Practitioner Experience Meets Graduate Academic Research: How Intersections Guide the Work of Returning Engineering Ph.D. Students

Dr. Jaclyn K. Murray, University of Michigan

Jaclyn K. Murray is a Research Fellow at the University of Michigan in the Department of Mechanical Engineering. Her interests include creativity in design, student learning, and the integration of engineering design into secondary science courses.

Dr. Shanna R. Daly, University of Michigan

Shanna Daly is an Assistant Professor in Mechanical Engineering at the University of Michigan. She has a B.E. in Chemical Engineering from the University of Dayton (2003) and a Ph.D. in Engineering Education from Purdue University (2008). Her research focuses on strategies for design innovations through divergent and convergent thinking as well as through deep needs and community assessments using design ethnography, and translating those strategies to design tools and education. She teaches design and entrepreneurship courses at the undergraduate and graduate levels, focusing on front-end design processes.

Ms. Erika Mosyjowski, University of Michigan

Erika Mosyjowski is a PhD student in the Center for the Study of Higher and Postsecondary Education at the University of Michigan. She also earned a Master's in Higher Education at Michigan and a Bachelor's in Psychology and Sociology from Case Western Reserve University. Before pursuing a PhD, Erika had a dual appointment in UM's College of Engineering working in student affairs and as a research associate. While grounded in the field of higher education, her research interests include engineering education, particularly as related to innovation, professional identity development, and supporting the recruitment and persistence of underrepresented students within engineering.

Dr. Diane L. Peters, Kettering University

Dr. Peters is an Assistant Professor of Mechanical Engineering at Kettering University.

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Introduction

Advancing knowledge significant to the broader academic community is the purpose of academic research. Professors—those engaged in academic research—have refined expertise in asking research questions, designing studies, analyzing data, and communicating findings. Newcomers, however, must develop their skills to attain similar levels of skill sophistication as acquired by experts. Newcomers, as novices, must learn to construct investigations that result in substantial findings that impact the field to be successful. In preparation for future academic work, research novices must refine research skills, develop their knowledge, and form a broad and accurate picture of the domain. Understanding the ways in which graduate students' skills, knowledge, strategies, and motivations are interconnected provides insight into how prior experience intersects and guides future academic research.

In the present study, we focused on examining alternate pathways that lead to academic engineering research. *Returners*—those with engineering degrees who work outside of academia for at least five years and come back to academia to earn their Ph.D.s—bring a unique blend of perspectives to their engineering work, making them well suited to discover new knowledge, design innovative solutions, and solve problems that will keep the U.S. globally competitive and contribute to finding solutions to the challenges of our present and future world. However, little empirical work exists to investigate how returners' prior work and Ph.D. training come together to shape research topics. An understanding of how research ideas and direction form can contribute to the education of the broader graduate population. The present study emphasizes returners because they have diverse and extensive experience with engineering practice and real-world engineering scenarios. We explored the extent to which a particular model, the componential model of creativity (CMoC),[1,2,3] helps us interpret how prior engagement with engineering practice influences graduate academic engineering research.

Conceptual Framework

We chose to investigate returners' experience through the lens of a creativity framework because success in academia may be grounded in essential components of creativity and innovation. Identifying the level of transparency of these elements made visible through novice academics' work, helps us to understand how returners engage with the design process and form research questions that guide academic work. We consider the contribution of prior professional and academic research experience to returners' views of academic research. Also, we explore how mindsets influence the nature of academic work, and describe the ways in which returner attributes align with the CMoC.

Several models and theories of creativity exist to explain how creativity manifests among individuals and organizations. Two broad perspectives of creativity research—internal and external approaches—situate creativity work from either an *individual* or *individual-in-context* standpoint, respectively.[4] The present investigation views returners' experience from an *individual-in-context* perspective because the extent to which participants engage in engineering practice before and after enrolling in doctoral programs varies by individual and milieu.

Amabile[1] conceptualized the componential framework of creativity (CFoC) to outline factors that affect an individual's engagement with the creative process. After refinement, the framework shifted away from the *individual*, and toward an *individual-in-context* stance, which eventually became known as the CMoC.[2] Ultimately, the CMoC evolved to encompass three essential components of creative performance (CoCP): 1) domain-relevant skills, 2) creativity-relevant processes, and 3) task motivation, embedded within an individual's social environment.

The level of proficiency with the three components of creative performance affects the outcome of the creative process. Robust domain-relevant skills and knowledge, as defined by a discipline's community of practice, includes facts, routine procedures, and special techniques unique to the discipline. For example, a knowledge of Newton's laws, an ability to solve routine statics and deformable bodies problems, and skill for computer-aided design software are necessary for designing a cantilever beam to support a 600 square-foot flag flying from the top of a skyscraper.

Creativity-relevant processes expand the number of available options. Ideas—manifested through implicit and explicit processes—arise from particular features of personality, cognitive style, work style, and familiarity with heuristics.[2] Attributes of a creative personality include self-discipline, persistence, autonomy, self-initiation, and willingness to take risks. Deconstructing complexity, suspending judgment, investigating the underlying assumptions for routine procedures, and an openness to experience exemplify creative aspects of cognitive style. Concentration and willingness to work hard for extended periods of time, persistence, and periodic breaks to refocus attention on particular tasks are work style characteristics that enhance creativity. Lastly, heuristics—non-algorithmic tasks that do not have a clear path to solutions—enable novel outcomes. Metaphors, analogies, playing with ideas, and analyzing case studies are examples of heuristics. To illustrate more clearly what a heuristic is, consider the design of the first light bulb. Through trial and error, and the process of elimination, Edison, and his staff were able to create a working prototype and develop a procedure to manufacture the lightbulb. The team turned a heuristic into an algorithmic problem by creating a standard procedure.

Task motivation, the last component of creative performance, encompasses two elements: 1) attitudes toward tasks and 2) reasons for engaging with tasks.[1] Attitudes, consistent with intrinsic motivation, are mindsets about personal interests in the task itself. Alternatively, individual's may have external motives for task engagement. If the task satisfies an objective as part of an overarching goal, it is a means to an end and not the end itself. For example, one may value performing well on group work tasks as a way to obtain a good grade in a course. The project itself is not stimulating; however, attaining a high grade in the course may be the overarching motivating factor.

The three CoCP frame the present study and relate returners' engineering experience to graduate academic research. The following section elaborates upon the three components.

Background

Most of the literature about returners focuses on the challenges and barriers returners face as they navigate through the graduate admissions process[5] and facets of the graduate program[5,6,7,8] Others investigated returner difficulty in securing employment after graduation[5,9] the decision to return,[10] and the motivation and costs associated with returning[7]. Moreover, Strutz et al.[11] examined how prior professional experience positioned returners to begin graduate engineering programs with *experience capital*—an accumulated wealth of knowledge obtained through engagement with professional engineering practice.

Here we focus on the ways returners' prior experience and mindset toward academic research foster original and appropriate production. The purpose of university preparation, in pursuit of a Ph.D., is to work toward becoming capable of generating original and appropriate ideas and investigating those ideas as independent researchers. Ph.D. students must demonstrate they can identify unique problems or answer important questions, useful to a domain, that dissertation committee members deem suitable.[12] Synthesizing previous research to form novel and useful questions or problem statements is part of the creative process.[13] Through successful use of the creative process, original and appropriate solutions arise.[14,15]

An analysis of relevant creativity research led Amabile to form the three CoCP.[1,2,3] The CMoC posits that the integration of domain-relevant skills, creativity-relevant processes, and task motivation impacts the creative process and consequentially, influences outcomes. The following sections introduce and elaborate upon each of the CoCP.

Domain-Relevant Skills

The creativity literature demonstrates that domain knowledge[16] and experience[17,18] are essential to creativity. Domain knowledge and skills are dependent on formal and informal intentional practice, experience, and longevity. Expertise—proficiency as a result of sustained engagement within a field—requires the construction of schematic knowledge organized by abstract principles. [14,19,20,21]

Chase and Simon's seminal study about chess suggests ten years of disciplined practice are necessary to attain expert status.[22] New case study work[18,23,24] related to creative performance also indicates years of practice are essential before expertise manifests creative production. Ericsson's review expounds on the connection between expert-level performance and experience.[25] In addition, An, Song, and Carr recently found a significant correlation between domain knowledge and creative expert performance.[26]

The next component—creativity-relevant processes—assumes a domain-general approach to creativity. Amabile's supposition is that creativity-relevant processes developed in one domain can transfer across to other domains.[1.2.3] However, to be successful in a particular field, one must amass the aforementioned domain-relevant skills to produce creative outcomes in a specific discipline.

Creativity-Relevant Processes

Past research focused on creative achievement as a function of personality and creative problem solving as dependent upon cognitive style. Feist determined, through meta-analysis, that creative people were autonomous, introverted, open to new experiences, norm doubting, self-confident, self-accepting, driven, ambitious, dominant, hostile, and impulsive.[15] The Adapter—Innovator,[27] and Assimilator—Explorer[28,29] continuums represent cognitive styles that describe typical patterns of thinking or approaches to solving problems, respectively.

According to Fiest, the personality characteristic—openness to experience—was most strongly correlated with general creativity.[15] Intellectual curiosity, intellectual interests, perceived intelligence, imagination, creativity, artistic and aesthetic interests, emotional and fantasy richness, and unconventionality were found to be traits associated with 'openness to experience.' Perrine and Brodersen questioned whether 'openness to experience' was expressed differently across domains.[30] Their study revealed that 'openness to experience' is split between *openness to aesthetics* and *openness to ideas* and is related to artistic and scientific disciplines, respectively. Other creative scientific traits included flexibility, arrogance, hostility, self-confidence, introvertedness, autonomy, and ambition.[15]

Kaufmann developed a cognitive-style continuum (Assimilator—Explorer) to identify differences in problem solving approach.[28] An *explorer* is someone who is determined to use a different process or solution even when an appropriate solution is readily visible. *Assimilators* push the boundary of what already exists, and work within the bounds of rationality to produce novel iterations. Martinsen found that explorers investigated scenarios by inquiring about information specific to the problem.[31] Explorers refined background knowledge because they tended to have less experience with the task domain than assimilators.[32] Assimilators, however, relied on experience to solve problems. As assimilators gained experience with relevant skills, creative performance increased.[32]

Martinsen and Diseth investigated the relationship between the Assimilator—Explorer cognitive style, personality characteristics, and inventiveness.[33] They determined that high novelty seeking, and weak preference for rules and planning described explorers. Assimilators were bound to rules, sought what was familiar, and carefully planned implementation strategies.

Amabile's CMoC also includes task motivation. People are most creative when they are passionate about their work.[1] Next, we present task motivation: motivation that enhances creativity.

Task Motivation

The creativity research community recognizes two types of motivation: intrinsic and extrinsic. Intrinsically motivated individuals choose to engage in tasks due to genuine interest,[34,35] and interest emerge from curiosity and a sense of competence and autonomy[36]. Alternatively, participating in tasks to reach some external goal, is an example of extrinsic motivation. Early research on motivation focused on motivation as a fixed trait; an individual's level of interest would remain stable across all conditions. Today, the predominating view is that intrinsic motivation is situational. Motivation as a state rather than a trail situates motivation research from an *individual-in-context* rather than an *individual* perspective. One might be intrinsically motivated to learn about and design heart valves but have no interest in spinal implants. An individual's motivational orientation is not transferable from heart valves to spinal implants.

For years, the *intrinsic motivation hypothesis of creativity* prevailed. As a result, the notion that intrinsic and extrinsic motivation were inversely related guided research on creativity.[37] In the past, individuals' internal processes were the focus; outside environmental factors were not considered. This lapse (*fundamental attribution error)* prompted some to investigate the relationship between intrinsic and extrinsic motivational factors associated with task engagement. Findings suggest that deadlines, competition, and expected evaluation tended to decrease intrinsic motivation when imposed.[35] However, in some cases, when individuals perceive reward as recognition for competence, extrinsic motivation enhances creativity.[38,39] This type of extrinsic motivation is synergistic because it boosts task motivation.[2,37] Nonsynergistic extrinsic motivators decrease intrinsic motivation because they provoke feelings of being controlled. In light of this new research, the *intrinsic motivation hypothesis of creativity* was replaced by the *intrinsic motivation principle of creativity* and accounted for the interaction between intrinsic and extrinsic motivation in creativity.

Task engagement can commence by either internal or external means; both may lead to creative achievement. Pursuing a problem one self-identifies with exemplifies an internal mean.[40,41] An external mean such as joining a lab to gain research experience to increase the chance of admittance into graduate school may also foster a sense of intrinsic motivation toward the research topic or task.[42] Both are valid pathways that can lead to creative achievement.

Methods

Research Questions

The overarching research question—*In what ways does the intersection of returners' prior engineering experience and Ph.D. training impact returners' academic graduate research?*— guided our work. The following sub-research questions emphasized key elements of the overarching research question:

1. What was the impetus for the transition from practice to academia?
2. How do past work experience and current academic experience influence academic mindsets and research topic selection?
3. To what extent do the components of creative performance frame the experiences of returners?

Participants

Type of prior experience, years of service to non-academic engineering institutions, and year in the Ph.D. program initially directed participant selection. Twenty-five participant viewpoints present the attitudes of both genders and a range of ethnicities. Six returners' perspectives are reported here and were selected to impart the mixed views, choices, and breadth of experience of the participant sample.

Returners' views exemplified the transition from engineering professional practice to academic research, and how that experience assisted in the formation of academic mindsets and research topics. We examined the extent to which the CoCP allowed us to interpret the experiences of a sample of returners and how those prior experiences shaped research plans. Table 1 provides information about each participant.

Table 1. Participant demographics.

Pseudonym	**Degree**	**Prior Experience**	**Years of Service**	**Year in Program**	**Topic**
ADAM	EE	Industry	7	5	Energy Harvesting
BRANDON	ME	Research Institute	20	4	Road Roughness
JOHN	EE Part-Time	Military	25+	Finishing Dissertation	Signal Processing
KRISTEN	ME	NonProfit	10 (8 in Eng.)	3	Energy Model
MICHELE	EnvironE	Industry & Government	13	1	Stream Restoration
ZACH	ME	Research Institute	6	5	Digital Imaging

Research Design

The exploratory investigation[43] shares features of case study research; however, the research design employed was not consistent with case study as a research method because multiple data sources and in-depth participant accounts were not collected. For the present study, we define a case as a *set of episodes and circumstances*. The episodes were the events experienced by participants in particular contexts (circumstances) that influenced mindsets and actions. The events endured by participants shaped how participants responded to and managed new experiences.

Participants engaged in semi-structured interviews that were approximately an hour long for the purpose of understanding facets of returners' engineering experience, decisions to return to academia, and plans for their degree. Audio-recorded interviews were transcribed for subsequent analysis.

All 25 transcripts were read and reread to gain a sense of each as well as the collective whole.[44] Themes emerged inductively to describe the data holistically.[45] Then data were coded based on a priori categories[46] to determine why participants enrolled in Ph.D. programs, how research topics emerged, and which CoCP surfaced.

We describe how each case encouraged our participants' proclivity toward research in the following section.

Findings

Six segments subdivide this section; each one represents a participant's case. Within each segment, there are two subsections: *Situating the Case* and *Interpreting the Case through the CoCP*. *Situating the Case* summarizes the primary attributes relevant to that participant's context. *Interpreting the Case through the CoCP* reveals an analysis of each participant's case(s) through the lens of the CMoC. All components of the model were not necessarily represented in each case.

Adam

Situating the Case

Born into a family of academics, Adam initially had no desire to obtain a Ph.D. He earned a master of science in electrical engineering directly after completing a bachelor's degree. Then Adam worked for four companies because he was laid-off from three. While unemployed, Adam reflected on his past and planned for his future. Adam realized he had not engaged in meaningful work when he was employed; he wanted that opportunity. He said industry tasks were procedural; everything could be looked up in a textbook and applied very easily. Adam wanted a challenge. He thought about how his father—a professor—was happy, and Adam began to consider a career in academia. Eventually, he decided to apply to Ph.D. programs.

Preparing for the GRE proved fruitful, as he was admitted to and attended his first-choice institution. Adam was excited about the proposition of being an independent researcher but perceived obtaining a Ph.D. as a hurdle to his ultimate goal. He wanted to work on ill-defined design problems. For Adam, choosing a research lab was predicated on finding a faculty member engaged in integrated-circuit (IC) design work. He was less concerned about the particular application as it was unlikely, in his view, that he would be able to craft his dissertation independently. Adam found an advisor willing to sponsor him for work with IC design projects. Other professors preferred to wait a semester before committing to funding him. Since Adam was familiar with the tools and technology involved in the research, he felt the opportunity was a good fit, and he joined the research team.

Adam's dissertation involved the design of an energy harvester for bridge vibration sensors. He said the challenge was to find a way to power sensors located in hard to reach places. Adam was excited about traveling to apply the technology to a particular bridge.

Interpreting the Case through the CoCP

It was clear that the domain-relevant skills required for Adam's graduate research were solid. Adam selected his advisor because he wanted someone with a knowledge of and shared interest in IC design. He commented that his research was related to "IC design—what I did in industry—same tools, same technologies. They're cool stuff". His interest and knowledge were situated in the domain of IC design; however, he was flexible about the application. To sustain interest, Adam required small shifts to occur in his work. At this point in his career, changing the application was one way to support Adam's continued active intellectual engagement with tasks related to IC design.

According to the Assimilator—Explorer cognitive style framework,[28] Adam appears to be an Assimilator. Adam's research resided in energy harvesting and bridge vibration (two established domains) where ideas already exist. Merging existing ideas rather than approaching the task from a perspective that does not depend on either field, supports the Assimilator cognitive style. Adam knew very little about harvesting energy and bridge vibration. He had to investigate those topics to gain a sense of their relevance to the project. After acquiring the necessary background knowledge, he designed an IC appropriate for the new context.

Adam explained it was a challenge to understand how to organize the constellation of elements required to identify particular problems in his research domain. He knew reading and attending conferences provided insight about possible gaps in the literature, but he was not yet skilled at recognizing significant problems. It was his advisor who had provided his dissertation topic and question. Although Adam was capable of solving heuristic type problems, he felt uncomfortable selecting problems to solve for the purpose of contributing to the broader knowledge base.

Brandon

Situating the Case

Brandon accepted a job at a research institute his last semester as a mechanical engineering undergraduate. Brandon struggled during the first two years in college but performed better than average the latter two years. He was satisfied to find any job at all. Early on at the research institute, he was invited to sit in on project planning meetings and listen to how the organization was run. The research institute did not have permanent positions; however, Brandon managed to secure employment for twenty-three years.

Within a decade, Brandon was functioning as a faculty member. One of his colleagues—a tenured professor—asked Brandon to enroll in one of his classes. After completing the course, Brandon applied to the master of science in mechanical engineering program. With the help of the professor, Brandon was admitted despite his undergraduate GPA. He completed coursework requirements while working full time, but had difficulty developing a research question. He eventually left the program.

Another decade had passed before Brandon considered pursuing a graduate degree again. His frustration with previously quitting a graduate program of study and acting as a professor without the benefits of being a professor bothered him. Before he reapplied to the program, he had a research question in mind. Brandon proposed measuring road roughness from a mechanical, rather than a civil engineering perspective. He claimed civil engineers know all about the road and nothing about signal processing. The current standard of measuring road roughness entailed measurements made at constant speed under ideal conditions. This approach did not accurately represent normal driving conditions. Brandon considered multiple factors and conditions in his approach, arising from his past project experience with the research institute.

Interpreting the Case through the CoCP

Brandon amassed substantial domain-relevant skills across domains over his extensive career. He was confident in his testing and design skills, his ability to analyze and synthesize data and concepts, and capability to develop and carry out research studies.

Brandon was group-oriented and was protective of his employees. It was important to Brandon that he not hire anyone he thought would defocus or disrupt the group's working environment. Brandon also displayed aspects of autonomy and leadership as he led many of the projects at the research institute.

Brandon illustrated he knew exactly what he needed to do in planning for his dissertation. It was only a matter of doing it and reporting the results. The act of carrying out a dissertation was not the learning experience for Brandon as it was for others. He was in the second half of his career with the skills and knowledge to do high-quality university research. Brandon had completed dissertation like studies for several years. Brandon was purely extrinsically motivated to earn his degree after several years of acting like a professor. He was, however, genuinely interested in the research, put the primary force behind his decision to engage in the research was to earn a Ph.D. and achieve the respect of his colleagues.

John

Situating the Case

John enlisted in the military after graduating with a bachelor of science in electrical engineering. He was able to earn a master of science in computer science while on active duty. The focus of his work, for the military, was in digital signal processing. John moved to a couple of European countries before leaving active duty. Since then he worked at military contract companies and was a member of the Reserve. At the time of the interview, John worked at a military lab in the Division of Radar Signal Processing as a systems engineer. He continued employment with the military lab while completing his Ph.D. degree.

John did not like his program management job at the military lab. He said, "Part of the problem…is that you have to deal with administrative people who seem to either be bipolar or have extremely short memories." Also, as he advanced in the company he had more authority and responsibility, and less technically focused work. He "came here [military lab] for the research environment that slipped away on [him]" since he was promoted to program management. The transition from his previous job to the military lab included a 40% reduction in pay.

John, disgruntled by the fact that he could not work on a project he thought was important, and the refusal of his employer to subsidize his education began to think about leaving his position. John started to seriously consider enrolling in a Ph.D. program when his research load lightened and he was spending more time than he wanted reading reports as part of his management duties. Also, he felt he was a jack of all trades and master of none. John wanted to obtain a deeper and more broad knowledge of the signal processing domain. For years, he worked on receivers but considered gaining a knowledge of transmission to help with the design of receivers. He chose to approach his dissertation from a communications perspective rather than a localization issue. If he succeeds, the precise position of transmissions could be determined by receivers.

Challenged by a problem posed by a professor, John worked to find a solution. John was determined to prove there was a solution. Eventually, he was able to find a method to address the problem. John and the professor published their findings, and John earned the respect of his professors.

Interpreting the Case through the CoCP

John had strong design process skills and signal processing knowledge. He developed numerous products from inception to production. He was open to new ideas, even when he believed many were impossible. His interaction with novice engineers taught him that. John said:

> I really enjoy mentoring junior engineers. I think that working with young engineers is just fascinating. Part of the reason for that is due to my experience. When we get lieutenants in our office, they often wind up working for me, because I have lots of work that I can parse out that's appropriate to them for their level of expertise. The nice thing about working with junior engineers, in general, is that they don't know that I know some things are impossible. On a fairly regular basis, it turns out I'm wrong. It wasn't impossible after all.

John sees the value of novice engineers. He realizes that his experience limits him at various stages of the design process. John said:

> I really enjoy the open investigation and innovative solution to problems. I find that at times, decisions I make are based on my experience, but my experience can be false. I mean, it can bear false testimony to this is how things should be done. Getting in young engineers who are a chock full of ideas that I can fund for a reasonably small amount of money to try things out, often leads to some very innovative designs that I find elegant and enjoyable.

John's dissertation topic did not intrinsically motivate John in the same way external factors prompted him to earn a Ph.D. The diploma would allow him to be more autonomous in an academic institution. He says his dissertation research is "significant, but it's not going to make or break the success of my career; it is just another endorsement of the 'you've done good things.'" He hopes there is more freedom to work and less administrative duties involved in his new job after he earns his Ph.D. in comparison to the military lab.

Kristen

Situating the Case

Taking the advice of an engineering faculty member, Kristen joined a non-profit organization after graduation for the summer to investigate cookstoves for developing countries. She met her husband there, and they decided to spend the next few years fulfilling their humanitarian sense of duty. Kristen was a pre-school teacher, worked with special needs children and adults, and re-joined the non-profit organization as a laboratory manager. She created test protocols, wrote reports, and traveled to developing countries. After eight years of traveling around the world with her cookstoves, she was enticed to return to graduate school by the same faculty member who suggested she spend a summer volunteering.

The university she previously attended was now offering online courses for students in the masters of engineering program. In addition, her advisor had offered to help her acquire a National Science Foundation Fellowship. At the time, she had just become pregnant and traveling across the world was no longer an option. She said:

> I guess the main reason was he offered to help me get the NSF Fellowship, which basically means I could work from home for three years on the day I found out that I was pregnant with my first child. It just totally was meant to be.

Kristen wanted to craft a dissertation that joined her interest in cookstoves and knowledge of mechanical engineering. For her masters, she created a cookstove heat transfer model. Upon completion of her thesis, she chose to move away from heavy mathematical analysis. Instead, she decided to focus on a developing country's village energy usage. Kristen was developing a framework and mathematical model to characterize and predict the effects on climate, health, energy efficiency, quality of life, etc. The dissertation shifted from cookstoves toward the broader energy concerns of villages. She said she was not skilled in finding problems; that was her advisor's role.

Her priority was her family. As a Ph.D. student, Kristen devoted three-quarters of her time to being a mother and the other quarter to graduate school. After graduation, she wanted to teach at a university or return to the non-profit cookstove organization.

Interpreting the Case through the CoCP

Kristen believed her work was meaningful to the people who used the cookstoves. She wanted to do something that would be just as impactful. Kristen said:

> The most important thing was that the work that we were doing was for people in the field who actually directly improved their stove designs and then go apply those changes to the stoves that they are putting out in the field, so it felt like it was really meaningful and important to be doing work that would have a real impact on real peoples' lives.

After completing her Masters with a thesis that she perceived as not immediately or directly related to helping people, she had to decide how she would satisfy dissertation requirements and be happy about her research topic. Kristen's advisor gave her two options. She discusses them and her choice in the following passage:

> [M]y masters research was into developing a transfer model of a cookstove, so a lot more heavier on the engineering side, and so for my Ph.D., I basically had two directions I could go, either adding combustion efficiency to that heat system model, which could have been groundbreaking, but really, really complicated, like really hard, very heavy math and understanding of really technical things, or to take this path, which would kind of broaden the picture and maybe end up making a bigger difference than just having this really specific computer model of the combustion.

Kristen's attitude about graduate school was lackluster. It did not appear as though she was interested in the research. There was no passion. Kristen talked about returning to the non-profit or becoming a teacher. In both cases, she would be directly helping people. It was unclear as to why she wanted to earn a Ph.D. There could have been some higher goal she did not share. Perhaps she wanted to do something while raising her children before she returned to the non-profit. Kristen said:

> Having a child, you really don't want to be traveling the world with a little one, so that was the main reason. And also, I love to learn and learn things and feel more confident in my understanding and my knowledge, so there's so many reasons that it worked out and I wanted to do it.
>
> I go to activities with my three-year-old all the time, and it's about 75% motherhood and 25% graduate, which is I'm grateful to have a mix like that.

No features of creativity-relevant processes revealed themselves in Kristen's interview. She fit school around her personal life while the other participants either balanced the two or fit their life around school. Kristen did not have confidence in her technical skills, so she opted for the less technical project. She had more important things to attend to in her personal life.

Michele

Situating the Case

Michele entered the mining industry upon graduating with a bachelor of science in environmental engineering. Before enrolling in graduate school, she worked for two consulting firms and a government agency where she either worked to obtain or approve mining permits. Initially let go from her first job, she found employment with the government reviewing underground mines and authorizing permits. Michele strongly disliked government work, so she left to prepare surface coal mining permits at a consulting firm. Her work at the firm involved stream research, flood analysis, and the design of environments in accordance with EPA regulations in surface mining regions.

Over time, the mining community began to suffer, and Michele re-examined what she wanted to do. Her environmental engineering degree had not been used in the way she had originally intended. Michele contemplated returning to school to refine her environmental engineering skills in preparation for obtaining an environmental engineering position. She enjoyed the research but was bored with the design work. Michele remarked that once a sentiment pond was designed, all the rest were the same. She was frustrated with the lack of creativity in her work.

Michele decided to reach out to a few stream restoration researchers at a local university to discuss her interest in their research. Conversations with faculty members were enough to compel Michele to apply and enroll in graduate school. At the time of the interview, Michele had not started her dissertation, but she had chosen to study stream restoration in mining areas. Michele's dissertation topic directly connected with her prior engineering experience.

Michele wanted to use her existing knowledge of environmental engineering principles for post-mining land use issues. She was familiar with the mining industry and its regulations, but she needed to learn about the ways in which streams could be restored. Michele's advisor provided her with the necessary background information. Since Michele's lab was funded before she joined, she was given a topic and question to research.

Interpreting the Case through the CoCP

Michele's mining industry experience and environmental engineering degree provided a robust set of skills that formed the foundation for her proposed academic research. However, she sensed she needed to strengthen her environmental engineering skills. Michele felt like she could not gain employment as an environmental engineering because she never held a position within the field, and it had been so long since she earned her degree. Michele did not speak about difficulties with the coursework or early stages of her research. She was excited to learn about stream restoration, just like she was when she designed a sediment pond or coal belt crossing for the first time.

As a first-year doctoral student, Michele was making connections between stream restoration and large-scale cityscapes in urban areas. In the future, she sees herself branching out into those areas. Before she applied to schools, she was insecure about procuring a job for which she had a degree. Now she is confident because she recognized the same principles apply across domains. Michele's confidence shifted across social environments. Industry limited what she could do. The enculturation into the academic community made Michele realize the value of diverse knowledge and the acceptance of skills transferred across domains.

It was evident Michele enjoyed heuristic problems solving. She was comfortable with creating procedures or designs for generic projects, but she did not want to revisit the same task in a different setting. This mindset aligns with the Explorer cognitive style type. When requisite knowledge was required, she would explore and determine solutions based on what others had done. Therefore, her creative work tends to lie in the Assimilator[28] zone of the problem solving cognitive style continuum. Michele relied on learning domain-relevant knowledge to guide her toward a solution based on previous research in the area.

Zach

Situating the Case

Zach graduated with a bachelor of science in mechanical engineering and began working as a design engineer at a medical device company. In the following five years, he would design ambulance medical equipment, join the new product development team, and become a senior design engineer. He spent half his time in front of a computer working with CAD and managing prototyping issues. The other half of his time was shared between testing and verification, and engaging with customers. Initially, Zach was excited about generating ideas, and he enjoyed being part of the entire product design process. Then the company displaced manufacturing to China, and Zach had to tackle non-engineering related issues. Zach began to reflect on his work and subsequently determined he should either seek a new position or enroll in graduate school.

Zach realized most of his time was spent working with CAD software for tasks that did not require an engineering degree. He felt the medical device company's other divisions (orthopedics) were doing more important work. Zach considered leaving the medical device company when his wife relocated for a medical residency position. At that point, he had two options: find a test engineer position in an economically depressed area or enroll in graduate school. He chose the latter, to pursue a Ph.D. in mechanical engineering.

Zach became interested in materials when one of his projects at the medical device company required a light-weight material. He thought about how bicycles were low-density and strong. This interest initiated a search for faculty members who specialized in materials research. Zach spoke with potential faculty advisors and their research team to find the right fit. Upon agreement, Zach chose an institution and research lab.

At first, Zach worked on his advisor's research to become acclimated to the research environment. Eventually, Zach's advisor gave him a dissertation topic and research question. Zach consulted the literature to develop multiple ways to proceed before conferring with his advisor. She would then offer advice, or permission, depending on the task.

Zach's dissertation centered on the design and verification of a digital imaging technique to capture the surface deformation of ultrafine-grained metals. The research contributes to advancing an imaging technique that characterizes the deformation of not only ultrafine-grained metals but also other materials, as well.

Interpreting the Case through the CoCP

After years of experience in industry, Zach became autonomous. He loved to solve problems and often utilized the design process to create products to meet customers' needs. However, he was not so confident when he started at the research lab because he knew he did not know much about imaging. Only after gaining knowledge and experience did he begin to feel confident. He was so motivated to engage in materials research that he was willing to exert the effort to accrue the necessary requisite knowledge to complement his well-developed design skills.

Zach made it clear that the motivation to engage with materials research provided the momentum for enrollment in graduate school instead of finding another job. He was confident that he would acquire the requisite domain knowledge required to work in material research.

Discussion

The participant cases organized by research question describe how participants experienced engineering practice in academic and non-academic institutions. Analysis of the data enhanced our understanding of why returners choose to enroll in Ph.D. programs and how intersections guide academic mindsets and research trajectory. Also, the CMoC may be an appropriate way to interpret the data if we want to compare or evaluate the level of creative capital returners' possess at different points in their career trajectory. A longitudinal analysis of returners' experiences could reveal strengths and weaknesses of the CoCP at instances across one's career to aid our understanding of how and why the CoCP transform through time.

The Impetus

Participants responded differently to questions about motives for transitioning into careers of academic research. Adam was unemployed, Zach had to relocate, Kristen wanted to settle down, Brandon desired respect, John was frustrated, and Michele was never passionate about her work. In each situation, participants were not complacent. They either wanted to make a change or balance their interests with family obligations.

The work environment limited Adam, Brandon, John, and Michele's creative performance in different ways. Adam and Michele were disappointed in the fact that they were not engaging in what they considered authentic design. They did not feel like engineers; both remarked that most of the tasks they were responsible for did not require an engineering degree. Adam referred to the straightforwardness of tasks; he suggested textbooks provided exact procedures for suitable solutions. Michele learned early on that any design work she engaged in was repetitively applied to all other related projects. For Adam and Michele, the challenge and subsequent reward of completing projects vanished over time.

Brandon and John—participants with years of engineering experience—realized they had reached the proverbial glass ceiling. Brandon's responsibilities were consistent with those of a professor, without the credit because he did not have a Ph.D. Brandon could not advance professionally without a Ph.D. despite performing research duties as professors at the research institute. This meant he could only support faculty on grants. He was not able to be the primary investigator of projects. John's industry trajectory led him down a path of management. With each promotion the less time he had for design work. Managing others and reading reports dominated his task list. He was not in a position to decide which projects the company should initiate, maintain, or discard. Instead, he helped execute and maintain the company's plan. John's motivation to return to school would enable him the chance to go back into research. The alternative would be to acquire a lower level position at the company so that he could design again.

Zach and Kristen each thought about going back to school, but they were not ready to commit right after completing a bachelor's degree. Both decided to enroll in graduate school as a result of shifts in their personal lives. Zach followed his fiancé to her residency appointment, and Kristen wanted to change her life to balance her interest in engineering and having a family. After weighing the options, both decided to engage in academic research.

The Intersection

Each participant's graduate research work connected to their prior engineering work in different ways and with varying levels of relatedness. Zach and Kristen chose to remain in the same domain or discipline as previous work while changing the topic. Adam and Michele's academic research shared different aspects of the same topic from previous work. Moreover, Brandon and John selected research problems directly related to industry work.

Zach became intrigued by material science while working on an industry project. His interest was so great that he decided to enter a field he was less familiar with than remain in an area where he had a vast domain knowledge. Kristen previously worked with designing cookstoves for developing countries. For her master's thesis, she created a theoretical heat transfer model of the cookstoves. She was not so interested in this research because it was too technical and not directly applicable to what she believed was important. Her dissertation research entailed developing a model to characterize the energy flow into and out of developing countries' communities. She hoped the research would be more impactful than her thesis.

Adam's industry and graduate research experience both revolved around IC design. He did not consider switching to anything else. He accepted an offer with a research lab working in the area of bridge vibration. There, Adam's IC design skills were put to use for the purpose of harvesting energy for vibration sensors placed in locations where electric power could not be accessed. Although in the mining industry, Michele did some work with stream design and dabbled a little in stream restoration research. That experience piqued Michele's interest, and she desired to engage in stream restoration. Michele sought out professors working on stream restoration in mining areas to combine her interest and present knowledge base.

Brandon and John knew what they wanted to study, as a dissertation topic, when they enrolled in their Ph.D. programs. Brandon wanted to solve a civil engineering problem related to road roughness with mechanical engineering methods. After spending his life's work on signal processing for military applications, John was intrigued to determine how to localize a transmitted signal. John thought about adding knowledge of signal transmission to his firm knowledge of signal processing. He believed he could then solve the problem. John decided to investigate the signal localization problem as a communications issue.

Componential Model of Creativity

Domain-Relevant Skills

All the participants possessed a minimum level of domain knowledge to be accepted to graduate engineering programs. The admissions requirements for each university guide decisions about admittance to graduate programs and who may engage in graduate coursework and academic research. Even with these guidelines, participants had a diverse set of skills and experience with their chosen topic of graduate academic research.

Zach and Michele had a little experience with their chosen academic research area gained through industry experience. For them, the introduction to the domain was the impetus for returning to graduate school. They committed to engaging in a new field which required attaining the necessary domain knowledge and skills. Digital imaging of ultrafine-grained metals involved requisite knowledge of materials. Zach had to learn about ultrafine-grained metals before he could appropriately design an imaging technique. Michele said she needed to relearn some of the environmental principles and processes she had forgotten since she was practicing in the mining industry. She was confident in her ability to switch from mining to stream restoration of abandon mining sites. Michele had a requisite knowledge of mining regulations, and she was certain she could learn what she did not know to engage in the field she found interesting.

Adam and John had substantial experience with IC design and signal processing, respectively, because they worked in the field for several years. Adam's focus was still IC design, but he was changing the application from computers to energy harvesting. To engage in this area, he had to visit bridges where sensors would be placed and gain a working knowledge of bridge vibration. In John's case, he thought his solid skills could be supplemented with knowledge of the broader situation. He believed understanding the science behind how signals are transmitted would help him to determine where signals came from. For Adam and John, an expansion of existing knowledge described the domain skills required for their chosen academic research.

Brandon, however, knew what he needed to do to carry out his dissertation. His position at the research institute enabled him to formulate a research plan that did not require learning additional requisite knowledge. In the case of Kristen, there was not enough information to determine if her academic research connected in any other way to her non-profit experience other than that they related to communities within developing nations.

Creativity-Relevant Processes

A glimpse into the experience of each participant revealed some insight into participants' creative mindsets and views of engineering creativity. Adam and Michele believed their work in industry was not creative because they did not have the opportunity to engage in original design. Kristen said it was the job of her adviser to provide the research questions for her thesis and dissertation. Zach was more autonomous in industry than he was on matters related to graduate academic research. Brandon and John had extensive design experience, and both developed research questions for their dissertations.

Michele and Adam discussed the dissatisfaction with the lack of design in their industry experiences. They described the design process as following procedure to arrive at a standard outcome. Michele said everything she designed was repeatedly used in different contexts. Adam considered industry restrictive and said he was able to take risks in graduate school. Both Adam and Michele were forced to operate in Assimilator mode when they wanted to be Explorers.

Zach treated his position in academic research as he had in industry. Adam met regularly with customers to discuss their product needs. Adam would listen, design, elicit feedback, and redesign to the satisfaction of the client. Adam did the same in graduate school, but because there were no customers, his academic advisor acted in their place.

The participants with years of engineering experience understood the domain they worked in from a big picture perspective. Their outlook on the significant problems emerged from a different perspective than the other participants. They chose to solve problems they knew had a practical purpose in the world. They merged topics they were knowledgeable about within domains that would result in practical applications. Brandon created a method of measuring road roughness for the department of transportation to determine when roads needed to be repaved. John designed a device to determine where a signal was transmitted from for military applications.

Task Motivation

Although John and Brandon had insight into the significant problems of their field, it appeared their motivation was less linked to the actual problem (task) and instead connected to an external force. If Brandon did not acquire his Ph.D., he would feel like a quitter. A decade ago, when he first enrolled in graduate school, he stopped and did not finish. Brandon's thesis was connected with an industry partner who ultimately did not want him to publish his research findings because of confidentiality reasons. A Ph.D. would mean respect from Brandon's colleagues. Once Brandon graduates he will have satisfied his, and his colleagues, desire for him to earn a Ph.D. In the case of John, getting a Ph.D. was a way to show his colleagues that what he wanted to do (for the military lab) had merit and applications for the military. It would be a way to communicate an "I told you so!" attitude. John was disgruntled by the fact that the military lab would not fund his education or allow him to work on a project he thought was important. Completing the dissertation would also contribute to earning a Ph.D. which ultimately allows him the autonomy[15] to freely research once hired in academia.

Adam was intrinsically motivated to solve complex, ill-defined problems. Luckily for Adam, his dissertation provided an opportunity to address a heuristic problem. Adam's interest was not confined to a particular application. He selected a research laboratory based on a general interest in problem solving within the domain of IC design.

Michele and Zach were intrinsically motivated by a project they encountered while in industry. Neither was able to investigate thoroughly the area that interested them. One of Zach's design projects included consideration for a lightweight, high-strength material to satisfy a particular criterion. Zach found that project to be interesting. He said the research he was doing in academia was meaningful[3] to him. Michele was introduced to stream restoration and hired at another company to work in the area, but it never happened. Her motivation to work in stream restoration was so great that she left her job to join a research group in academia to focus on stream restoration.

Kristen had the least motivation for research task. She was mostly motivated to continue to work in the field while raising her children. To balance the two, she prioritized her family and acquired a fellowship so she could work on her dissertation in her own time. Her motivation to earn a Ph.D. would give her more flexibility with her changing lifestyle.

Conclusion

The six case synopses of participants' experiences reveal insights into why returners elect to seek engineering Ph.D.s, how intersections of prior experience and Ph.D. training shape academic research, and the possible use of the CMoC to clarify components of creative performance visible in returners experience that enhances creativity in engineering academic research.

Four participants (Adam, Brandon, John, and Michele) emphasized autonomy and a drive to change their situation as the impetus for returning to school. Creative personality[15] is an element of creativity-relevant processes within the CoCP[1,2,3]. Both autonomy and drive are consistent with empirically derived characteristics of creative personality.[1,2,3,15]

All participants chose areas of academic research with which they had prior experience. Each participant had varying levels of skill and knowledge before they began working with a faculty advisor on academic research. Mature participants were more likely to have a stronger knowledge[23] of the research area in comparison to those with less than ten years engineering experience. Intersections of prior engineering experience and academic training related most closely to domain-relevant skills and task motivation. Participants made choices about academic research based on the level of comfort with requisite domain knowledge and the degree to which they were motivated to engage in the research. For example, Adam selected energy harvesting because he had a solid background in IC design. He was initially drawn toward research he was skilled in rather than motivated to do. Zach, however, moved from hospital equipment design to digitally imaging materials. For Zach, the gap in knowledge was larger than in Adam's case. Zach's intersectionality was driven by an intrinsic motivation rather than the level of domain knowledge.

Brandon and John developed many products in the twenty or more years they worked in the engineering field. By definition that makes them experts. They were able to see the big picture and identify problems in their domain. Both created research question that guided their academic research. John displayed openness[30] characteristics when he spoke about young engineers solving problems he thought could not be solved. The novice engineers occasionally proved John wrong by generating appropriate solutions to problems. John loved a challenge and proved to professors that solutions did exist for problems that seemed unsolvable. The persistence John displayed is a characteristic associated with creativity. The less experienced participants had varying degrees of experience with the design process and ability to conceptualize significant problems.

Task motivation was and was not interconnected with domain-relevant skills and creativity-relevant processes. Zach became motivated to engage with materials research after working on an industry problem and personal obligations. Kristen did not appear to be motivated to do research or to earn a Ph.D. Raising her family was her priority, but she did not want to lose a sense of herself while transitioning to motherhood. Trade-offs occurred as a result of interest. Zach had to change his field, Adam chose a new application that intellectually stimulated him, and Michele selected an application related to protecting the environment. Engaging in the task was meaningful in some way, either directly or indirectly.

Implications and Future Work

Personality, design experience, cognitive style, domain-knowledge, and motivation were all acknowledged as factors that contributed to answering the research questions. Each participant had a different case, and in turn, varying reasons for enrolling in Ph.D. programs and choosing particular research areas. Understanding the experiences of returners and the choices they make helps us comprehend the extent of their diversity, needs, and aspirations.

The next step in this investigation is to analyze the larger participant sample to answer the question, *In what ways does interest guide direct-pathway and returning Ph.D. students' academic engineering research, and to what extent does research progress sustain the motivation to persist?*

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