable to inspiring knowledge workers to perform and innovate.

Influential Models of Innovation

Great Groups. A model that has been conducive to innovation in business, government, and academic environments, albeit more abstract, is the concept of "Great Groups". The concept of Great Groups is reviewed from the viewpoint of Warren Bennis, a pioneer of Leadership Studies. Bennis identified and systematically reviewed seven groups deemed to be 'Great Groups": Walt Disney Studios in 1973, Xerox's Palo Alto Research Center (PARC), Steve Jobs and the engineers who created the Macintosh, the 1991 Bill Clinton Campaign, Lockheed Martin's Skunk Works, Black Mountain College, and the Manhattan Project (Bennis & Biederman, 1997). These groups are similar in that they were all made up of incredibly talented individuals, produced something radically novel, and were largely influential to society (Bennis & Biederman, 1997). The analysis of these groups produced take-home lessons which apply to great groups of all types (Bennis & Biederman, 1997): Great groups are composed of greatly talented people who work together cohesively. Great Groups need a strong leader who loves talent and knows where to find it. Those within Great Groups believe they are called to a mission to achieve something vital. Great groups are often isolated from the world around them, build their own cultures, and have a lot of fun pursuing their work. Great Groups believe that they can achieve the impossible and are more optimistic than realistic. Leaders of great groups provide what is needed and keep their groups away from bureaucracy. Lastly, Great Groups are places of action that make and ship solutions, rather than exist as think tanks that only seek to generate ideas (Bennis & Biederman, 1997).

Skunk Works. One archetype example of a great group is Lockheed Martin's Skunk Works, which was designed to avoid the bureaucracy that often exists within an organization and impedes innovation (Thompson, 1965). During World War II, the group emerged and demonstrated a model for how radical innovation could be conducted within a bureaucratic organization. At its founding, Skunk Works was ‘a small and intensely cohesive group’ consisting of around 50 engineers and 100 machine-shop workers, tasked with developing advanced aircraft that would carry out secret missions (Rich & Janos, 2013). With an urgency to develop innovative warplanes on time and under budget, Kelly Johnson - of Lockheed Martin - successfully lobbied the company’s executives to establish what would become ‘the Skunkworks’ (Bennis & Biederman, 1997). Johnson was granted the authority to establish a hand-selected team of highly talented individuals who would operate in secret and be free from all bureaucratic influence of Lockheed Martin and government agencies. During the fifty years of cold war, Skunkworks managed to create over a half dozen breakthroughs in military aircraft or weapons systems that influenced the strategic balance of world powers for years, as enemies of the United States were unable to counter or duplicate the technologies that were created (Rich & Janos, 2013).

In 2013, around 55 Skunk Works models were operationalized within various industries. Ben Rich, of Lockheed’s Skunk Works, questioned why this number was so small given the unquestionable success of the model. He suspected that, “...companies don't really understand the concept or its scope and limitations, whereas others loath to grant the freedom and independence from management control that really are necessary ingredients for running a successful Skunk Works enterprise (Rich & Janos, 2013)”.

Although Skunk Works models have been replicated often within industry settings, they were less commonly found in academic settings until recently. In 2015, the National Science Foundation (NSF) awarded six universities with a total of $12 million to engineering and computer science departments to help bring about "groundbreaking, scalable and sustainable changes in undergraduate education." Through this initiative, Purdue University was tasked with developing a Skunk Works concept within the context of mechanical engineering that enlisted 15 students to aid faculty in the endeavor ("NSF awards $12 million", 2015). It is unclear what the outcome of this initiative has been, however, Purdue's Skunk Works appears to focus primarily on revolutionizing the pedagogical approach to teaching mechanical engineering, rather than cultivating a group of individuals to rapidly produce radical innovation as intended by a Skunk Works design.

University Models of Innovation. Outside of Skunk Works inspired concepts, a review of the literature shows that Universities have produced many models to spur innovation. Many universities offer entrepreneurship and innovation programs, for example: Harvard University (iLab and Launch Lab), Babson College (Arthur Blank Center for Entrepreneurship and First-Year Innovation Center), University of Utah's Lassonde Studios, UNC at Chapel Hill (Launch Chapel Hill and 1789 Venture Lab), and Arizona State University's student-led Changemaker Central spaces (on each campus), an Entrepreneurship+Innovation HEALab (health innovation), an Innovation Hub (ideation and prototyping), MKR services (maker-space and services) and a New Media Innovation and Entrepreneurship Lab (focused on collaboration between journalism, computer engineering, design and business students). Although these programs offer many opportunities to university students, the primary focus for most of these programs is on entrepreneurship. These programs exist to mentor students who desire to start their own companies and provide these students with opportunities to compete for start-up funding.

Some of these entities offer prototyping capabilities, however, in most of the stated cases these efforts are minimal. Though these programs are valuable to students, they are more likely to educate students on how to run corporate R&D departments, than they are to teach students the technical steps of developing their own R&D (Rideout & Gray, 2013).

Living Labs are a model that exist within universities and have been shown to produce innovative results within the right operating conditions. Living Labs are open innovation ecosystems that exist in real-world environments, in which innovation is open and integrated in the co-design of new services, products, and technologies (Bertolin, 2017). Living labs promote experiential learning through iterative and continuous development of prototypes and operate in environments in which the aim is to benefit the socio-economic aspects of their surrounding community (Bertolin, 2017). Living Labs do well within university environments, as universities emulate cities and constantly promote interactions between students, researchers and staff. In fact, the initial concept of Living Labs was conceptualized within a university environment by William J Mitchell of the MIT Media Labs in 1990 (Bertolin, 2017). The MIT Media Lab is not only an effective archetype of a Living Lab but is also most closely aligned with the mission and design of Arizona State University's Luminosity Lab (see Appendix A). The Media Lab conducts research in a collaborative and anti-disciplinary environment. The Media Lab is a proven model of both interdisciplinary research and innovation (Brand, S., & Crandall, 1988), however does not provide a model that is simple to scale. The Media Lab operates on an annual budget of around $80 million dollars, which supports hundreds of faculties, post docs, staff, and students. Although this success is to be desired, it is a model that is out of reach for most institutions to emulate. Furthermore, the underlying factors that contribute to the success of the Media Lab are not well understood or adequately researched, with only one personal review of the lab existing in the literature (Haase, 2000).

Conclusion

This review of literature shows a shift in theories of motivation over the years. In recent years, motivation work has seen an uptick in the exploration of motives for high-performing knowledge workers. Most importantly, the shift has seen an emphasis in internal over external factors of motivation. Exploring collegiate models of innovation, there are deficiencies in models which facilitate the full project life cycle of research & development. The literature finds an even greater deficiency in research labs that are primarily student driven. For the few exemplars, such as the MIT Media Lab - which has demonstrated its ability to leverage students effectively in producing innovations, their models are difficult to scale and replicate. Thus, there remains a need for a scalable, student-centric innovation lab that benefits from the best practices of Skunk Works, Great Groups, and motivation theory.

CHAPTER 3

THE LUMINOSITY LAB—AN INTERDISCIPLINARY MODEL OF DISCOVERY AND INNOVATION FOR THE 21ST CENTURY

Origins

Conceived over a lunch conversation in a burger joint, the concept of The Luminosity Lab was first proposed by Arizona State University's (ASU) president, Dr. Michael Crow, and executive vice president of research, Dr. Sethuraman Panchanathan. They desired a new model of discovery and innovation for the 21st century—an interdisciplinary model driven by students who would strive for moonshot ideas capable of impacting society. It would be Arizona State University's rendition of a 'Skunkworks' lab, where the students would be shielded from organizational bureaucracy and given the agency and resources to innovate.

I set off to launch this initiative at the age of 24. As the lab's director, I was naïve about the typical operations of a research institution, yet eager to deploy new ideas and untraditional methodologies. Within two months, the lab was established with a diverse group of 15 influential students hailing from a wide range of academic backgrounds. Fast forward three years, and there are now over 100 students involved in the program, 50 of whom are funded, with the remaining students serving as volunteers or receiving academic credit. These students come together and fuse their diverse skill sets to tackle large-scale, socio-technical development projects in topic areas such as healthcare, education, energy, and sustainability. The lab maintains a portfolio of over 20 projects of varying complexity and scope. Each of the lab's projects focus on synthesizing human-centric design with emerging technologies to produce impactful and resilient solutions. Students are responsible for determining which initiatives to pursue, and all projects are led by interdisciplinary teams of students from start to finish.

The lab is now focused on expanding its model and will soon launch its fourth location. Most recently, a Luminosity Lab in Washington, DC, was established with a focus on sustainability, public policy, and international development. The students in DC are helping to expand Luminosity's network and are cultivating relationships with federally funded agencies, such as the United States Agency for International Development and the National Science Foundation. Luminosity intends to establish labs throughout the world, with the aspiration to create a network of students working collectively to solve global challenges.

The main question at the onset of designing The Luminosity Lab was whether this model would work. Could students, without faculty involvement, be self-sufficient in successfully moving projects through their life cycles? The lab's success has demonstrated that the model can work in the right conditions and is primed for scaling. This article discusses the critical components of the lab's design in order to provide insights into how similar models can be achieved and is interlaced with project vignettes that elucidate our approach.

Interdisciplinary by Design

The interdisciplinary nature of The Luminosity Lab is a critical component to its success, and the lab was intentionally designed up front to promote multidisciplinary work. The organizational positioning of the lab within the university was paramount to achieving this design aspiration. The lab benefits from operating within ASU's

Knowledge Enterprise, which is the department that oversees all research, innovation, and entrepreneurship activities at the university. This is important when contrasted with traditional structures. University research labs commonly reside within their respective academic colleges. This positioning is not optimized to promote interdisciplinary work, with each lab inherently accountable to its academic unit and ultimately sympathetic to its overall objectives. While interdisciplinary work exists in this structure, often it amounts to two labs from different fields meeting periodically to have discussions, share findings, and/or temporarily exchange researchers. This approach can be effective, but it limits the potential impact of interdisciplinary research.

Being decoupled from the traditional structure of research labs, Luminosity operationalizes a new kind of interdisciplinary approach—where students from various disciplines are integrated from the start, with no predetermined research focus apart from solving problems and generating value. In this model, students do not feel like they are visiting or being embedded in an alternative field. The nature of the work conducted by the lab demands a variety of skills that a single domain could never provide. As students engage in projects throughout their lifecycles, they are required to work with their colleagues and leverage their talents to address each aspect of a project. If a gap in capabilities is identified, the students utilize the network of the university to recruit and onboard additional students to address the need.

The lab is an eclectic mix of students studying subjects such as design, engineering, law, business, computer science, biology, chemistry, sustainability, public policy, nursing, human factors, psychology, journalism, and architecture. While the lab employs the talents of students from all academic backgrounds, effort is made to intentionally maintain a core competency of specific skills that are critical to conducting innovative development work. These core skills are design, research, physical prototyping, software development, and analytics. These skills complement the academic backgrounds of the students and help to provide a foundation of tools that are conducive to tackling 21st century challenges.

Our Approach

Luminosity utilizes a systems engineering approach to project planning and design, and drives projects forward with an agile methodology that allows the organization to quickly handle and adapt to change. The Luminosity Lab prides itself on systems thinking, strategic design, and rapid product realization. These approaches complement Luminosity's core ideologies and are defined as follows.

Systems Thinking. Luminosity utilizes systems thinking (Checkland, 1999) as a comprehensive and holistic approach to solving problems. Rather than deconstructing and analyzing components as distinct elements, researchers within the lab aim to analyze the system as a whole through the exploration of relationships among components and seek understanding on how these relations affect a system's behavior over time.

The lab leverages visual tools, such as graphs and diagrams, as well as simulations to model and predict the behavior of systems, and these techniques allow real problems to be addressed with holistic solutions that lead to lasting societal impact. When the students wanted to look into the problem of food waste, they developed a systems dynamic model (Figure 1) to simulate and analyze the system as a whole to achieve a more holistic understanding of the problem, rather than jumping into a solution that might not address the root issue.

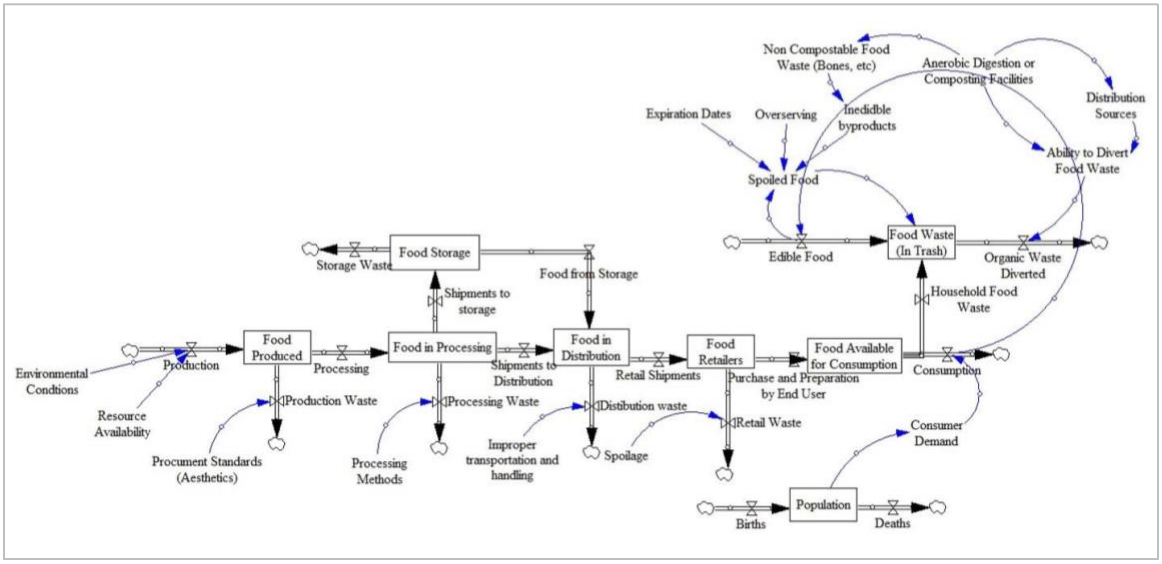

Figure 1. A systems dynamic model developed by students in VenSim to explore food waste.

Furthermore, students are encouraged to analyze projects from multiple viewpoints in order to achieve different perspectives of the system. The View Model (Shames P & Skipper J, 2006) used by the lab includes the following viewpoints that can be tailored to help breakdown and understand existing and future systems: the Enterprise Viewpoint, the Information Viewpoint, the Computational Viewpoint, the Engineering Viewpoint, the Technology Viewpoint, the Services Viewpoint, and the Standards Viewpoint.

Trident One. Luminosity students at ASU's Polytechnic Campus are in the process of retrofitting a Chevrolet Camaro to be a fully autonomous vehicle (Figure 2). To be successful in this effort, students continuously analyze the project from various perspectives. The Standards Viewpoint allows the students to understand the industry policies, standards, guidelines, and constraints that are applicable to the project. The Engineering Viewpoint promotes understanding of the mechanisms and functions required by the vehicle to support interactions among components. Lastly, the

Information Viewpoint provides students with an understanding of how data interacts with the system and helps clarify the various data inputs, outputs, and interfaces that play a critical role in processing the system's information. Upon completing this work, the lab will have access to one of few existing vehicles of this type, opening the door to a portfolio of research on autonomous vehicles operating in high speed conditions.

Figure 2. Reminiscent of IBM's Chess Playing A.I., 'Deep Blue' (Campbell et al., 2002), the team aspires to challenge one of the world's top NASCAR racers with a fully autonomous vehicle capable of winning a head-to-head time trial race.

Strategic Design. Luminosity uses strategic design as a method to leverage future-oriented design principles for envisioning and planning future systems. This method is useful for addressing 'big-picture' challenges in domains such as education, healthcare, energy, and sustainability. Strategic design is guided by the use of data analytics and anecdotal evidence to inform design features. By blending aesthetics with practical functionalities, strategic design produces consistent, effective, innovative, and resilient solutions.

Gridbase. Gridbase is an example of our students implementing the method of strategic design to tackle energy issues in the developing world. Inspired by students' research into energy problems in Beirut, Lebanon, Gridbase aims to improve energy stability and renewable energy integration in developing communities with microgrid technologies (Figure 3). Strategic design led the students to focus on a system that is low-cost, easy to assemble on-site, and produces power with high efficiency and reliability. The system is designed to interoperate with existing infrastructure and loads and will distribute equitable allocations throughout the network during times of electrical scarcity.

Figure 3. Using strategic design, students visualized various aspects of Gridbase to conceptualize the ways in which the solution can be delivered and deployed in the field.

As part of strategic design, Luminosity uses design thinking (Brown, 2008) as a human-centric approach to problem solving. Design thinking involves empathizing with people to understand and define problems, discovering solutions through convergent and divergent thinking, and iterating through cycles of prototyping and user testing. With strategic design, Luminosity bridges innovation, research, management, and design to produce strategic and actionable plans that lead to implementable solutions.

AXIO. Conceived through the design thinking process, AXIO is an adaptive lifelong learning platform driven by an A.I. personal companion whose purpose is to cultivate the overall self-development of an individual. AXIO is designed to learn from its human companion and leverages personalized information to add value throughout a user's life relative to age-specific objectives. The platform itself contains a crowdsourced learning tool that allows the community to add and curate all content, encouraging users to learn by teaching. Not only is AXIO an example of our students' capability to design, develop, and deploy enterprise-level software systems that leverage modern software frameworks and advanced machine learning algorithms, but it also highlights our students' ability to leverage design thinking to create a technical system that can effectively interact with human users.

Rapid Product Realization. A core competency of Luminosity is the ability to quickly perform all work needed to develop, manufacture, and deliver finished products, solutions, or services. An agile approach to project management is followed to achieve this aim and positions the organization to adapt and respond to change. In particular, students utilize Scrum (Schwaber, 1997) as their agile framework for project management. Within Luminosity's implementation, Scrum decomposes projects into two-week sprint cycles of iterative development. Before initiating a sprint, a sprint backlog is populated by the students with tasks that should be performed during the upcoming cycle. Each task is assigned to a student and given ‘story points’ based on the complexity of the task. Once the backlog has been completed, the sprint begins. Within a sprint, stand-up meetings occur twice a week. These meetings are less than 10 minutes and provide the team members an opportunity to declare what they worked on the prior day, what they will work on during the current day, and identify any impediments to their progress. Sprints conclude with a review and a retrospective. Reviews are informal and are used to update the full team on the progress made during the sprint. Retrospectives are opportunities for the team to reflect on the completed sprint and identify ways for the team to improve in the future. Through this agile approach, students are able to confidently and efficiently move projects forward in a way that leads to quicker realization of the final solution.

Guardian Drones. Guardian Drones is an autonomous drone system designed by our students to facilitate a campus safety escort service (Figure 4). Using a proprietary mobile application, students can request to be escorted through campus by an autonomous drone. The drone fleet provides illumination and establishes a live video link for ASU’s Police Department to monitor. To ensure the success of the system, the drones were designed with multiple functional safety features, such as deployable parachutes and encryption protected software. The Scrum framework was critical to the success of this project due to the complexity of the technical systems involved. The project’s initial sprints began with simple yet viable prototypes of both the software and hardware deliverables needed to support the overall project objective. These systems were incrementally iterated upon to eventually lead to a solution capable of being deployed and operationalized.

Figure 4. Seen above, Luminosity students developed and submitted an invention disclosure for a base station capable of automatically docking and charging the guardian drones through a contact-driven system (Photo by Charlie Leight/ASU Now).

Project Life Cycle

The students within Luminosity lead all aspects of the projects, from ideation to the eventual deployment of the solution. The Luminosity Lab follows a project life cycle that includes the stages of ideation, chartering, planning, development, deployment, and maintenance. Throughout a life cycle, the lab uses a 'phase gate' approach (Cooper, 1990), where a project is segmented into distinct stages that act as checkpoints. At the various stages in the life cycle, Luminosity's full-time staff reviews the project and makes a determination to either pass the project on to the next stage, send the project back to the students for rework, or terminate the project and reallocate the resources. The following synopsis is provided to further explain this process.

Problem Identification: First Phase-Gate. Projects are initiated by the identification of a need. Our students facilitate weekly sessions where they pick topics of interest, discuss current events, and explore relevant literature to help identify problems worth pursuing. More often than not, problems and initial ideas are identified by our students in their social interactions, be it during a coffee break or a lunch meeting. When a problem has been identified and can clearly be articulated, the students disclose the information to Luminosity's staff members, which initiates the first phase gate review. The first review simply involves a determination of whether the identified problem is a proper fit for the lab to solve. This consideration is made around the factors of societal need, competitive landscape, and feasibility. Upon passing this phase, the project enters an ideation phase, and the lab's calendar is updated to reflect weekly sessions that are open to all students.

Ideation: Second Phase-Gate. The ideation phase includes alternating sessions of ideation, design, and review that allow students to dream big, conceptualize tangible solutions, and critique each other's ideas. Students, during the ideation phase, strive toward the creation of a project charter. For the charter, students are asked to outline the following: a vision statement, problem statement, period of performance, scope of work, desired deliverables, estimated operating costs, projected timeline, and proposed project team. Submission of a project charter initiates the second phase-gate review, and staff use the charter to decide if the project moves into the planning phase.

Planning: Third Phase-Gate. Within the planning phase, students focus on creating the backlog of tasks that will drive the development of the project. The backlog is made by eliciting requirements from relevant stakeholders, formulating and analyzing the end-user profile, and performing ‘as-is’ and ‘to-be’ modeling. As-is modeling is a process to define the current state of the system and is often a visual process that leverages storyboards and enterprise modeling techniques to describe the system’s behavior and its actors. To-be models represent the ideal state of a future redesigned system. These models provide the team with artifacts that can be vetted by stakeholders and iterated upon as project requirements are generated and revised. Based on the produced backlog, a number of project sprints are established, and a project plan is submitted to initiate the third phase-gate.

Ceryx. Early in its project life cycle, Ceryx is the realization of our students’ desire to redesign and develop a modern Electronic Health Records (EHR) system that is better suited to address the health needs of today. The software will better enable physicians to provide data-driven, tailored care to patients while automating a number of tedious tasks that often burden physicians. Ceryx is being designed with security in mind, leveraging client-side encryption technology to prevent patient data from being exposed and paving the path for the future establishment of a globally standardized EHR. To develop the plans for Ceryx, the lab’s design students produced a series of As-Is and To-Be models in the form of storyboards that aided the team in both understanding the current system and proposing what the design of an ideal future state could be (Figure 5). Through these storyboards, the team was able to have more productive conversations with stakeholders in order to extract the requirements needed for development.

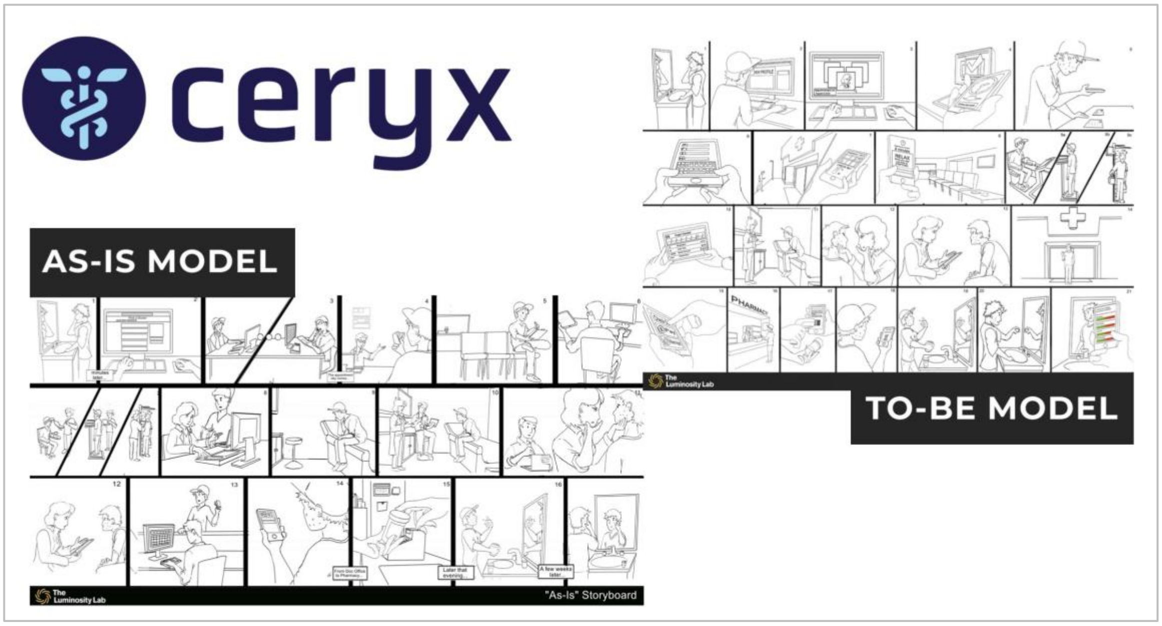

Figure 5. Examples of ‘as-is’ and ‘to-be’ models developed by students to analyze EHR systems.

Development and Maintenance: Recurring Phase-Gates. An approved project plan marks the beginning of the development phase. Development follows the agile framework of Scrum. Once a project is in the development or maintenance phase, it is reviewed by Luminosity’s staff twice during the academic semester. During these reviews, earned value management (Fleming, 2016) is used to quantify and track project progress, and a tailored rubric is used to assess deployed solutions. Based on the results of this review, staff recommendations are made. There is always a chance that the staff will determine to decommission a project; however, this usually occurs after a period of time is allocated for realignment.

Culture of Innovation

Luminosity’s success stems from the students it engages and the culture of innovation that it fosters. Many observers of the lab have asked how the students are selected. The recipe is simple. I look for good hearts, curious minds, quick learners, and students who are passionate about positively impacting the world. At universities, a dichotomized body of students can be identified. One side is comprised of students who are simply going through the motions to get their degrees. On the other side of this dichotomy are students who recognize their few years in college as an opportunity to learn and pursue many great things. A trained eye is not needed to discern the difference. While identifying students is one aspect of the challenge, motivating and maintaining their involvement is equally critical.

Students who are of the caliber to be selected for Luminosity also participate in myriad other engagements. Thus, the lab must constantly inspire and motivate the students in order to compete for their time. Author Daniel Pink identified what I have found to be the best motivators for our students: autonomy, mastery, and purpose (Pink, 2011). Our students are granted autonomy to self-direct their work, and they are given the freedom to choose when and how they best work. Through the projects, our students' skill sets are challenged each day, and they are continuously developing mastery within their fields of study by applying their knowledge directly to real-world problems. Additionally, students within the lab are passionate about learning and are encouraged to pursue mastery of topics outside of their academic fields. Lastly, our lab grounds itself in purpose. All projects are purpose-driven and initiated by our students. The expectation that the lab can and will change the world is the binding mission that brings the students together and keeps them engaged.

I have found that when the right students are brought together to pursue impactful and collaborative development projects, camaraderie forms among the students. They begin acting as a family unit, taking care of one another, and strengthening their friendships outside of lab work. When these dynamics are observed, they are indicative of the ‘great group’ environment that I aspire to cultivate.

Conclusion

The Luminosity Lab serves as a proof of concept that students are capable of leading and executing on large-scale projects, from inception to design, and from implementation to deployment. In the model of innovation and discovery presented, a lean team of full-time staff members exist primarily to motivate the students in their acquisition of mastery through applied work and to teach students how to lead the execution of project life cycles.

Over the past three years, Luminosity went from a mere idea to a model that is rapidly expanding within the U.S., one that will soon spread to countries abroad. The lab has rapidly grown to over 100 students from more than 20 academic disciplines and has a portfolio of over 20 projects that are yielding patents, funded partnerships, and potential spinouts.

To those who seek to adopt this model at their institutions, the model’s success depends on your ability to grant students the agency to conduct meaningful work. Avoid stifling student creativity with the traditional top-down faculty-driven model. Today’s university students are the luminaries of tomorrow. With the right conditions, approach, and culture, your students will be best positioned to generate the ideas, solutions, and frameworks that will solve the world’s greatest challenges.

CHAPTER 4

QUALITATIVE ANALYSIS OF COLLEGIATE KNOWLEDGE WORKER'S MOTIVATIONS WITHIN AN INTERDISCIPLINARY R&D ENVIRONMENT

Introduction

In 2016, an initiative was established at Arizona State University with the aim of developing a novel, interdisciplinary model of student-led innovation. The model's design was informed by the following desired outcomes: i) the model would be well-suited for the 21st century, ii) it would attract, motivate, and retain the university's strongest student talent, iii) it would operate without the oversight of faculty, iv) and it would work towards the conceptualization, design, development, and deployment of solutions that would positively impact society. This directive resulted in the founding of an organization called The Luminosity Lab - commonly referred to as Luminosity. Luminosity launched with a vision "To establish a new model of discovery and innovation for the 21st century driven by a lean, interdisciplinary group of exceptional scholars who fuse youthful spirit with intellectual prowess and business acumen, and who strategically leverage their position within an academic institution to take risks and produce radical innovations capable of impacting society (see Appendix A)".

Within Luminosity, students are empowered to lead and execute on large-scale projects, from inception to design, and from implementation to deployment. This model deviates from traditional, faulty-led university research models, where faculty initiate and lead the research process. Figure 6 provides a high-level comparison of the differences between Luminosity's approach to pursuing and managing research efforts and the traditional approach often seen within research universities. In Luminosity, a lean team of full-time staff members exist primarily to motivate the students and mentor them, while they lead the execution of project life cycles as the primary investigators.

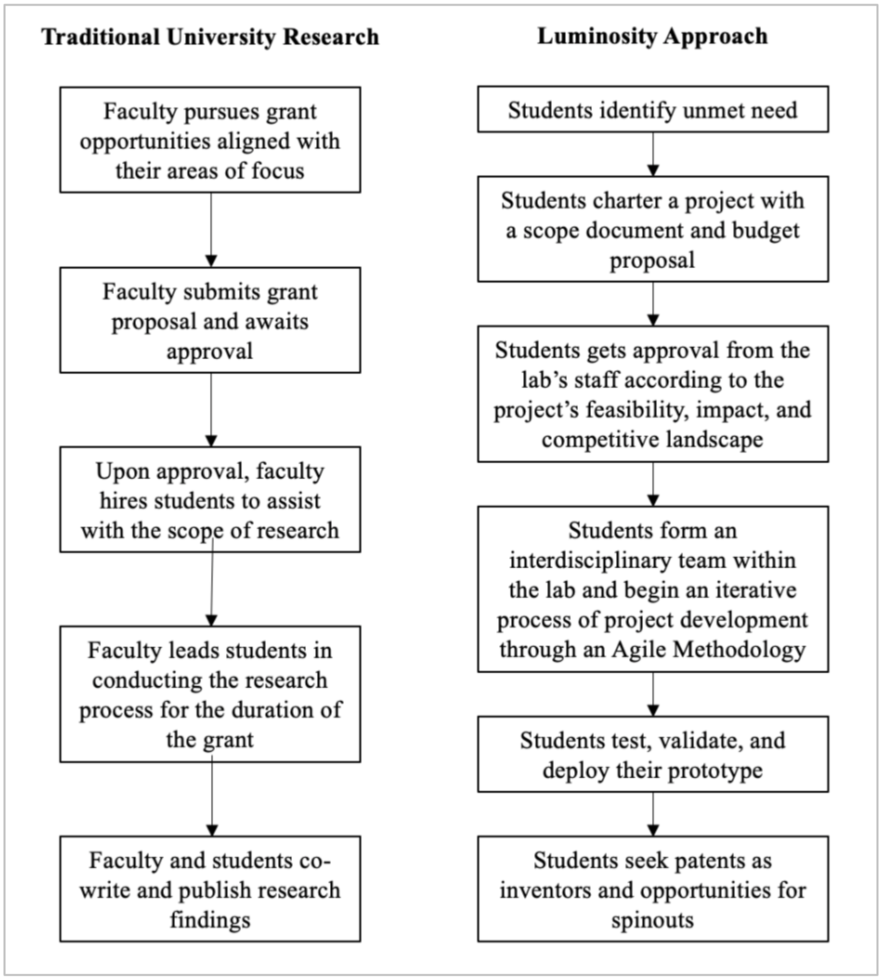

Figure 6. An overview of the high-level processes of traditional university research pursuits and Luminosity's student-driven approach.

For 4 years, The Luminosity Lab has been successful in attracting, enlisting, and retaining over 50 of the university's brightest students on an annual basis. The lab has cultivated over a dozen corporate partnerships, and through this process, has delivered novel software and hardware solutions to address specific challenges facing the sponsoring companies. The students have been effective in rapidly producing prototypes of complex hardware and software systems that provide potential solutions in the areas of energy, education, health, and sustainability (Naufel, 2020). These proofs of concepts have begun to convert into multiple invention disclosures and provisional patents. In FY2020, Luminosity's most recent fiscal year, the lab established a revenue stream of $1.33 million to support research and corporate sponsored projects, obtained seven provisional patents on intellectual property developed within the lab, and engaged over 100 students from various academic disciplines. Most importantly, the lab has produced a cohesive group culture that seems to be integral to the effectiveness of the organization.

The lab provides a novel design for a system of human innovation within an academic context and leverages concepts from the field of Human Systems Engineering (HSE; Roscoe et al., 2018). Given the societal importance of cultivating and scaling innovation within institutions of higher learning, the model provides a unique opportunity for research and discovery. A qualitative, grounded theory analysis was used to examine the phenomena of the students engaging within Luminosity, who have demonstrated their ability to serve as the principal investigators and innovators in conducting substantial discover, research, and innovation work through the full project life cycle. This study explores two key research questions: i) What are the motivators and culture that enable student success within Luminosity's model, and ii) How does Luminosity differ from traditional research opportunities and learning experiences?

Methodology

A qualitative analysis was conducted through observations and interviews to explore the motivations of students within The Luminosity Lab, and to determine if and how Luminosity differs from traditional learning experiences and research labs. Face-to-face interviews were held with current and former students within the lab to gather the data. Interviews were chosen as the method of gathering data, since they are effective in gathering opinions, motivations, and experiences (Lindlof & Taylor, 2011), and they are a popular choice, with 90% of all social science investigations relying on the use of interviews (Briggs, 1986). Intimate, one-on-one interviews with members of the lab allowed the interviewees to "get to the heart of the matter" (Tracy, 2019) and these interviews were useful in exploring the local phenomena of Luminosity. In line with the goals of Human Systems Engineering, understanding the users of the Luminosity system, allows for future improvement towards this model of research and innovation (Roscoe et al., 2018).

Sampling. Maximum variation sampling was utilized to ensure that the full spectrum of participants were heard (Tracy, 2019). This approach helped ensure that no voice was marginalized, since the lab engages students from a wide range of cultures, academic backgrounds, and age groups. Within each subset identified, a random sample of students was asked to be interviewed. Student subgroups were graduate, undergraduate, domestic, international, design, engineering, science, alumni, and current students.

At the time of this study, 200 students had participated in The Luminosity Lab, across the 4 years. Twenty-five students were interviewed, and this was sufficient in achieving saturation. A sample size of twenty-five was chosen, as it has been found to be the adequate size for achieving saturation and redundancy in grounded theory studies which leverage in-depth interviews (Dworkin, 2012). This number is considered acceptable for journals, as it allows for thorough analysis of the research question to discern conceptual categories of interest, maximizes the probability that enough data were collected to clarify relationships and identify variations between conceptual categories of interest, and maximizes the chances that negative instances that may exist have been explored (Charmaz, 2006; Morse, 1994; Morse, 1995).

Structure of the Interviews. For this qualitative study, semi-structured interviews were conducted with a pre-defined set of questions (Jamshed, 2014). Although structured questions were asked, the researcher conducted narrative interviews, in which the participants were encouraged to tell stories and share experiences, rather than simply answer questions. The questions asked were straightforward, generative, and not direct or threatening (Tracy, 2019). Additionally, time was allotted at the end of each interview for open-ended conversation that allowed for spontaneous, lively, and unexpected answers (Tracy, 2019).

Interview Questions. The questions from the structured portion of the interviews are listed below:

- How long (have you been/were you) a member of The Luminosity Lab?
- Can you tell me the story of how and why you joined the lab?
- What (do/did) you study at Arizona State University?
- What (is/was) your role in the lab?
- What are some opportunities that you were granted due to your participation in the lab?

- What other organizations and/or research labs have you been part of?
- In what ways, if any, is Luminosity different or unique to previous experiences you have had?
- (Do/Did) you feel motivated within the context of the lab? What do you believe are the factors that (motivates/motivated) you?
- Can you describe the differences of your learning experiences in the lab, compared to your academic experiences in the classroom?
- How would you define the culture of Luminosity?
- Can you describe the leadership structure of Luminosity? (Is/Was) that leadership structure effective for you?
- Why (have you remained/did you remain) a part of the organization?
- What (do you/did you) dislike most of your experience within the lab.
- What (do/did) you enjoy most while participating in Luminosity?
- Would you like to share a story or memory of your time in the lab?
- Is there anything else you would like to add?

Data Collection & Analysis. Interviews were conducted using Zoom Video Conferencing (Zoom Video Communications Inc., 2016), and data were captured through both audio and visual recordings. The audio recordings were automatically transcribed using Zoom's transcription platform. When the data collection was completed, a data immersion phase was undertaken, where the researcher digested and reflected on the data while noting reflections and reserving judgments (Tracy, 2019). During this phase, codes were developed to help summarize and aggregate common themes found within the data. Coding helped track various phenomena, such as, concepts, beliefs, actions, themes, relationships, and cultural practices (Tracy, 2019; Charmaz, 2006). The constant comparative method (Charmaz, 2006) was used to compare data to the initial set of codes and allowed for the addition or modification of code definitions to better fit the data. On the completion of this phase, secondary-cycle coding (Tracy, 2019) was used to analyze and synthesize the codes into concepts that were interpretable.

After generating interpretable concepts, examples and vignettes were used to generate strong examples that helped to describe the full complexity of the data and the concepts induced (Atkinson, 1990). Pseudonyms are used when reporting the results of the study to protect the identifies of those interviewed. Although qualitative analysis does not excel at generating universal laws, it is argued that qualitative research is far better suited than quantified approaches at developing explanations on local causality (Maxwell, 2004; Miles & Huberman, 1994). The qualitative analysis was used to provide answers and explanations to the proposed research questions. In total, 25 students were interviewed, equating to 8.5 hours of interview time and 448 pages of raw transcribed text.

Table 1. Demographics of Interviewees

Student	Gender	Academic Area	Race	International	School Level While in Luminosity	Alumni
1	F	Design	White	N	Undergraduate	Y
2	M	Engineering	Asian	N	Undergraduate	Y
3	M	Engineering	White	N	Graduate	Y
4	M	Science	Asian	N	Undergraduate	N
5	F	Computer Science	Asian	Y	Graduate	Y
6	M	Engineering	White	N	Graduate	N
7	F	Science	White	N	Graduate	N
8	F	Engineering	White	N	Undergraduate	N
9	M	Engineering	Asian	Y	Graduate	N
10	M	Design	White	N	Graduate	N
11	M	Liberal Arts	Asian	N	Undergraduate	N
12	F	Engineering	White	N	Undergraduate	N
13	F	Design	White	N	Undergraduate	N
14	M	Computer Science	Black	N	Undergraduate	Y
15	M	Engineering	Asian	N	Graduate	Y
16	M	Computer Science	Asian	Y	Graduate	Y
17	M	Computer Science	Asian	Y	Graduate	Y
18	F	Design	White	N	Undergraduate	Y
19	F	Design	Asian	Y	Graduate	Y
20	M	Design	Two or More	N	Undergraduate	N
21	F	Design	Two or More	N	Undergraduate	Y
22	M	Liberal Arts	White	N	Graduate	Y
23	M	Computer Science	Asian	Y	Graduate	Y
24	F	Business	Asian	N	Graduate	Y
25	F	Computer Science	White	N	Undergraduate	N

Of the 25 students interviewed, 14 identified themselves as male and 11 as female. The ratio of domestic to international students was 21:6. There were 14 alumni students and 11 current members of the lab interviewed. Of the interviewees, 12 were undergraduate students and 13 were graduate students at the time of their lab participation. Although, many of the graduate students had formerly participated in the lab as undergraduates. Students' areas of academic study were generalized into six categories to protect their identities, as many of the students participated in specialized academic programs.

Results I: On Motivation

Students described a highly motivating environment within The Luminosity Lab. Interviews showed a clear consensus of motivating factors amongst the lab's participants. Although no existing theory of motivation fully covered the factors expressed by the students in Luminosity, overall their motives aligned with well-established motivational frameworks relating to knowledge workers in the modern workplace (Frick, 2011; Pink, 2011). These frameworks reference motives, such as, meaningful work, belief in mission, public service, relationship with coworkers, autonomy, and mastery. Additionally, the students' motivations aligned with final versions of Maslow's famous Hierarchy of Needs, which in addition to physiological, safety, love, esteem, and self-actualization needs, included cognitive and aesthetic needs, as well as the concept of self-transcendence (Maslow, 1954; Maslow 1969).

Within Luminosity, the motivating factors felt by students were: i) agency and trust, ii) desire to impact society, iii) acquisition and dissemination of knowledge (i.e. mastery), iv) competence and achievement, and v) affinity towards co-workers. For each motivating factor, students produced stories that showcased how these motives kept them engaged in their work and dedicated to the lab's mission. These identified factors were intrinsic in nature, and aside from a reference to food at meetings, none of the students interviewed described their desire to participate in the lab for external rewards, such as monetary compensation.

Throughout the lab's history, nearly half of the lab served as volunteers that did not receive monetary compensation or course credit (Naufel, 2020). Hourly wages were provided to some students as a result of their involvement on sponsored projects.

However, these students did not mention monetary payment as a reason for their participation. An international graduate student studying electrical engineering, who chose to volunteer in his time in the lab in spite of having many other paid opportunities available to him, explained, “I had all of my friends who were making money and critiquing me, saying, ‘Are you insane working in this place?’”, in which his response was, “You guys are not understanding the value of this place, this is something tremendous. You’re looking at immediate benefits, but I’m over here looking at lifelong, vested benefits.” Similar sentiment was expressed by multiple students, demonstrating a common motive within Luminosity members in seeking long-term, intrinsic benefits from the lab. Shane, another engineering student stated, “The people who did the best in the lab, we're not the people who were there for a job or for a paycheck - it's the people who had a very strong curiosity for learning. They saw the lab as a way to learn new things and explore new areas of interest. And, it's for the people who want to develop or help contribute to something that is more than just a product that puts money in their wallet.” Shane went on to explain that, rather, the lab was for those who wanted to solve critical societal issues.

The intrinsic motivators of the lab were effective in such a way, that if a student remained a part of the lab for the first 3 months, over 90% of the time they remained actively involved in the lab up until their graduation, regardless of if they were paid or volunteers. Of the five motivating factors identified, 24 of the 25 students interviewed expressed being motivated by at least three of the factors during their time in the lab, with 68% of the interviewees expressing all five of the identified motives. Table 2 looks at the cross-sectional comparison of graduate and undergraduate students against the five identified factors of motivation. There was not a substantial difference between the motives felt by the undergraduate students when compared to the graduate students interviewed. Table 3 compares the motivational factors against the student's academic areas of study and highlights that the trends were comparable amongst students from different academic areas. Most surprisingly, international students interviewed in this study each felt all five of the identified motivating factors, as seen in Table 4.

Table 2. Comparison of motivational factors for undergraduate and graduate students

	Total	Affinity for Coworkers	Mastery	Achievement/Competence	Desire to Impact Society	Trust/Agency
Graduate	13	13/13	12/13	12/13	11/13	11/13
Undergraduate	12	12/12	10/12	12/12	8/12	11/12
Both	**25**	**25/25**	**22/25**	**24/25**	**19/25**	**22/25**

Table 3. Comparison of motivational factors among students' academic areas of study

	Total	Affinity for Coworkers	Mastery	Achievement/Competence	Desire to Impact Society	Trust/Agency
Business	1	1/1	1/1	1/1	1/1	1/1
Computer Science	6	6/6	6/6	6/6	6/6	5/6
Design	7	7/7	7/7	6/7	6/7	6/7
Engineering	7	7/7	6/7	7/7	5/7	7/7
Liberal Arts	2	2/2	1/2	2/2	0/2	2/2
Science	2	2/2	1/2	2/2	1/2	1/2
All Academic Areas	**25**	**25/25**	**22/25**	**24/25**	**19/25**	**22/25**

Table 4. Comparison of motivational factors among domestic and international students

	Total	Affinity for Coworkers	Mastery	Achievement/Competence	Desire to Impact Society	Trust/Agency
Domestic Student	19	19/19	16/19	18/19	13/19	16/19
International Student	6	6/6	6/6	6/6	6/6	6/6
All Students	**25**	**25/25**	**22/25**	**24/25**	**19/25**	**22/25**

Trust & Agency. Agency as a motivating factor is absent from some motivational frameworks, such as Maslow's Hierarchy of Needs, however, is reminiscent of what motivational researcher, Daniel Pink, describes as motivation through autonomy. Pink believes his motivational theory to be more relevant to the modern workplace, in which autonomy is a critical factor, representing an individual's control in who they work with, what they do, and how they conduct that work. The concept of agency, trust, and self-responsibility was prevalent throughout conversations with Luminosity members and was expressed by 88% of the students interviewed. Students expressed that they felt an authentic sense of agency and ownership within the lab. The trust they felt motivated their performance due to a sense of freedom and agency it provided, as well as a comfort in the belief that their colleagues would not let them down. The students' trust and sense of agency created a lasting environment that cultivated what was described as a free-flowing stream of ideas and discussion. Riley, one of the lab's original members, and a mathematics graduate, stated, "It was like we could do anything we wanted and that was encouraging… Let's think about what would be cool to build and what would be useful to people, and let's try and do it. And I think this sort of free following nature of ideas was probably the most defining aspect of the culture." Similarly, another student pursuing their Ph.D. in electrical engineering, explained how the lab's free flowing nature was a source of innovation, "Of course there is structure and everything, but we have a freedom on what we want to do, and that freedom is seldom something you get in other places in academia… That freedom is very valuable, and that freedom made us more innovative."

Students described a sense of trust and agency that originated from the lab's founder and staff leadership. When describing the lab's staff members, the majority of students who spoke on the topic felt that the lab's staff were seen as mentors and friends, rather than traditional managers, and they did not perceive a strict hierarchy among students or staff members. One student explained, "There's no hierarchy, though there are leaders and a leadership team, and there is kind of a hierarchy of roles, that is so pseudo, it's just there to make sure people are on track, but I've never felt a hierarchy." Often, students did not know the official titles of the staff members, but greatly valued their role in facilitating, mentoring, teaching, and removing roadblocks within the lab.

Trust started with the lab's director and became a model that others strove to emulate. A graduate student, studying public policy, highlights this stating, "The leadership structure, in my opinion, is one of a lot of trust from the get-go... I've learned a lot from (the director) in terms of how I approach people when I talk about my projects... I always give them the benefit of the doubt. I always trust in them initially... The leadership (directive) when I first came in was, 'I want you to make the biggest impact. I want you to come to me whenever you have problems.... I trust you to make decisions and to have that freedom to do so'".

A sense of agency was strengthened from the lab's bottom-up approach to management, in which students controlled the lab's portfolio, despite there being staff facilitators. Outside of externally sponsored projects that came to the lab, students were responsible for identifying, designing, and developing the lab's internal projects, with students serving as the projects' leads and managers. Shane, the student lead from the lab's first major R&D project reminisced, "Pretty much everything was student driven. There was very little input from administrative figures or faculty figures... So, we as students and student leaders, were really able to kind of forge our own path and develop our own process of exploration, iteration, and development... Luminosity gave us that space and ability without having to worry about backlash, both political or financial".

Students described the Luminosity staff's role in cultivating motivation among students by instilling agency, promoting confidence, and reducing bureaucracy. One student, who had at one point dropped out and later returned to the university, remarked, "I think being younger you just assume everything has barriers that can never be overcome. I think The Luminosity Lab shows you that no barrier is unbreakable, or that no barrier is so big that you have to give up on your dreams... The confidence that Luminosity gives you for being part of that group and understanding that good solutions and good people can overcome whatever we think red tape is." The ability of the lab's staff to remove roadblocks and red tape, was critical in creating an innovative environment and provided students with further freedom in pursuing their solutions unhindered.

A Desire to Impact Society. Part of Luminosity's vision statement is to "take risks and produce radical innovations capable of impacting society (see Appendix A)". 76% of the students interviewed expressed their desire and ability to positively impact society as a primary motivating factor. This motivation felt by the students interviewed is akin to Maslow's concept of self-transcendence, which he introduced in his later years (Maslow 1969). Maslow described self-transcendence as a moving beyond self-actualization, into a position where an individual puts the needs of others before their own. Students demonstrated this when they described being motivated by impacting the lives of others over personal rewards, intrinsic or otherwise. This also suggests that these students had self-actualized and were having their high-level needs of meaning and purpose met. Nolan, a student studying biology stated, "I want to impact people's lives. I want to change the world, and the lab is the closest thing that I've done in my life to have the opportunity to do that". This desire to impact society, was observed by students within their coworkers, "I think that's what the lab brings, when you see a full room of these people, they all they all have one thing in common, which is they want to change the world for the better, but every single one of them is different", noted Danny, a graduate student studying digital culture.

Students appreciated the lab's aspirations for a global impact and that projects revolved around high-impact areas such as energy, healthcare, and education. In each story provided, the students' work toward impacting society was not something that benefited them directly, rather it was to the benefit of the identified target groups in need. Students were not only motivated by the aspiration to impact society, but by their ability to do so. The lab's work in response to the COVID-19 pandemic was used as a direct example of how the lab is able to directly impact some of the larger challenges in today's society. Taylor, a student participant in Luminosity's COVID-19 response efforts explained, **"**Some of the COVID-19 projects we worked on, both the development of rapidly manufacturable personal protective equipment, as well as systemic, larger scale issues, like distributing that PPE, and identifying needs in the community. That was not only really meaningful for me to work on, but it was one of those all-out experiences that I was just describing where everybody is faced with this seemingly impossible problem and you know you're just working around the clock to do what you can during a time of unprecedented need for that sort of skill set. And so, while the circumstances may have been dire, it was a really rewarding experience and I think that's probably the thing that will stick with me the most."

Competence & Achievement. The students interviewed felt motivated by their ability to create and deliver solutions. These motivations, expressed by 96% of the Luminosity students interviewed, are similar to what Maslow refers to as esteem needs in his Hierarchy of Needs (Maslow, 1943). Maslow breaks down esteem needs into respect from others and self-respect, which were both needs students expressed having fulfilled through their achievements within the lab. More recent motivation models of the modern workplace refer to the motivational driver of competence. Extending on the early work of White, Susan Harter developed a motivation theory centered around effectance, or also known as competence (White, 1959; Harter, 1978). Harter recognized enjoyment as a motive for individuals to interact with their environment, as well as the desire to demonstrate competence. Harter believed that mastery attempts that resulted in a successful outcome would lead to an increase in motivation, whereas unsuccessful attempts would negatively impact a student's motivations. Harter's beliefs were consistent with findings from the interviews with Luminosity students.

The students of Luminosity described a research and development lab that placed a strong emphasis on development. They described how they were motivated knowing that their creations would eventually be utilized in the real world, in contrast to school projects that they did not move past the classroom. Students also appreciated that Luminosity is more action oriented than other groups focused on innovation, which they perceived as simply talking about ideas. These sentiments were especially seen within the Luminosity's engineering population. Taylor, a graduate student in robotics, stated, "I think one of my biggest motivators was seeing that the lab was actually able to develop products and innovative solutions and then get them out, either to market, or disseminate them amongst whoever the end customer was going to be. And that was inspiring for me, honestly, because I know a lot of student projects and a lot of projects that were tied to coursework that just never made it that far. You know, maybe you had a really promising idea and did a little bit of development and then the semester is over, and everybody just kind of goes their separate ways. So being in a group where you knew that there was a light at the end of the tunnel and that the problems you were working on may actually be addressed. That was really encouraging and I'm not always the most optimistic person but working with the lab made me more optimistic."

Creation and achievement as key motivating factors of the lab was reinforced further when the students were asked to tell a story of their time in the lab. Of the students who told stories, there was a particular pattern that was found in over half the stories told. This pattern was defined by stories about late nights spent working toward a tangible deliverable or end-goal. Students remembered sleepless nights, and looked on these nights fondly, as they were proud to be accomplishing something meaningful. The motivation students felt was described to be enhanced when students were able to find success within these situations. As the pattern emerged, the interviewer gave pushback with follow-up asking why the students viewed these experiences so positively. Riley, a former member of the lab and mathematics student, recalled the night before a demonstration at the ASU GSV Summit, where he and his team were showcasing their haptic based device that assists individuals with visual impairments. "The whole thing totally crashed the night before and it was just the four of us sitting up, getting it to work and testing everything… and all of a sudden it was under this time pressure because now we were showing it to people." Riley was interrupted with interjection, "So I have to clarify this is a positive memory in your mind. Riley replied, "This is absolutely a positive memory… It wasn't like this imposed deadline, where you had a paper due or something like that, and you just had to get it in because you're going to be graded on it. It was because we had spent a long time working on this and we had devoted a lot of energy and a lot of brainpower to this problem and to getting this system to work. And we really wanted it to work. And we had a lot of personal stake in it because it was our project. Knowing that we knew it could work and wanting other people to see it work. Well, to be fair, I'm not sure if that would have been as happy with memory if it hadn't worked. Yeah, I think it's just like the satisfaction when you put it on and you click run and it works, like that is enough to motivate you staying up all night for weeks, for sure."

A Desire to Learn and to Teach. The students within the lab expressed a desire to learn and a passion for disseminating their own personal knowledge as defining motivators of the lab. Although not included in Maslow's original Hierarchy of Needs, the motivations students felt for learning aligns with what Maslow would later define as Cognitive Needs, which is defined by a need for curiosity and understanding, and related to the attainment of knowledge (Maslow, 1954). The motives to learn exhibited by students within Luminosity can be aligned with Pink's concept of Mastery, which is described as a desire to improve at things that matter (Pink, 2011). When asked, 88% of the twenty-five students interviewed, expressed learning or teaching within the lab as a main motivating factor for their involvement. Learning within the lab occurred through applied, hands-on projects, and the main source of knowledge transfer was from the students' interactions with one another. Students took pride in 'trading' their personal skills with one another and were exchanging skills that they identified as highly relevant and not always taught in the classroom. A common interest for knowledge attainment, shared amongst students in the lab, created a culture of mutual learning, and mutual teaching, as explained by undergraduate architecture student Ava, "The way the lab differs is that everyone is so open to teaching you. If you don't know something, and if you want to learn, say I wanted to learn coding, I could totally do that. And it was the same for me, I can teach people about architecture or design and everyone is open to that."

Students enjoyed both the roles of being a learner and serving as a teacher to other students. Graduate student, Jordan who has participated in the lab for over two years, stated, "It's been really cool to be able to be a member who trains and hires new members and it's also been amazing to be someone who gets trained and learns from experts in the field. I think I've really had a lot of opportunities to experience both of those roles and play a big part of that."

Affinity for Coworkers. Students described being motivated by an admiration for, and camaraderie between their coworkers. This camaraderie in the lab was strengthened by a perceived, open, and diverse family culture. This desire for camaraderie is similar to what Maslow defines as love and belongingness needs, which is the need for affection and acceptance (Maslow, 1943). Twenty-five out of the twenty-five students interviewed described a strong affinity toward their coworkers as a critical motivating factor within the lab. Students described friendships with co-workers that often extended outside of the lab, and that were deep connections not often made in their other organizations. One of the lab's international students stated, "These are relationships that (will) last me a lifetime, and that that was the good thing about (Luminosity). I'm not in touch with anyone, I've worked with in my previous organizations, so that says a lot about Luminosity". The camaraderie within the lab promoted the idea amongst the students that the lab was a life-long organization, and they recognized that their connections would persist long after they had graduated. Shane, one of Luminosity's first members was an exemplar for this, "A majority of the people who were in (the first year of) Luminosity were at my wedding... Going through those experiences and that level of learning and growth together really helps create lasting bonds. And these are still people I am very close with and talk with on a regular basis."

Multiple students made comparisons between the camaraderie felt within the lab, and that of which they perceived students who participate in social fraternities and sororities might feel. The students who made these comparisons were either members of Greek organizations or were students that did not desire to join a Greek organization, however appreciated that their social need was being met within Luminosity. Jessica, a sophomore studying material science, commented, "I have a lot of friends who are in engineering sororities or fraternities and they're like, 'you know, why don't you join? you would have a lot of fun'. But I feel like I don't need that because Luminosity is kind of like its own little family in its own way". Carly, a former graphic design student within the lab, explained, "The lab in a way was that fraternity, or those deep connections that I'll always remember post college... We all very much believed in each other's abilities and skills and it was celebrated. Although I had very different perspectives than my engineers, they never were critical of me... I never encountered that friction in the lab because once again, we all supported and believed in each other's abilities… Lab felt like a family".

The word 'family' was brought by a third of the students and was used to describe the lab's dynamic and culture. The culture of the lab itself was described to be a key factor in motivating and maintaining student engagement. Students described the lab's culture in many ways, that can be summarized as a culture of friendships, freedom, achievement, openness, and fun. Lisa, a graduate of the lab who studied accounting and business analytics described the culture as: “It was a bunch of people who wanted to do something fun. I think it was mostly about this playful kind of curiosity… Doing things because you like doing it and because it's fun, and a lot of that exploration is gone from our institutions…. People were together and motivated to come to the lab every day because they're working on something cool and they were hanging out with their friends. And it's just play”. Lisa’s comments provide an exemplar that represents the overall view students had of the lab. They viewed it as a place to call home, and one where they are free to explore, create, and have fun, all while producing work that would have a positive outcome for society. The culture of the lab was so strong and defining that one student noted: “If you did a speed dating round of 500 students… There's a (very high) chance you could tell who's in Luminosity while you run through them all”. With this statement, the student highlighted their personal opinion that student participants of Luminosity were easy to distinguish from other university students, specifically by those who had already participated in the Luminosity program.

Results II: Comparison to Industry & Traditional Research Experiences

Students were asked to list other organizations they had been a part of, outside of Luminosity. Each student had participated in multiple opportunities, ranging from other research labs at the university, industry internships, and social organizations. In total, the students interviewed made comparisons against twenty-one distinct research labs and forty-two industries in which they had participated in. Former members of the lab were able to contrast their Luminosity experience to their post-graduate careers, which included Intel, Facebook, Amazon, and many other Fortune 500 companies. The students articulated that the lab was substantially different then their other involvements. The lab’s motivating factors identified in this study were often key differentiating factors between the Luminosity experience and students' other organizational experiences. For example, agency was described as a differentiating factor, with students feeling that the lab gave them more opportunity to pursue what they were passionate about than any other organization they had been involved in. In Luminosity, the students felt that they could pursue anything that interested them, as long as it had a clear value proposition. They also felt that Luminosity had less bureaucracy and restrictions than other lab experiences. This freedom allowed students to take risks, explore, and innovate more than they were afforded in their other opportunities.

Students described the lab being the antithesis to their usual experiences, where they worked standard hours, their hours were tracked, and they operate within a traditional management structure. "I would say (Luminosity) is more relaxed than the job I'm at right now, where we structure everything on an hourly basis... So, there's this centralized task management that covers all of the work that I would possibly be doing, and everything is tracked very accurately. Whereas for the lab, there's a lot more individual discretion. It's something where you agree with everybody else on what you're working on that week during weekly meetings, but the individual time is not really kept track of. Also, in (Luminosity), there's more of a broad strategic creativity… Everyone is on an equal footing… Everyone is contributing what they can to the overall trajectory of the project, rather than that being dictated from the outside."

Furthermore, students noted Luminosity's innovative environment, interdisciplinary approach, and the group's passion as differentiating factors. Students felt that Luminosity was working to combat the status quo, in contrast to other organizations who they felt had become complacent. Hansin, an international student studying computer science stated, “All the organizations have some amount of smart people, but (not) that amount of energy. I think a lot of organizations, like in my previous organization, it was that nobody was trying to change the status quo. Everybody was like okay this is our work, (and when) they're done with their work they go home. And in Luminosity… we were thinking about the work even after we went home. We were actually trying to solve (the) problem we were facing.”

Research Labs. Specific to traditional research laboratories, students appreciated the minimal amount of designated faculty involvement, and the Luminosity’s bottom-up approach to leadership. Students sometimes viewed faculty involvement as a constraining factor within aspects of their collegiate experience. Students noted a disconnect between students and faculty, and that the tight-ship management approach often employed by faculty on projects and coursework did not resonate with nor motivate them to put their best foot forward. An active graduate student within the lab stated, “(Faculty) aren't willing to just talk to you on things other than work progress… I know the faculty has a job to get done and I'm sure that they're always worried about getting student work to fulfill their job as well… And so (there is a) disconnect between a student who's working for free, just for just for information sake, and someone who's getting paid full time and their job is to manage the students. There's oftentimes this pressure I feel like for them to get the students to succeed in order for them to succeed.” This was contrasted by the student with their experiences in Luminosity, “If something was going on in my life that I felt like was not necessarily work related, but was affecting me, I definitely would feel more comfortable (speaking about it) in Luminosity”.

One student explained their opinion on why faculty could sometimes limit innovation in the research process, “You see a lot of this in academia where you get (faculty) who either have to be involved because it's their area, or (else) they throw a fit and say, ‘Well, you're not allowed to do that because that's my thing’... And that always leads to conflict which again slows down progress”. The goals of faculty were described to bring about differences in how projects were selected and pursued, as described by Rahul, a graduate student and original member of Luminosity, “The motive to start our own project (in Luminosity), I never ever could have done that anywhere else in traditional academic units. The way it works (in traditional academic units) is that the professors write for some grants, and the grants would be very specific for one topic of research. They get that money (and then) they look for students (to) specifically work on that project.”

When asked what they disliked least about their lab experience, a student within the lab described her experience on a project in the lab that required collaboration with a faculty member. She described that her poor experience stemmed from a disconnect between how the faculty member viewed and treated her, over the agency and respect she had within Luminosity. “There was a tendency to butt heads, and I would say that this professor would try to motivate us in ways that were very different from how the team was actually going to be motivated. He would try to put deadline pressure on and say we were underperforming in certain ways, when that really wasn't necessarily the case, and used that as a way to try to generate more work when really, we were working from that intrinsic perspective and we're working towards those goals as best we could.” Media accounts of this effort show that it was considered a significant success, and that the success of the project was attributed to the Luminosity students who implemented the project.

The undergraduate students within Luminosity appreciated that the lab made them feel as though age did not matter, whereas in many other research labs, this was either a barrier to entry altogether, or a factor to be overcome. Freshman Mechanical Engineering student, Krista, explained, "(Luminosity) is different from my other lab, especially as a freshman in a typical research lab. You (are) considered the underdog, which very rarely have I ever felt at the Luminosity lab. Everyone's always very encouraging and very willing to help me." Hannah, who is an undergraduate student leader on multiple projects within Luminosity, stated:

> "(In) my old lab, I felt very isolated. It didn't seem like the people in the lab were friends with one another. It was a very academic setting and the relationship between members in the lab was extremely professional. I definitely felt like an intern in that lab. I didn't have as much experience as the senior members of the lab, who were mostly postdocs and stuff. Because of that, I didn't have as much input into the projects that we were working on - I was mostly an observer in those situations. So, I never really felt like I contributed that much to my lab meetings, I was pretty quiet, and I didn't feel like I was using the potential that I have. In Luminosity, I've noticed that I have a lot more input into what goes on in the projects, no one treats me like an inferior or like someone who doesn't know as much (as them). I think that I have pretty equal say on what goes on and I feel a lot more respected. The biggest thing that I've noticed is the community in

Luminosity is much stronger than any community than I've been a part of at ASU."

Industry. Students found their Luminosity experience to differ from their experiences in large companies and likened the lab to the environment found often within start-up companies. A graduate who has worked at both traditional corporate environments and startups stated, "(Luminosity) has the same kind of atmosphere that comes up in startups, because in a startup, as a young company, they're still formulating the rules and formulating (the) culture. And it really comes down to how are we going to interact with each other." Students believed that Luminosity was more energized and action-oriented than organizations and industries they had participated in. One student, now working for a Fortune 500 company in Silicon Valley stated, "You know really old companies, large organizations, right, (there) I was used to a certain work pace or style that was completely flipped on its head in (Luminosity). In the lab, everybody had a lot of energy, everyone was really eager to collaborate, and it was very much about a bias towards action and doing things, rather than doing a lot of research... So, I think the lab was where I was first exposed to a concept of take action first, and that's how you gain confidence and that's how you gain expertise."

Students appreciated that the lab was not just a think tank, they mentioned their appreciation of being part of the ideation, the design, and the development of the solution. Whether it was research labs, or large-scale industries, students felt that the lab widened their engagement and provided a more holistic approach to developing solutions. A student, speaking about their working experience at Amazon stated, "You really don't have that much control over anything end-to-end, or that much influence. And so being in like a small group (Luminosity project team), where again you were working on every aspect of the problem, or that you were at least involved or aware of every aspect of it and had control over it. That was appealing about the whole thing."

Students described that it was easier to find purpose in a group like Luminosity, over the large companies they worked at. A former member of the lab, currently working at a Fortune 500 company stated, "There is a partial sense of purpose when you work in a large company, but in The Luminosity Lab, every day we felt a complete sense of purpose, all of us coherently felt that". The student continued to describe what brought about this sense of purpose within Luminosity, "The whole sense inside the lab is that we all got each other… and the problems we were solving, we are not just solving a project that makes money… We are solving a world problem (with) unlimited potential for it to be applied. It's amazing".

In a direct contrast, one student explained being engaged in two simultaneous projects for one of the Luminosity's corporate sponsors. In one instance, the project was being managed by the corporate sponsor's stakeholders, and in the other, the project was being managed under Luminosity's standard processes. The student explained that the project being managed by corporate stakeholders was the part of her Luminosity experience she disliked the most. "Sometimes it does feel like we're being micromanaged a bit, and that we're not getting as much ownership over the product vision and strategy... So (with) that project, to me, it feels more that I have to do this right now versus I want to do this". When asked which project she thought would generate a better solution, she replied, "I think that the (Luminosity) project is going to be way better because of the perspective, we've been able to bring to it...I think that there's also a lot more passion in that project... A lot of times (passion) equates to cooler stuff on the other end, because we're all intrinsically motivated to work on it."

Luminosity Learning Experience vs Classroom Learning. In the case of each student who spoke about the differences between classroom learning and learning within Luminosity, their learning experience in Luminosity was described to be substantially different to their classroom learning and was also perceived to be more beneficial. Students described Luminosity as an immersive, applied learning experience, and contrasted it to their traditional learning experiences at the university. Outside of the benefits of learning foundational theory associated with their degrees, students found classroom learning to be static, outdated, and limiting. Students were more motivated to learn through the hands-on learning experiences of Luminosity, and also felt that this strengthened their learning outcomes. Students recognized an advantage in learning from one another, Ava stated, "The way the lab differs is you're being taught by your peers. And that's something that's really special because you can relate to each other on the level of, you know, it wasn't that long ago that they didn't maybe know this information so they know how to explain it to you in a way that you can digest it."

Students felt that academic cadence of the university was too slow and defined, relative to Luminosity. Two of the undergraduate females in the lab mentioned not learning much their first few semesters of official university coursework, compared to what they had been learning in their public high schools. Jessica spoke about her first few semesters at the university, "I'm just going through your basic science and math classes. So I didn't feel very connected with my degree. But my work here at The Luminosity Lab. I was actually able to start doing material science stuff before I even had taken my first material science class." Krista, a freshman mechanical engineering student, explained this in the context of learning Computer Aided Design (CAD), "CAD was a good example because for mechanical engineering, I had already done the CAD stuff that we were supposed to have done. And I didn't learn anything more than what I learned in high school. But Jessica and some other people at Luminosity have already shown me some (advanced CAD) things I'd actually be using as a mechanical engineer… So, it's kind of filling in the knowledge gaps that my major doesn't necessarily cover."

Students enjoyed having the freedom and flexibility to learn what they wanted in Luminosity, rather than following their course curriculum, and felt that the lab allowed them to learn more relevant skills than what the classroom provided. The students felt that their research in the lab allowed them to learn about cutting edge techniques, theories, and algorithms that they would have never gotten from a classroom, and these were directly integrated into the solutions they were developing. Kishore, an international student who studied computer science, explained how Luminosity allowed for open-ended learning, "In the Luminosity Lab we read papers published by anyone. We learn about the frameworks that were built by some someone in some part of the world, which is thriving. For example, if there is a new API library that was built for a particular kind of natural language processing. That may not be part of the curriculum, but that is booming in the industry. We learn about that in (Luminosity), we talk about that, and we implement that. The kind of projects we do in an academic setting are pretty regular, I would say, for the most part, compared to what we solve in The Luminosity Lab." A former graduate of the lab, spoke on the difficulty traditional learning faces when trying to serve many different types of students in one environment, "(With) in class learning, you have absolutely no say over what it is that you learn... I think that's the difficulty with building a class for lots of people... people are going to have very different backgrounds and experience... And so for some people, you're stuck on things that you already understand, but you have to do them repetitively because that's just how the class is set up.... Self-regulating what you spend your time on and how much time you spend on things, based on the needs of the project, is very different between the two**.”** Hannah echoed these sentiments, “I am going to be honest, I spend about 80% of my time doing stuff for Luminosity and 20% of my time doing stuff for school, because I enjoy my work for Luminosity that much more. In class, I feel like we're working in a vacuum, and so much of what I have been doing this semester in particular has just felt like busy work and a lot of assignments that don't apply to what I would want to do in real life.”

Students also described how their learning in Luminosity went further than their applied learning experiences in the classroom. A graduate student studying robotics at ASU’s polytechnic campus stated, “I think that even in some of the best hands on learning classes, the project scope is still fairly narrow, you're probably looking at a small problem that is very well defined, possibly even just dictated by the instructor. Whereas I think (Luminosity) is a more realistic experience, because in real life you don't have, or at least you don't always have a clearly defined problem statement. Oftentimes, you have identified some area that you know have some problems in but getting to choose the scope of the project and having to make strategic choices about what areas of the identified problem can you tackle feasibly. I think that's one of the largest differentiators”

A former member of the lab described how sometimes the professors were the source of limitation in the classroom, “I definitely had times where professors discouraged me from doing things that were maybe more difficult or more outside of just the narrow scope of my major. Because they just don't see that as something that's part of their role or something that they should be encouraging, they were more worried about meeting my degree requirements."

Overall, students felt learning was better reinforced through the Luminosity's development process, in which they were able to discuss and revise their work with experts, stakeholders, co-workers, and potential end-users of the solution. In addition to the benefit of learning hard skills outside of their degree, students also felt that they were able to learn a great deal of soft skills through their work in the lab, skills such as project management, communications, leadership, and time management. Furthermore, students felt that their learning was inspired by the interdisciplinary nature of the lab, and that working with students from all academic disciplines, cultures, and backgrounds allowed them to further develop their skills, both technical and interpersonal. Nik, a student who entered the lab as a freshman, stated, "What I've learned in the lab is far beyond anything I've ever learned in a classroom. You know, just interpersonal skills, working with people from different backgrounds understanding all of these different perspectives that can come together. It was almost subconscious, like I didn't know I was learning all of this until a year later when I started to apply it and realized, oh, this is where I got that from… it's been incredible."

Discussion

The students of The Luminosity Lab expressed a great deal of excitement, passion, and motivation for the work they were conducting. Their energy seemed to become a catalyst for innovation, and a magnet which attracted many like-minded students to the lab. Aside from the initial students of the lab, who were directly recruited by the lab's founder, students described being identified and recruited to the lab by other students within Luminosity. Through self-recruitment, the lab cultivated and maintained a culture of camaraderie and shared intrinsic motives, despite each student differing in their personality traits, academic backgrounds, and research interests. This persistence of culture was recognized throughout the interviews, as the lab's culture and motivating factors were described similarly by students across the 4 years of the lab's existence.

The motivations felt by students could not be explained by a universal framework of motivation, rather they covered factors shared by multiple theories of motivation. This study found that young, talented knowledge workers rejected older models of motivation, such as Taylor's 'carrot and stick approach', in which motivation is based on a system of rewards and punishments (Taylor, 1914). Although, these models are considered archaic in modern scholarly literature, the Luminosity students provided clear examples of their use in other collegiate environments. Instead, the students preferred to be moved by human-centric and intrinsic motivations. From the various examples provided by students, it is likely that the students involved in Luminosity would not have been as engaged in the lab, nor as successful on their projects, if more rigid motivational techniques had been employed. Students explicitly denounced being micro-managed, and felt their success and creativity was fueled by the intrinsic motivations they felt and the agency they were given. Students within the lab showed that they did not need external rewards for their involvement, and that they were not going to be motivated through punishments. Rather, they sought the reward of continuously improving themselves through their efforts to positively impact society, and only feared the indirect ‘punishment’ of letting down their colleagues and mentors, who had put their trust in them.

The motivations identified within students of the Luminosity Lab aligned with motivation factors of high-performing knowledge workers (Frick, 2011), for example, Daniel Pink’s Motivation 3.0, which is defined by the motives of mastery, purpose, and autonomy (Pink, 2011). Mastery was seen within the students’ desire to learn and improve themselves, as well as their enjoyment of achievement. Autonomy aligned with the trust and agency felt by the students in leading Luminosity’s portfolio of projects. Purpose was seen within the students’ desire to change the world and positively impact society through their work. Outside of these factors, the most expressed motive in Luminosity was the students’ affinity for one another, and the close-knit, family-oriented culture propagated within the lab. This concept of ‘relationship with co-workers’, was found to be the fourth most relevant motivating factor, in Frick’s study of high-performing knowledge workers (Frick, 2011). It is also closely aligned with Maslow’s love and belonging needs defined in his Hierarchy of Needs (Maslow, 1943).

Although Maslow’s theory didn’t cover all aspects of motivations found within the lab, such as the factors of agency and achievement, overall there was substantial overlap of motives, particularly around Maslow’s higher-order needs that are more intrinsic in nature. The students exhibited concepts Maslow described, such as self-actualization and some aspects of self-transcendence, as they demonstrated a yearning to achieve their full potential, and also to impact society in a selfless way. When telling stories of their time in Luminosity, students mentioned many experiences that could be considered what Maslow called ‘peak experiences’ (Maslow, 1969). Peak-experiences are a criterion of self-transcendence and are experiences that lead to feelings of bliss or euphoria. The students interviewed exhibited many patterns found to be consistent with characteristics of self-actualized individuals. Students expressed a tolerance and openness to all other students in the lab and did not feel the need to pretend to impress others (Talevich, 2017). The students were independent and resourceful and did not rely on external authorities to direct them (Martela & Pessi, 2018). Additionally, the students were accepting of their own flaws, often with humor, and were easily able to cultivate deep and meaningful relationships with their colleagues (Talevich, 2017).

This study gives credence to Maslow's later revisions of his hierarchy, which are not commonly referenced in academia, relative to his original model. His final model included concepts of cognitive needs and self-transcendence, which were found to be motivating factors within Luminosity. Students expressed a strong desire to expand their knowledge and demonstrated a great sense of self-efficacy and self-regulation in setting and achieving their goals – goals that often resulted in the benefit of others. Although, it can't be said that the motivating factors expressed by students in Luminosity are the norm throughout the general population of college students, this study suggests that the identified motivational factors are effective in attracting and engaging high-performing knowledge workers with innovative mindsets. The interviews also suggest that prior to their involvement in Luminosity, these top-performing, highly motivated students were not having their full set of needs met in their other collegiate experiences. Overall, the motivations felt by the students, cultivated an environment within Luminosity that caused the students to believe that they were part of something bigger than themselves, and this was likely critical to their continued engagement, and why many of the students described Luminosity as the defining moment in their college careers.

The motivational drivers found within the lab were derived by an intentional design and structure of the lab, one that provided students agency in all aspects of ideation, design, decision making, and development (see Appendix A). In designing the lab, Luminosity's founder sought to omit faculty involvement and create a 'Skunkworks' environment that protected students from organizational bureaucracy, provided them with the resources they needed, and granted students agency and responsibility in leading projects from start to finish (Naufel, 2020). The students interviewed felt that these design aspirations were accomplished and conducive to their experience in the lab. As reported by the students, the function of the Luminosity's leadership and staff was focused primarily on motivating students within the lab, through a genuine interest in each student, and mentorship that provided confidence and reinforced the agency and trust given to them. Overall, the students in Luminosity gravitated toward the lab's mission to impact society, and remained engaged when they realized that, through their work, the lab was capable of achieving this lofty aspiration.

Students expressed recognition of the value and merits of faculty, but they felt that the student-led management style of Luminosity was conducive to their individual success. Students described experiences, outside of the lab, where they felt that their labor was being used to the benefit of the faculty member and that they experienced little intrinsic motivation within the faculty-led structure. Some students conjectured that the university's incentive structure for faculty may be to blame. The grant-oriented workflow pursued by faculty, as well as the restriction of their research work to primary domain spaces, were postulated as possible limiting factors. The master-worker relationship that students articulated often led to less personal connections and more strict management approaches. These experiences were demotivating to the Luminosity students. Students contrasted these faculty experiences to their experiences with Luminosity's founder and staff, who were also degree-seeking students. These staff members developed strong personal bonds, with the students, and allowed them to pursue projects with a clear value proposition, so long as it fit within the lab's mission to positively impact society. Overall, the students felt that the lab's staff was there to benefit them, not the other way around. Luminosity's design, which intentionally omits faculty management, created the space, ability, and agency for students to lead their own substantial R&D projects and to feel genuine ownership in the end result. It is likely that faculty could facilitate a similar process, and achieve a similar model, however it seems unlikely that this could be feasibly implemented without a change to the current structure of research universities.

It was not surprising to find that students enjoyed their applied learning experiences within Luminosity, over classroom learning. This was the result of the benefits they found working with teams on tangible, open-ended problems, and learning from the roadblocks they encountered. Students also critiqued the linear pathway of collegiate curriculum as limiting to those who were ahead of their defined roadmap. For many students within the lab, studying material within their curriculum that was not relevant to their career aspirations, or which had already been mastered, was a demotivating experience that occurred all too often. What was surprising, was that students found their lab experiences to be similar to what they experienced in their industry careers. In many cases, students also preferred their lab experience to their current places of employment - even when hired into highly sought-after career spaces in Fortune 500 companies. When this was the case, students explained it as the result of the motivating factors promulgated by the lab, specifically the agency and freedom they were given, the competency of the team, and the purpose of their work - which was not always experienced, even within some of the world's most innovative companies.

Although the majority of Luminosity students were enthralled with their time in the lab and viewed it as a defining moment in their young-adult lives, the lab's environment was not well-suited for everyone. Throughout the interviews, some students postulated about why certain individuals had left the lab. Students suggested these outliers may have been due to mismatches in personality or lab culture. One student believed that those who left may have needed a more structured environment and didn't enjoy the hands-off management approach of the lab. Given that the lab was designed specifically to suit the needs of self-motivated knowledge workers, this explanation is reasonable. Furthermore, in the early years of Luminosity, as the lab began to grow, it expanded rapidly to three additional locations. While these expansions were largely successful, there was one identified in a student's interview, which did not capture the true spirit of Luminosity. The student, who had participated across locations, suspected this location was not successful since this lab had not been formed around a tangible initial project for the students to rally around and leverage their hard skills on. Rather, this location attempted to be more of a 'think-tank' group, as students from this location were studying fields of humanities, journalism, and law. This was in contrast to the other locations who had populations of predominantly engineering and design students. This led to a lack of motivation and excitement, which ultimately caused students to fizzle out of this particular lab expansion.

Limitations

This study represents the views of students participating in The Luminosity Lab. Therefore, the conclusions are mostly applicable to these top-performing, highly motivated students. This study was not intended to apply to all collegiate students or student participants within other labs. Some of the elements reported within the students' interviews may be specific to the individual and/or their environment, and therefore generalization should be left up to the reader.

This study contains inherent limitations due to the interviews having been conducted by Luminosity's founder, who the students had worked beside throughout the years. Whereas the study found that students viewed the lab's founder as a mentor and advocate, rather than an authoritative figure, the possibility still existed for interviewer bias. Students were asked to share information both positive and negative related to the lab and were informed that honest answers would benefit the study and ultimately the improvement of the lab's model. Since the students felt great ownership over the lab, the author believes that students were authentic in what they conveyed during their interviews. The pride and ownership students felt about the lab, made it difficult to elicit disconfirming cases. The author also believes that, despite potential drawbacks, there was added value to this interview approach, since the interviewer was intimately aware of the lab's environment and could contextualize the students' responses and the phenomena that the study sought to explore. The students interviewed were not made aware of the hypotheses being explored and this helped mitigate potential instances of demand characteristics. Future research of the lab could benefit from interviews conducted by an external research panel, as well as, anonymous, quantitative analysis for comparing this model and its students to alternative research groups.

Implications & Future Work

While these findings are limited in their generalizability, they suggest many intriguing implications. The findings imply that highly talented students at universities, who are ahead of their defined curriculum trajectories, may have certain unmet needs – needs that would allow them to self-actualize and reach their full potential.

This study suggests that colleges and universities should consider adopting a new, 21st century model of discovery and innovation that allows undergraduate and graduate students to have the agency in leading meaningful R&D efforts through the full project lifecycle. This model is intended to be complementary to existing academic environments and would not replace existing faculty-led efforts, as both have distinguishable merits.

This study demonstrates a prototype for an interdisciplinary, student-driven model of innovation and discovery at the collegiate level. Further work is necessary to explore the generalizability of this model outside of its originating environment and conditions. An anonymized quantitative study that surveys Luminosity students and students from comparative models, would help confirm and formally establish the performance, experiences, and outcomes of students within the proposed model. While scalability is implied, further research is required to understand if that model is truly scalable, both financially and otherwise.

Conclusion

Luminosity has demonstrated itself as a student-driven lab that is capable of successfully developing innovative solutions to complex challenges, as well as engaging high-performing, highly motivated knowledge workers. This study explored how Luminosity differentiates itself from traditional labs and learning experiences, and the study sought to understand the motivations driving students within the lab. When compared to traditional research labs, Luminosity was found to be unique in that, by design, it omits faculty oversight and enables students with a true sense of agency and autonomy in pursuing R&D efforts. Furthermore, Luminosity was described to be more open-ended than traditional labs and this freedom increased students' interest and provided them additional room to explore and learn things outside of their defined academic major. The community within the lab was found to be stronger than that within traditionally structured research labs. Students expressed this as a result of the collective competency of Luminosity students, as well as the deep relationships that they formed. Similarly, the students' learning was improved by the environment in Luminosity, which allowed students to tackle real-world challenges, and learn from their peers through the process of teaching one another. Students found a sense of holistic learning that they did not find in the classroom, and they were encouraged to learn things outside of their academic major, which they viewed as important for the future of the workforce. Students preferred their time in Luminosity over their alternative research and industry experiences as a result of the motivating factors they felt within the lab. This study found that the students within Luminosity were motivated by a purpose of impacting society, an affinity for their co-workers, a sense of competence and achievement, a desire to acquire and disseminate knowledge, and through the agency and trust that they were given. These intrinsic motivators were the reason students joined the lab, found success, and remained a part of the lab until their graduation, despite having other promising opportunities. The students rejected old, process-based motivational theories, in favor of more recent intrinsic-based motivational frameworks, such as Motivation 3.0. The lab's design and leadership structure promoted these motivational factors and created an environment in which students believed they were part of something bigger than themselves.

CHAPTER 5

CONCLUSION

This dissertation explored Arizona State University's Luminosity Lab, which has established itself as a novel, student-driven model of research and development for the 21st century. This model was analyzed to determine the following: i) Can a collegiate, student-driven interdisciplinary model of innovation designed for the 21st century perform without faculty management? ii) What are the motivators and culture that enable student success within this model, and iii) How does Luminosity differ from traditional research opportunities and learning experiences?

The ability of Luminosity to perform was demonstrated through a proof of concept review of the lab, in which the lab's design, processes, and outputs were explored. This proof of concept demonstrated Luminosity's ability to successfully design and develop highly complex projects in the areas of healthcare, energy, and education, without the oversight of faculty members. Last year (FY2020), the lab established an additional revenue stream of $1.33 million from grants and corporate partners, obtained 7 provisional patents, and engaged over 100 students from various academic disciplines. Through a qualitative analysis of current and past members of Luminosity, a set of motivating factors were identified that were essential to the success of the lab. The motivations identified within students of Luminosity were: i) purpose of impacting society, ii) affinity for co-workers, iii) sense of competence and achievement, iv) desire to acquire and disseminate knowledge, and v) agency and trust. These motives aligned with existing models of motivation, especially those that have been found to be critical to high-performing knowledge workers. The motivating factors within the lab were shown to be the impetus for the attraction and continued engagement of highly talented students, and were the differentiating factors when students compared Luminosity to their other industry, learning, and research experiences. Similar to the students of the University of Bologna in the 13th century, who were given agency over their institution, students in the 21st century are looking for agency in their collegiate experiences. Strict and rigid management styles were reasons that students differentiated and preferred their experiences in Luminosity to their experiences in traditional research lab structures. The students interviewed rejected carrot and stick approaches to management, as well as linear and stringent learning curriculum within academia.

This study highlighted Luminosity's processes and approach; however, these processes were not often discussed by students in their interviews. Students spent their time elaborating on their motivations, experiences, and the group dynamic of the lab - attributing success to the culture of the lab, not process itself. Rather, the processes of the lab were valuable in that they were designed to promote the culture and motivating factors that enabled students with purpose, agency, competence, and a sense of belonging.

A review of literature found Luminosity to be a unique model of interdisciplinary research and development within collegiate environments. The model is primarily unique in its omission of faculty oversight, and genuinely allows students to lead the identification, design, development, and deployment of substantial research and development projects. This study suggests that there is a need within colleges and universities for student agency in pursuing research and innovation, which is not currently being met. Luminosity's model, which does not require faculty involvement, shows that a cost-effective, scalable model of innovation can be achieved to address this need. The model established within Luminosity, if replicated and scaled to additional universities around the world, has the potential to spur a new wave of innovation to meet the challenges of the 21st century. Luminosity started with humble beginnings and has been able to scale rapidly, providing countless peak experiences for the students it engages. In the words of Jessie, a founding member of Luminosity, “You cannot forget that we started out as a rambunctious group of kids. In this room in the middle of nowhere and in the middle of the night. And look at us now. We have establishments all over Arizona and in other parts of the country. All kinds of people are interested in working with us, whether it be companies or students within the university... And I'm glad that I've been able to be a part of that. I don't think I'm ever going to forget it.”

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APPENDIX A

DESIGN & OPERATING PROCEDURES

Luminosity's Vision & Mission

Vision. To establish a new model of discovery and innovation for the 21st century driven by a lean, interdisciplinary group of exceptional scholars who fuse youthful spirit with intellectual prowess and business acumen, and who strategically leverage their position within an academic institution to take risks and produce radical innovations capable of impacting society.

Mission. To utilize strategic design, systems thinking, and rapid product realization to develop and deploy ideas, tools, and technologies that provide unconventional and effective solutions to complex challenges.

Our Approach

Luminosity utilizes a systems engineering approach to project planning and design, and drives projects forward with an Agile methodology (Srivastava et al., 2017) that allows the organization to quickly handle and adapt to change. As defined in our Mission, The Luminosity Lab prides itself on systems thinking, strategic design, and rapid-product realization. These approaches complement Luminosity's core ideologies and are defined as follow:

Systems Thinking. Luminosity utilizes systems thinking as a comprehensive and holistic approach to solving problems (Checkland, 1999). Instead of deconstructing and analyzing components as distinct elements, systems thinkers work to analyze the system as a whole through the exploration of the relationships between components and seek understanding on how these relationships affect the system's behavior over time. Luminosity members are prepared to recognize and handle properties found within complex systems, including: nonlinearity, stochasticity, interdependencies, and feedback loops (Naufel, 2020).

Computer simulations, as well as visual tools, such as diagrams and graphs, are used to model, illustrate, and predict system behavior and allow Luminosity to tackle real problems with holistic solutions that lead to lasting societal impact. Luminosity uses the Systems Development Life Cycle (SDLC) for planning, analyzing, designing, implementing, deploying, and maintaining solutions and services which address identified needs.

Furthermore, Luminosity leverages a view model to evaluate systems and their environments from various viewpoints. These viewpoints, categorized as follows, are tailored to help breakdown and understand existing and future systems (DoD, 2007; ISO/IEC/IEEE 42010, 2011; ISO/IEC 10746-1, 1998):

- Enterprise Viewpoint - is concerned with the purpose and behaviors of the system as it relates to the organization's objectives and processes.
- Information Viewpoint - is concerned with the nature of information handled by the system, as well as the constraints on the use and interpretation of that information
- Computational Viewpoint - is concerned with the functional decomposition of the system components that exhibit specific behaviors and their interactions at interfaces
- Engineering Viewpoint - is concerned with the mechanisms and functions required to support the interactions of the computational components

- Technology Viewpoint - is concerned with the explicit choice of technologies for the implementation of the system and the communications among components
- Services Viewpoint - is concerned with articulating the Performers, Activities, Services, and their Exchanges that support or provide operational and capability functions.
- Standards Viewpoint - is concerned with the operational, business, technical, and industry policies, standards, guidance, constraints, and forecasts that apply to capability and operational requirements, system engineering processes, and systems and services.

As System Thinkers, Luminosity Prefers

- Interconnectedness over Discontinuity
- The Whole over the Parts
- A Circular Approach over a Linear one
- Synthesis over Analysis

Strategic Design. Luminosity uses Strategic Design as a method to leverage future-oriented design principles for envisioning and planning future systems. These systems are focused on addressing 'big-picture' challenges in domains, such as education, healthcare, energy, and sustainability. Strategic Design is guided by the use of data analytics and anecdotal evidence to inform design features. By blending aesthetics with practical functionalities, strategic design produces consistent, effective, innovative, and resilient solutions. To complement this process, Luminosity uses Design Thinking (Brown, 2008) as a human-centric approach to problem solving. This process involves empathizing with people to understand and define problems, discovering solutions through convergent and divergent thinking, and iterating through cycles of prototyping and user testing. With Strategic Design, Luminosity bridges innovation, research, management, and design to produce strategic and actionable plans that lead to implementable solutions.

As Strategic Designers, Luminosity Prefers

- Data-Informed Design over Intuition
- Systemic Solutions over Inconsequential Pursuits
- Meaningful Visualizations over Aesthetics
- Actionable Plans over Spontaneous Actions

Rapid Product Realization. A core competency of Luminosity is the ability to quickly perform all work needed to develop, manufacture, and deliver finished products, solutions, or services. An Agile approach to project management is followed to achieve this aim and positions the organization to adapt and respond to change. Rapid-prototyping and effective iteration cycles transform ideas into delivered solutions. Luminosity understands that process alone is not enough to be successful, and that people are the most important factor in the rapid and effective execution of tasks. Luminosity maintains strong leadership and talent within the organization and is committed to the continuous development of its members. Beyond focusing on individuals, Luminosity thrives on the synergy created from collaborative teams. This dynamic is achieved through cultivating and sustaining a strong group identity.

As Agile Developers, Luminosity Prefers

- Individuals and Interactions over Processes and Tools
- Working Systems over Comprehensive Documentation

- Responding to Change over Following a Plan

Luminosity Culture

Extraordinary Expectations. Luminosity members recognize and aspire to achieve the extraordinary expectations set for them. The lab exists to design and deploy complex and novel systems that will improve society. Furthermore, the students acknowledge, embrace, and take ownership of this as their task.

The members dream big, take risks, and are fearless in their pursuit of the unknown. They constantly strive for self-improvement and empower those around them. Members carry a belief that anything is possible and recognize their time in Luminosity as an opportunity to accomplish great things.

Ambitious expectations, while daunting, motivate members with a passion of being in a great group and working towards meaningful outcomes. The expectation that the lab can and will change the world is the binding mission that brings us together.

Inclusivity & Collaboration. Individuals in Luminosity recognize that great things are not achieved alone. They appreciate the importance of collaboration and maintain a passion for sharing their talents with others for the betterment of the whole. Luminosity members cherish working with students from all backgrounds and do not discriminate on the basis of race, nationality, gender, or religion. Rather, the diversity of the membership is celebrated and appreciated.

Members acknowledge that everyone adds value to the lab, regardless of age or academic background. Through collaboration, Luminosity is able to synthesize various viewpoints, talents, and thoughts into well-informed designs and solutions. With time, members come to understand that the smartest person in the group - is the group itself.

Humble Confidence. Members of Luminosity are confident. They trust their abilities and acknowledge their shortcomings. They believe that they are capable of learning anything and that, with time and resources, any problem can be solved. Confidence allows members to admit mistakes and learn from them.

Lab members do not stake individual claims on accomplishments, and do not fight to take sole credit for their successes. They have the confidence to know that boasting is not necessary and understand that the value they bring is substantial and will be recognized.

Confidence allows Luminosity members to openly present their ideas and receive criticisms graciously. Furthermore, members are expected to and are comfortable with providing constructive critiques to others.

Luminosity members are okay with being temporarily uncomfortable and are happy to tackle ambiguous challenges. Members enjoy engaging in experiential learning with a ‘trial by fire’ approach.

Passion for Improvement. Luminosity members love to build and genuinely enjoy seeing things improved. They yearn to be part of something bigger than themselves and achieve this through developing ideas, knowledge, services, and physical solutions. Luminosity members walk into all situations thinking, ‘how can I add value?’, and have a passion for working towards the betterment of the organization, its members, and the projects. Members engage in initiatives with an altruistic desire to create solutions that add value and prioritize this over the aim of achieving financial gain.

Luminosity members believe in continuous improvement. They constantly self-reflect and analyze the world around them with the intent of identifying needs and taking corrective actions. Luminosity members are always willing to help out wherever a need presents itself.

Creative Energy. Luminosity members are creative spirits who strive to produce new ideas. They constantly daydream and synthesize existing knowledge with new experiences to develop novel thoughts. Luminosity members are self-starters and are capable of setting and achieving their goals. Members do not wait for assignments to be productive. They create and pursue their own tasks which align with the mission of their projects and the organization as a whole. Luminosity members take initiative and think through solutions, rather than dwelling on problems.

Positive Spirit & Good Heart. Luminosity members maintain a positive mindset and an attitude that even in the worst of times, they are capable of improving their situation. The members' positive spirit promotes passion and energy within the operations of the organization. This spirit is the magnetic attraction that draws others to the group.

The students recognize that negative thoughts tend to reinforce negative results, and that positive thinking often produces favorable outcomes and beneficial opportunities. They do not waste time or energy complaining. The tenacity required to maintain positivity during times of adversity is a strength that uniquely characterizes members of the lab.

Furthermore, Luminosity members have good and true hearts. They exhibit kindness to all and listen to others. They are always willing to help those in need and will selflessly sacrifice their time and energy for others. Members are quick to forgive and slow to anger. They empathize with others, which makes their design of solutions better informed and more humanistic.

Trust in the Process. By design, Luminosity is an intense and exhilarating environment filled with uncertainty and new experiences. Luminosity members thrive in this environment because they trust in each other, the process, and the leadership of the organization. Members respect each others' abilities regardless of academic background and recognize the intrinsic strengths that each individual brings to the table. Luminosity members are patient and acknowledge that great pursuits are not achieved overnight. Members trust leadership to handle decisions pertaining to membership and project life cycles. Trust and respect allow members to move forward confidently in the pursuit of the mission and vision of the organization.

Project Life Cycle Overview

Stage Gate Process. As new projects get chartered and launched, they will follow a formal 'stage gate' process to ensure the success of the project throughout its lifecycle. Each Luminosity Project will follow the stage gate process outlined below. Luminosity's Executive Team, as defined within the section on Organizational Structure, is responsible for conducting the review at each stage gate to determine whether an idea/project will move past the gate, be sent off for rework, or be terminated. The Executive Team is responsible for establishing a formal rubric that each gate will be assessed by.

Initiating a Project. Aside from formally held ideation sessions, ideas often come about organically. Commonly, students will have an identified area of interest for exploration or an identified problem that needs solving. When either of these occur, students will strive to articulate the problem and produce a general direction for possible solutions. At this stage in the process, the student that initiated the concept will be responsible for gathering interest and support from other Luminosity members. This student can hold and lead unofficial meetings and working sessions with other Luminosity students, and these students will self-organize around the goal of developing the concept into something concrete. When the initial idea has been developed to the point where (a) a problem has been clearly identified and articulated and (b) a general direction for solving the problem is outlined, the students will approach the lab's Director, and this will initiate the first review gate. Arriving at this gate does not have to take long and can take anywhere from an hour to weeks.

First Review Gate. Luminosity's executive team will review the idea to determine if the concept fits within the scope of the lab and is worthy of moving through the remainder of Luminosity's project life cycle. This determination will be made based on initial considerations around Societal Need/Impact, Competitive Landscape, and Feasibility. These considerations are detailed in the life cycle process sections below. This gate will be a simple and quick review. If a project does not pass this gate, it will not be considered a Luminosity project, and can be pursued outside of the organization. If the idea is approved, the official ideation process will be initiated. Luminosity staff will work with the leading student to schedule the official ideation sessions and place them on the Luminosity calendar for all students to be aware of. This development will be announced at the next bi-weekly full team meeting.

Once a project has entered the ideation phase, it will follow the Ideation Phase processes outlined within this document's 'Project Life Cycle Processes' section.
The ultimate goal of these ideation sessions is to create and submit a project charter to the lab's director. This charter should be developed using the information provided in the succeeding section on Project Charting.

Second Review Gate. The second review gate is initiated once a project charter has been submitted. Luminosity's executive team will review the details of the charter and make a determination on whether the project should move on to the planning phase. If a project doesn't pass the gate it can be sent for further work, or can be terminated indefinitely.

Projects passing this gate will be assigned a project level and will enter an initial planning phase, as defined in the Planning Phase section below. Based on the project's level, the planning phase will warrant different requirements. The Project Level section below provides a guideline on what should be produced for each project level.

Third Review Gate. The third review gate begins upon the lab's director receiving the project plan. At a minimum, this should include a product backlog of tasks, the number of planned iterations, and defined project teams. Student leadership and Project Sponsors will be finalized in this phase. If a project passes this gate, then development on the project will officially begin and will follow the process outlined below in the section titled, 'Development Phase'.

Recurring Review Gates. Once a project is in development or maintenance, it will be reviewed by the executive team twice each semester. Once in the middle of the semester, and once at the end of a semester. During these reviews, Earned Value

Management - described later in the Standard Operating Procedures - will be used to track projects in development, and a tailored rubric will be used to assess deployed solutions. Based on the results of this review, recommendations to the project's leadership will be made and there is always a chance that a determination to decommission the project will be made, however this will usually only occur after a period of time is allocated for realignment.

Project Life Cycle Processes

Ideation Process. The ideation process is the most important system in the Luminosity Lab. It allows for novel ideas to be presented/reviewed by all stakeholders in a respectful and thoughtful manner. These methods allow for all voices to be heard and fosters trust within the lab. It is imperative that leadership consistently ensure there is respect for every stakeholder's opinion within these sessions. The ideation phase is iterative and continuously rotates between processes of ideation, design, and review. Throughout the ideation phase, convergent and divergent thinking is used to explore broad areas of opportunity, and later allows the team to narrow into a focused problem space from which a single project can be derived.

Ideation Sessions. The process of ideation begins with a pre-identified need or problem. Alternatively, this process can begin with the exploration of a chosen domain for the identification of needs. Industry experts external to the lab are encouraged to be brought in to assist in discovering unmet needs and to help identify where solutions can be created to produce value. The group will be asked to discuss ideas that lead to resilient, efficient, and feasible solutions. Designated ideation meetings are an opportunity for participants to propose concepts without worrying that their ideas will be criticized. The ideation process is one of concept creation and heavy criticism of these concepts are reserved for review sessions.

During brainstorming sessions, participants will be asked to wear two hats as specified by the de Bono Group's Six Thinking Hats (de Bono, 1985). These hats are:

- The Yellow Hat: "Symbolizes brightness and optimism. Under this hat you explore the positives and probe for value and benefit."
- The Green Hat: "Focuses on creativity; the possibilities, alternatives, and new ideas. It's an opportunity to express new concepts and new perceptions."

The meeting will conclude with the prioritization of ideas and the establishment of next steps for evolving the identified concepts.

Design Process. The design process of ideation is conducted for the purpose of evolving ideas into conceptual models. These can be held as separate meetings or as a subsection of ideation meetings. Visualizations will be developed to aid the understanding of a problem and the proposed solution. Prototypes and Wireframes may also be developed during design sessions to assess whether the proposed solution has the ability to address user needs. The design process should be iterative and agile. Designs will be reviewed each week in ideation meetings for feedback. Ultimately, the conceptual designs will have a large influence on determining whether or not a project should be pursued for development.

Review Process. The review process of ideation exists for the purpose of criticizing, evolving, and vetting ideas proposed throughout the ideation process. Review meetings will be held in lieu of ideation meetings at the discretion of the student lead. These meetings help the originators of a concept reach a formal decision as to whether they want to submit an official Project Chartering document. Reviews are designed to be an opportunity for critique and help to filter out projects which are not mature enough to reach the Project Chartering process. It is encouraged to invite participants who are not familiar with the proposed solution to allow for genuine critique of the idea.

Participants will be asked to wear a different set of de Bono Hats during the review process (de Bono, 1985):

- The White Hat: "Calls for information known or needed. 'The facts, and just the facts'"
- The Black Hat: "Represents judgement – the devil's advocate or why something may not work. Spot the difficulties and dangers; where things might go wrong."

Throughout the various aspects of the Ideation Process, participants should be working toward the creation of a project charter as outlined below.

Chartering Process. The project chartering process is intended to allow all stakeholders of the lab to start and guide projects towards an ideal exit strategy. It is a methodology for all participants to discuss novel ideas without hindering creativity. The lab recognizes that enforcing too much structure on a project can stifle the creative process, but an absence of structure can lead to lack of direction. This process is also designed to address the temporary nature of projects, so goals and ending criteria must be established.

Maturity. Once an idea has been developed, the project chartering process can begin. Typically, it begins with discussing the high-level goals of the project and how they will be implemented. Project maturity should be addressed and is defined by the following criteria.

Societal Need/Impact. The project being developed must have a positive impact on society. This includes the intended use-case, but more importantly the unintended use-case. For example, if you want to develop a service which detects errors in research papers, it could also have false positives which result in harming a scientist's reputation. The product must also have an ideal customer outlined (the End User Profile). This allows the future chartering document to have a target audience and helps narrow the scope of the project.

Feasibility. The project must also have a realistic level of complexity which factors in current availability of technologies, scope of work, and project level. Usually, the timeline for a Level III project is on the order of years, while Level II and Level I projects are measured in months. See below for a further description of project levels. The scope must not include technologies which are severely unrealistic given the current state of technology. For example, if the project were created in 2018 and it requires the lab funding a mission to Mars, the idea would be considered infeasible due to lack of budget. If, however, the project included a partnership with existing companies who could provide that funding, it would be considered feasible. The scope of work must also match the project level and the budget must be considered for the lifetime of the project. If the costs are high compared to the desired effect on society, it should be considered infeasible due to lack of societal impact.

Competitive Landscape. There must also be research into the current competitive landscape around the project. This includes an analysis of products which exist that are similar to the proposed idea. A visual representation of this using a two-axis graph is highly encouraged. A stakeholder should be able to look at the competitive diagram and form an opinion about the novelty of the project. Honesty is crucial in this step to avoid recreating something which has already been done successfully. However, many great companies are minor tweaks of existing solutions, so competition does not mean that the project cannot be pursued. However, there must be documentation of the intended benefits over existing products.

Project Chartering Document

A project is formally chartered by submitting a Project Chartering document to all stakeholders of the lab, including the students who would be regularly contributing time as well as the leadership of the lab. A Project Chartering document contains the following sections (at the minimum).

Introduction. Explanation of the problem and a brief outline of how the project will solve it. This is intended for high-level stakeholders to be able to understand the project without fully reading the Project Chartering document. The Level of the project should be included.

Vision. Outline the "dream state" for the end result of the project. For example, if it is to create a null results database for researchers, the vision would be, "Evolve the way researchers view and use null results to promote scientific collaboration."

Problem Statement. Describe in detail the problem which the project has set out to address. This must be in the beginning of the document to give context to the solution. The solution should not be included in this section.

Period of Performance. A basic outline of the begin/end date of the project should be considered. This should align with the proposed Level of the project.

Scope of Work. The scope of work gives a detailed description of the desired outcomes of the project. It should detail what it is trying to accomplish; as well as, features not included in the scope. This should be the most detailed section of the document and give the reader a clear, concise understanding of the goals. The project manager should be able to use this as a template for building out milestones and features to be delivered.

Deliverables: Outline the main components being delivered. Every main software/hardware element should be listed here. This should be in an easily digestible form to allow readers to recap what was discussed in the scope of work.

Operating Costs: Detail the monthly costs of the services/products which will be built. These are expected to be rough estimates from the initial deliverables.

Timeline: A detailed visual timeline with main events should be described. This should include building the team, forming main components for the project, and eventual project end and exit strategy.

Members. The ideal members should be outlined with all roles defined. This should be realistic in accordance with the timeline given.

These sections are crucial to starting a new project and provide all stakeholders with reference documentation for the proceeding planning phases.

Example Chartering Document

Introduction. Project Phoenix will be an application which provides a platform for scientific researchers to anonymously share their null results with limited effort and the incentive of potentially gaining authorship on related projects. This will result in a database of null results, allowing researchers to learn from the limitations of failed experiments and reducing the risk of redundancy in scientific research. Further, this application will serve as a tool to increase collaboration and communication within the general scientific community. This is proposed to be a Level III project.

Vision. Evolve the way researchers view and use null results to promote scientific collaboration.

Problem Statement. Null results are usually not shared in scientific research, as they risk the reputation of the author and require large amounts of work for a relatively low reward. As a result, there is redundancy, wasted data, and a general lack of collaboration in scientific research.

Period of Performance. The development shall commence on 10/1/2018 and shall continue through 5/1/2019.

Scope of Work The members shall provide the Services and Deliverable(s) as follows: The scope of work includes all planning, design, and development for an minimum viable product of Project Phoenix. Project Phoenix will include an interface which allows a researcher to quickly provide basic information regarding themselves and their purpose for accessing the database, allowing the application to quickly serve the researcher's needs. A researcher will then be able to publish abstracts or short summaries of their null results anonymously using this log-in, or choose to have their name tied to it. Project Phoenix will also include an interface allowing a user to quickly search through and navigate the abstracts in the database. If the user then decides to learn more about a specific article and how it may relate to their work, they will be able to communicate with the author through the application. Once this communication is established, there will be a mutual agreement that any follow-up work which is done regarding the initial article will result in co-authorship for the author of the abstract. The enforcement of this will be outside the scope of this project. There will also be an interface for searching abstracts easily, and flagging/saving them for easy access in the future.

Deliverable Materials. To summarize, the deliverables due at the end of this project are as follows:

- An engaging interface capable of searching and contacting authors of abstracts.
- A backend which allows user sign-up, content creation, and facilitates user communication.

Project Timeline

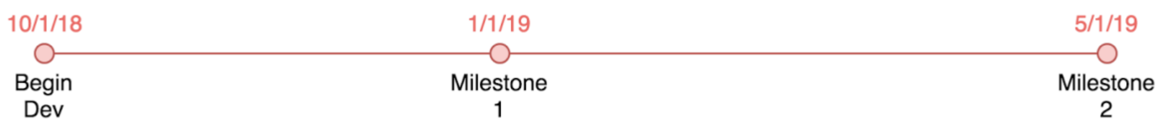

Figure 7. A high-level example timeline.

The project will follow the timeline above, with the major milestones of:

- 10/1/18: Project kickoff, Luminosity begins development of UI and API layer.
- 1/1/19: Milestone One is reached with an initial deliverable of a web app which is capable of user sign-up, basic search functionality, and abstract creation.
- 5/1/19: Milestone Two is reached with the second iteration on the prototype with a more advanced UI, further search capabilities, flagging and saving abstracts, and user profile page.

Initial Technologies

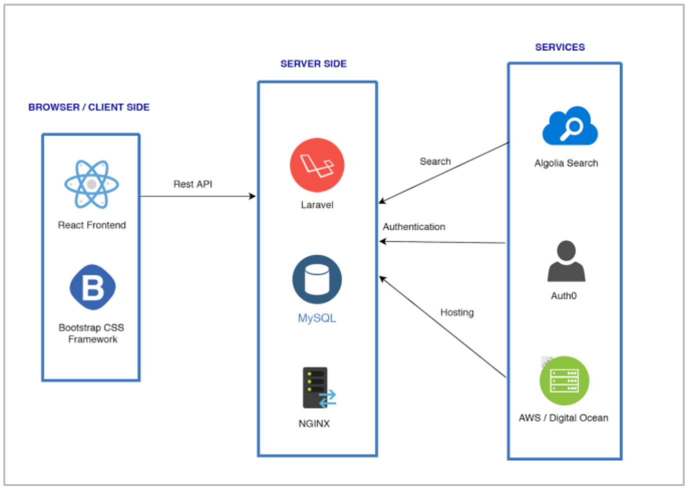

Figure 8. Example architecture of full-stack technologies used within the lab.

Cost Estimation

Table 5. This table highlights an example of project cost breakdowns.

Service	Expected v1 Cost	Expected v2 Cost
Algolia Search	Free (10K search record limit)	$35+/month
GCP	$20-30/month	$40-50/month
Auth0	Free (but 7,000 users limit)	$13+/month

Members

- Project Manager - Nikhil Dave
- Software Team Lead - Shivam Sadachar
- Software Team Member - Luke Mains
- Project Sponsor (Software) - Chase Adams
- Project Sponsor (Vision) - Robb Olivieri

Project Levels. The project chartering document must define a “Level” to be considered. This is driven by the deliverables of the project, resources needed for completion, and how long the project will take to reach its exit strategy. *Implementer* as used below is defined as the person(s) responsible for designing or building a project from start to completion. If a project requires more than the maximum in a category, it is elevated to the next Level. The Levels are outlined in ascending order.

Level I Classification. A Level I project is defined as needing the following resources:

Table 6. An example breakdown of project implementers, timeline, and costs for a Level 1 project.

Implementers	Timeline	Projected Operating Costs
3-4 students	3-6 months	<$300/month

Requirements. A Level I project would require at minimum the following documentation before starting development:

- *Chartering Document* detailing the scope, timeline, key members, and other information as listed above.
- *Project Presentation* which describes the project at a high level in a slide-deck format to stakeholders.
- The project is required to have at least one meeting per week.

Level II Classification. A Level II project is defined as needing the following resources:

Table 7. An example breakdown of project implementers, timeline, and costs for a Level 2 project.

Implementers	Timeline	Projected Operating Costs
5-6 students	6-12 months	<$600/month

Requirements. A Level II project would require at minimum the following documentation before starting development:

- *Chartering Document* detailing the scope, timeline, key members, and other information as listed above.
- *Project Presentation* which describes the project at a high level in a slide-deck format to stakeholders.
- *As-Is and To-Be Visualizations* of the existing and reimagined processes. This is in storyboard format to graphically illustrate the vision.
- The project is required to have at least two meetings per week.

Level III Classification. A Level III project is defined as needing the following resources:

Table 8. An example breakdown of project implementers, timeline, and costs for a Level 3 project.

Implementers	Timeline	Projected Operating Costs
7+ students	12+ months	$600+/month

Requirements. A Level III project would require at minimum the following documentation before starting development:

- *Chartering Document* detailing the scope, timeline, key members, and other information as listed above.
- *Project Presentation* which describes the project at a high level in a slide-deck format to stakeholders.
- *As-Is and To-Be Visualizations* of the existing and reimagined processes. This is in storyboard format to graphically illustrate the vision.
- *Beachhead Market and End User Profile* which defines the target market which the product will be built for and its ideal user.
- *Product Backlog* to represent the initially scoped milestones and user stories to be completed.
- The project is required to have at least two meetings per week. It is also required to be managed with Scrum/Agile methodologies. It is recommended to follow 2-week sprints with an established product backlog. This ensures a professional level of project management and more efficient input from stakeholders.

Chartering Proposal Analysis

All participants who are responsible for analyzing a Chartering Proposal grade the project on a 1-5 scale based upon the outlined criteria above and include a brief reasoning for each score. For example, a project around recreating electronic health records could be graded as:

- Societal Need/Impact: 5 – "The proposed impact could permanently change healthcare."
- Feasibility: 4 – "The project will be large in scope, but achievable given Level III status."

- Competition: 5 – "Competition exists but is extremely outdated and difficult to use."

The submissions would be regarded as anonymous to ensure honesty. Each would be discussed and if the reasoning is valid the score would be included in a running average. After all scores are discussed, the project is voted upon for chartering. There must be a 75% consensus in order to charter the project, with the Director reserving the right to override the final decision. If the project is denied chartering, the originator may iterate on the proposal to address the concerns presented by her/his peers and resubmit to the group.

Project Management Phases

The management of the lab recognizes that every project is encouraged to be highly exploratory in nature. This is atypical for organizations in industry and calls for a different method of management to ensure success. The Agile framework is purported to be the solution for modern project management, but it does not adequately address systems which are highly complex and ill-defined. Therefore, the lab has implemented a solution which incorporates the most important facets of Phase-Gate (Waterfall) (Royce, 1987) and Agile project management methodologies (Srivastava et al., 2017), Lean Startup business strategies (Ries, 2011), and Design Thinking (Brown, 2008) approaches to ensure projects are well-defined while also being capable of adapting to ever-changing requirements.

Planning Phase. The planning phase is devoted to exploring the existing competitive/regulatory/social landscape around the product and forming opinions about eventual features it should include. The goal of this phase is to ensure that the components being built will solve a problem for the end user. Refer to the above Level definitions for the requirements for the planning phase.

As-Is & To-Be Modeling. As-Is modeling is the process that helps developers define the current state of the system. Often this is a visual process that leverages storyboards and enterprise modeling techniques to help describe the system's behavior and its actors. Once an As-Is model is completed, the team can then develop a To-Be model, which represents the ideal state of a future, redesigned system. This model provides the team with an artifact that can be vetted by stakeholders and iterated upon as requirements are revised and expanded.

Product Backlog. The Product Backlog is a representation of the initial and best-understood requirements of a project. The Product Backlog changes as the needs of a project change and is ultimately determined by the project team. The team will be responsible for eliciting, defining, and specifying user requirements which are eventually translated into a Product Backlog that will be used throughout the Scrum process. This is expected to be capable of constant change due to evolving requirements. The Product Backlog should be organized into Milestones which are further broken down into user stories. The Product Backlog consists of all tasks which need to be completed over the timeline of the project.

Development Phase. Every project in the lab is managed using a modified Agile framework. Software projects in particular are managed using Scrum. Agile is a framework that reflects the way in which the lab operates. The Agile Manifesto was released in February of 2001 and called for a development process that encompasses the following principles (Beck et al., 2010):

- Customer satisfaction is the highest priority. This can be achieved through early and continuous delivery of valuable results.
- Receptiveness to change. Agile processes welcome changing requirements anywhere in the development lifecycle.
- Projects should be built around motivated individuals. They should have the space and support they need and should be trusted to get the job done.
- Continuous focus on technical excellence and great design.
- The most effective method of communication during development is a face-to-face conversation.
- The team should continuously reflect on how to become more effective and adapt appropriately to address these issues.

The Scrum Process

Sprint Planning. Before each sprint, a Sprint Backlog is prepared from the Product Backlog. This is done by holding a Sprint Planning meeting at the start of the sprint, where team members figure out how many items they can commit to and then create a Sprint Backlog – a list of the tasks to perform during the sprint.

The format of these meetings is driven by the Product Backlog, which is continuously updated by the Product team. In the Sprint Planning, from the highest priority story to lowest:

- The motivation behind the user story is discussed at a high level.
- The implementation details are considered.

- Detail is added to the story definition so that any member of the team could work on it.
- Each member has a chance to ask final questions around the goal of the task.
- The leader of the meeting provides a countdown and the members vote on the "story points" for each story.

This is repeated until there are enough stories in the Sprint Backlog for the team to complete.

Standup Meetings. Typically Scrum requires a daily meeting to address current progress, but it is recognized that students do not have time for this. A Standup Meeting is held at least once a week (and for Level III projects, at least twice a week) to address this. All team members should attend these meetings, including all leadership. During that time, team members share what they worked on the prior day, will work on that day, and identify any impediments to progress. This is a way to synchronize the work of team members as they discuss the work of the sprint.

Sprint Review. The Sprint Review meeting is very informal and intended to provide an update to members of the team for what has been accomplished in the sprint. A sprint review meeting should not become a distraction for the project team. It is usually used to show a new feature that was implemented, a new tool which has been discovered, or a piece of an end deliverable that was built.

Sprint Retrospective. The Sprint Retrospective is used to find opportunity to improve. Although a good Scrum team will be constantly looking for improvement opportunities, the team should set aside a brief, dedicated period at the end of each sprint to deliberately reflect on how they are doing and to find ways to improve. This occurs during the sprint retrospective.

The sprint retrospective is almost always the last thing done in a sprint. Many teams do it immediately after the sprint review. The entire team should participate. You can schedule a scrum retrospective for up to an hour, which is usually quite sufficient. However, occasionally a hot topic will arise, or a team conflict will escalate, and the retrospective could take significantly longer.

Although there are many ways to conduct an agile sprint retrospective, our recommendation is to conduct it as a start-stop-continue meeting. This is perhaps the simplest, but often the most effective way to conduct a retrospective. Using this approach each team member is asked to identify specific things that the team should:

- Start doing
- Stop doing
- Continue doing

This allows the team to iterate and change their processes to continuously improve and become more efficient.

Project Verification & Validation. The process of Verification & Validation involves answering the two following questions:

- Verification: Are we building the system right?
- Validation: Are we building the right system?

Verification is the process of making sure the system being developed satisfies the defined requirements, while Validation is the process of confirming the system meets the end user's needs. The process of Verification & Validation should be conducted within each Scrum Sprint to verify that the development is conforming to both the project requirements and the stakeholder needs.

Deployment Phase. Once a system has been sufficiently built, it will be deployed for use. A successful deployment will require proper training for those who intend to use or maintain the developed system. The system should be evaluated once it has entered production to review how it operates in this environment. Additional verification and validation can take place at this point to ensure that user requirements are still being properly met. Bugs should be properly documented and resolved throughout the deployment phase, and this process should continue into the maintenance phase of the system up until the system's disposal. A Deployment Plan should detail the following:

- Pre-release considerations - Assumptions, Constraints, and Dependencies
- Timing of the release - How and when to release the solution
- Training Plans - How to train end users of the solution
- Documentation - Capture all important and necessary information regarding release
- Release Plans - How releases will be conducted

Maintenance Phase. Luminosity will be responsible for properly maintaining the system until the determination is made to decommission the product. A team will be assembled for this purpose prior to the system being deployed into production. This team should consist of those who are capable of upgrading the system and handling defects that arise. Additionally, support personnel should be acquired to provide guidance regarding the use of the product, as well as sales staff to market the product.

Projects will have differing maintenance phases depending on the nature of the project, but in general, a process to track and handle defects and issues should be established. For example, for software related projects, GitHub should be used as a means to document, track, and address all issues, bugs and improvements submitted by testers and users of the system. Patches and additional releases must be carefully planned and executed to address all identified issues.

Team Composition

Luminosity brings students from all disciplines together for various projects. Teams are typically comprised of members from engineering, design, business, and computer science. Each project must have the following high-level roles and each role may apply to multiple members.

Visionary. The Visionary is responsible for formulating the concept and envisions what the world would be like with the product. They are also responsible to driving the product to its fullest potential by constantly striving to push the boundaries of its functionality. They imagine the perfect outcome which the product will provide and communicate that to everyone in the project.

Designer. The Designer is the one who takes the vision for the project and creates an initial outline of what it should look like. This includes the mockups for any user interface, initial CAD modeling for a physical product, and general modeling of user interaction with the end product. This may be comprised of multiple people and they serve as the mediator between the Visionary, Hacker, and any customers or stakeholders.

Hacker. The Hacker is the person who knows and learns the technology to implement the project. This may be one person or a group of people, but there is usually one or two who drive the vision for how the project will be implemented. They are the one who chooses the programming languages to use, manufacturing techniques, and technology frameworks.

Project Manager. The Project Manager is responsible for implementing Scrum/Agile techniques, creating and ensuring delivery on timelines, and making sure that all requirements are translated to the Hacker(s). They are also responsible with communicating with the management of the lab and discovering where roadblocks exist for every member of the team.

Project Sponsor. The Project Sponsor is a staff member of the lab who is responsible for the overall accountability of the project. The Project Sponsor will champion the project and provide business guidance and expertise to the project's student manager. This individual will help steer the project in the right direction and will act as an arbitrator when decisions are beyond the authority of the Project Manager.

Lab Tools

Communication. The Luminosity Lab uses Slack as the main communication tool between lab members. Slack is a chat tool for business which is focused around search as well as integrations with external applications. We organize Slack channels in the following manner:

- announcements - Used to share general announcements around events/activities/updates for the lab.
- general - Used for any content that does not fit into other categories.
- resources - We use this channel to share general resources useful to the lab.
- project-{name} - We organize internal projects with this nomenclature.

- resources-{name} - This indicates a channel around providing resources to other lab members with a theme.

Document Storage. The main tool used for document storage is Google Drive. Luminosity stores all relevant Google Docs/Sheets/Slides, Word Docs, PowerPoints, image assets, etc. in this. A lab member should be able to go into the Google Drive and find all documents/supporting data/images which are important to the project. If there is a logo for the project, it should be held in multiple formats in the Drive. Similarly, the Chartering Document and reports for the project should be stored within Google Drive.

Calendar Events. Google Calendar is used to manage calendar invites internal to the lab, since it is the dominant tool used by students. However, it is recognized that Microsoft Outlook has a solution which is recommended for ASU staff to use. Therefore, Google Calendar is not prescribed, but is encouraged if the majority of students use it. For each meeting that is held, it is required to send out a calendar invitation to all project members. In addition, the regular weekly meetings must also be added to the general Luminosity calendar, in order for lab members external to the project to attend if they are interested.

Project Management. The main tool for project management is Freedcamp. This is used to manage both small tasks; as well as, full user stories in Scrum-managed projects. The Kanban view is highly encouraged as it reflects the management style of the lab. The tool is used by management to communicate expectations for a task, set deadlines for milestones, and gain insight into project throughput to determine if the resources allocated are sufficient.

Documentation and Reporting

Task Updates. During each meeting for a project, every member is expected to give an update about their current progress, any blockers they are facing, and offer support to other members of the group. The meeting cadence for each Level of a project is addressed in previous sections, but it is required that for each, an update is given by the team member. If it is held virtually or a member is unable to attend an in-person meeting, a concise Slack message with a brief recap of progress is expected.

Project Meeting Minutes. Each project meeting should maintain written meeting minutes that are to be dated and submitted to the project's folder in Google Drive after the conclusion of the meeting. Before starting a project meeting, a team member should be appointed to keep minutes for the meeting. These meeting minutes should cover what was discussed in the meeting, but additionally, updates, next steps, and current issues should be tracked and documented.

Sprint Review. At the end of each sprint, a Sprint Review is held to recap the progress made on a project. This is intended to provide motivation, give an opportunity for feedback, and update stakeholders on the project. If an in-person meeting cannot be arranged, it is expected that the Team Lead provides an update to the Slack channel and recognizes each member's individual accomplishments.

At the end of each Sprint Review, a written update should be produced by the project team and submitted into the project folder within Google Drive.

All-Hands Meeting. All-Hands Meetings are used by the lab to allow all students to gather and provide insight into all of the various ongoing projects. During the meeting, each project is iterated through and discussed.

For each, the Project Lead gives an update on current progress with a 2-minute max time. A period of up to five minutes is then used as a time for non-members to ask questions about the project and project members to present any major blockers which could be solved by non-members (such as a missing skill from the current team or problem which the team requires help to solve). If any members are identified who can contribute to the issue, they may set up a separate meeting to address it.

Student Progress Reports. At the end of each month, each student within the lab will be asked to submit a progress report to their supervisor. This report will detail all that the student accomplished in the current month, what they plan to accomplish in the succeeding month, and any roadblocks that they are currently facing.

Risk Management

Risk management is an important factor of any organization, program, or project. Any decision made has risk involved and it's important to quantify those risks appropriately. Risks can be broken up into four different categories based on severity and likelihood that fall into one of the quadrants below:

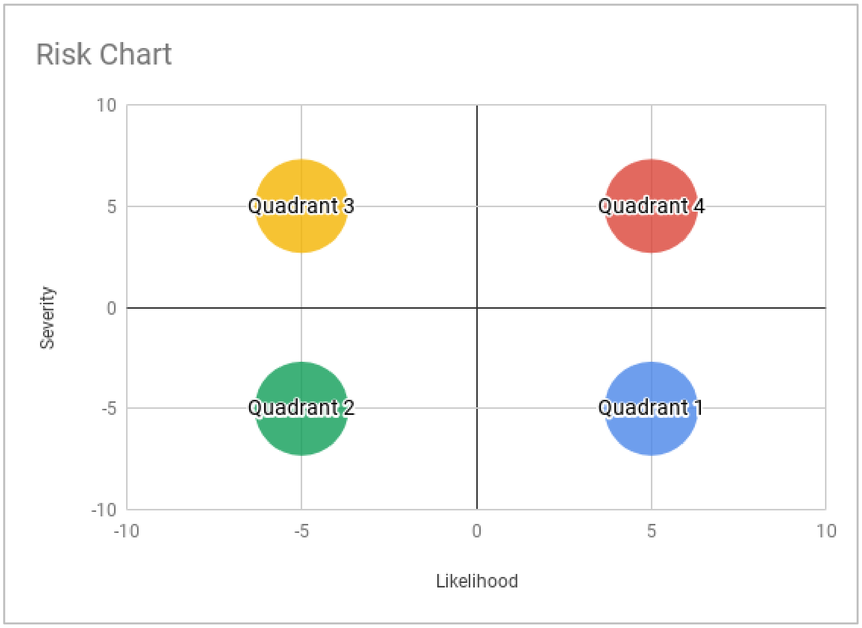

Figure 9. An example risk chart highlighting the four-quadrant layout.

Risks that fall into quadrant 1 are those that are likely to occur but are low in severity and can be mitigated by proper preparation and attention to detail. Risks that fall into quadrant 2 are unlikely to occur and low in severity and can be mitigated with properly developed processes. Risks that fall into quadrant 3 are risks that can be severe but the likelihood of them happening is low and they can often be mitigated with forms of insurance. Risks that fall into quadrant 4 are those that are likely to occur and have high severity. Risks in quadrant 4 are the types of risks that need to be managed with a proper risk management plan. This section of the strategic plan will outline best practices for managing risk.

The first step to develop a well thought out risk management plan is to first identify all risks involved. In most cases Luminosity will be evaluating risks associated with new projects and lab sites. This risk management plan will break down both types of risks and the proper procedure required for assessing the risks.

Project Risks. A risk management plan will be addressed for each project commissioned by Luminosity. Depending on the category of the project (Level I, II, and III) the risk management plan will be more detailed and comprehensive. For a project, a risk is defined below.

Project Risks. Anything that will cause the project to fail at achieving its deliverables or missing its deadlines. Common risks associated with projects are technology limitations, environmental limitations, regulatory limitations, time, personnel, and supplier lead time. It will be the role of the project lead to determine the risks associated with the project and categorize them using the Risk Quadrant in the figure above. They will then include a list of the risks and a corresponding figure of the risks in the Risk Quadrant in their Statement of Work document that is submitted before a project is launched. Below is the risk management requirements for each of the project level.

Level III. For Level III projects, a comprehensive risk analysis will be performed prior to the launch of the project. This will include a living document with list of the risks and their appropriate categorization according to the Risk Quadrants as well as a figure with the risks listed. For each of the risks found in Quadrant 1, 2, 3 a general plan of action will be created. For each of the risks in Quadrant 4, an evaluation will be completed, and the risk will be evaluated with a more comprehensive analysis such FMEA. A mitigation plan will be developed for each risk and the risks will be evaluated and tracked as they arise.

Level II. For Level II projects, a risk analysis will be performed prior to the launch of the project. This will include a comprehensive list of all the risks found and their appropriate categorization according to the Risk Quadrants as well as a figure with the risks listed. Each of the risks found in Quadrant 4 should be identified and a plan should be put in place to mitigate them. If more than 2 risks are found in Quadrant 4, the project should be reevaluated and potentially moved to a Level III project. The risks will be tracked, and the proper mitigation process should be followed.

Level I. For Level I projects, a risk analysis will be performed prior to the launch of the project. This will include a comprehensive list of all the risks found and their appropriate categorization according to the Risk Quadrants as well as a figure with the risks listed. If there is more than 1 risk is found in Quadrant 4 then the project should be reevaluated and potentially moved to a Level II project.

Project Risk Management Plan

Open the Google Sheet Risk Quadrant Template and create a copy of it with the following title format: "*Project Name* Risk Quadrant". Populate the sheet with the risks identified for the project. Give each risk a Likelihood and Severity score between 0-10. Once the sheet has been populated with each risk identified, copy the graph image and insert it into the Risk Management section of the Scope of Work document.

New Initiative Risk Management Plan. For new Luminosity Lab Initiatives, it is critical that a rigorous risk management plan is created. For new initiatives, the team should follow the CMMI Level 3 Risk and Opportunity Management (RSK) guidelines (see RSK 3.1-3.5 in the CMMI section). A formal risk management plan needs to be completed and should include the following sections that are based on CMMI RSK 3.1-2.5:

- Identify Risk Categories: use Risk Chart outlined in previous section to identify potential risks for new initiatives

- Develop Risk Management Strategy: For identified risks, develop a strategy that will mitigate the risks. Make the Risk Management Strategy a living document that can be updated as risks change

Meeting Cadence

Proper meeting cadence and structure is crucial to keeping projects on track. There is a fine balance between productive meetings and bogging the teams with too much structure and unnecessary meetings. Our desire is to maximize productivity while maintaining the freedom and responsibility that allows the students the creativity to be at their best. The balance we've found as best practice is outlined below.

- Per project (depends on project level, see proceeding sections)
    - Weekly team meetings at beginning of the week (30-60 minutes). This is ideal for big picture discussions and discussing next steps.
        - Held on a Monday or Tuesday
        - More formal meeting with agenda and weekly and/or sprint deliverables
        - Keep the team and project organized and everyone on same page
    - Mid-week slack standups (5-10 minutes). The standup is helpful for keeping each other accountable and to keep everyone up to date on what each other are working on.
        - Held on a Wednesday or Thursday
        - Each team member provides updates on tasks completed, working on or any questions or help someone may need

    - End of week team roundup (15-20 minutes) to keep everyone on the same page.
        - Held on a Thursday or Friday
        - Quick recap of week and next steps
        - Informal and casual
- If working with outside partner (Practice Lab)
    - Determine best frequency of communication with partner
        - Minimum of monthly calls but can be weekly or bi-weekly if needed
        - Reporting and documentation (monthly or semesterly) as contract dictates
    - All other team meeting cadence structure is followed as outlined above.

Programing

Aside from the retreats and meetings, it is important for members to interact in an informal and more personal manner. Doing various events can build camaraderie amongst the group, such as:

- Monthly social events
    - Everyone gets together for a fun gathering outside of the lab
    - Informal meeting with high level updates by project and leads
    - Cancel meetings for that day
- Speakers come in to talk to the lab
    - Subject matter experts or interesting people present and interact with lab members

- Personal and professional development (open to whoever wants to attend)
    - Topics like AI, IoT, autonomous vehicles, etc.
    - Technical skill like a programming language
    - Soft skills like communication, running effective meetings, conflict resolution, etc.
    - Ideal to empower students and lab members to put these on and present
        - Give them ownership and leadership experience
        - Peer to peer teaching
    - General topics like time management, writing, budgeting, wellness, etc.

Student Reporting

Each student is supervised by one of the staff members. It is based off of technical area, per project, or location. This is a critical piece for our staff to provide individual instructions and guidance to the students.

- Students should have 30 minute, one-on-ones set up with their supervisor. Bi-weekly (every other week) is the standard for optimal productivity. Can be more or less frequent depending on a case by case basis, depending on the individual.
    - Dependent on individual, some need more direction and others don't need much
    - Get questions answered on an individual level rather than a group setting
    - Give and gather feedback
- Lunch outing with supervisor and their project leads
    - Go to a more relaxed environment
    - Discussions about higher level information

- Get questions answered on an individual level
- Ensure students are inputting hours properly by EOB Thursday before end of each pay period
    - Supervisor must review and approve before end of following Friday

APPENDIX B

PREVIOUSLY PUBLISHED WORKS

Chapter 3, The Luminosity Lab—An Interdisciplinary Model of Discovery and Innovation for the 21st Century, was published previously in 2020 in the National Academy of Inventors' Technology & Innovation Journal.

Abstract

Historically, higher education institutions have been designed with a focus on developing mastery and furthering the body of knowledge within distinct academic disciplines. Unfortunately, this intended design has resulted in a lack of collaboration between academic units and has stifled interdisciplinary research between students and faculty across domains. The Luminosity Lab, located at Arizona State University, is an archetype for a new model of collaborative interdisciplinary research teams. Exceptional students are hand-selected from all areas of the university and come together to fuse youthful spirit, academic prowess, and business acumen—the makings of a 'great group.' Students work together to produce system-level projects that are capable of having a large-scale societal impact. Building upon concepts from systems engineering, the lab employs the use of a view model to analyze current and future systems from various viewpoints (e.g., enterprise, functional, computational, engineering, technology, services, standards). By leveraging the strengths of systems thinking, strategic design, and agile methodologies, our interdisciplinary team is positioned to tackle systemic challenges in domains such as healthcare, energy, education, and global climate. This model of interdisciplinary research was tested at Arizona State University across three academic years with participation from over 100 students, who represented more than 20 academic disciplines. The results have shown successful integration of interdisciplinary expertise to identify unmet needs, design innovative concepts, and develop research-informed solutions. By adopting this approach, higher education institutions can begin to break down the walls that exist between academic units and start to use a holistic view of research and innovation for solving global issues.

Keywords: Interdisciplinary; Discovery; Innovation; Systems engineering; Systems thinking; Strategic design; Agile; Business acumen; Great group