# Catalyzing Engineering Student Identity Development through an Independent Design Project

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**Abstract**

This paper examines the engineering identity development of an undergraduate engineering student through an auto-ethnographic look at an independent design project advised by a senior faculty member (co-author) at the United States Military Academy. The lead author undertook this study during the summer between his second and third year of undergraduate mechanical engineering education. This study of student development arose midway through the course of the independent design project, during a meeting between the lead author and the advisor. The advisor suggested that the author's rich expression of individual development should be recorded and reflected upon. Chief among this theme of individual development was the author's frustration with the gap between his performance, his ability, and his ambitions. His academic performance had yielded a top 40% ranking among his peers, while his tested academic aptitude was within the top 3%. Research in Engineering Education has demonstrated the value of developmental experiences conducted in concert with post-graduate advisors to foster identity development and increase the academic performance of undergraduate engineering students. This study sought to provide an example of this precedent as applied to an undergraduate student. Auto-ethnographic memos were used as evidence of the student's identity development. These memos were used to record a diverse collection of experiences occurring concurrently with the study to include; advisor meetings, a summer internship with a national research laboratory, challenges encountered, and individual reflections. Key takeaways from the author's developmental experience were changes in technical competence, technical collaboration, and engineering design, subjects of interest to engineering educators. These modes of individual student growth were mapped to an established, professional identity development model. The application of this model yields the conclusion that the student was fundamentally changed as a result of this study. This fundamental change represented a critical juncture in the student's development preceding entry into the bulk of his mechanical engineering coursework. The lead author anticipates that resulting personal identity growth from the independent study experience may close the gap between academic aptitude and current performance for the remainder of his undergraduate experience. This study provides engineering educators with a highly contextualized example of how an individual design project may provide opportunities for undergraduate engineering student identity development and the critical role project advisors may play in mentoring this development.

## Introduction

This study is intended to provide insights into the educational experience of a rising third-year engineering student that conducted a summer independent design project. This accounting of undergraduate engineering student identity development may afford other undergraduate engineering students and engineering educators an ability to replicate and improve upon similar experiences during formative years of engineering education. This experience occurred during the "middle years of engineering study" and "highlights a creative, successful effort" that can be adapted to individual engineering students or various engineering programs [1]. Records of the experience occur in the form of auto-ethnographic reflections taken from the participant-observation standpoint, consistent with previous research [2], [3]. These auto-ethnographic reflections were recorded weekly, and after specific instances of major development or learning. The problem statement for the independent design study was as follows:

> "Develop a means of brewing coffee and other hot beverages that is cost effective, zero maintenance, and conducive to increased collaboration and socialization between Civil and Mechanical Engineering cadets, faculty, and staff [4]."

This problem statement was developed through conversations between the project advisor and the author, as well as research backed publications testifying to the value of collaborative spaces at universities [5]. The auto-ethnographic insights arose as a subject for further exploration during a meeting between the author and project advisor. This conversation took place at the 50$^{th}$ hour of a 110-hour project; prompted by the author's account of struggling and overcoming an obstacle in the project. Key takeaways from the author's developmental experience were changes in technical competence, technical collaboration, and engineering design, subjects of interest to engineering educators [1].

## Background

This study used Kajfez's Model of Professional Identity Development (Figure 1) to explain the identity development of an undergraduate engineering student during a summer independent design project. Kajfez's model was originally developed to explain the development of graduate teaching assistants (GTAs) in first year engineering programs [6]. This model was employed in the context of the paper because of the unique nature of the United States Military Academy (USMA). This model is not used to liken the author's current stage in education to that of a GTA. Rather, this model is considered valuable because of the relatedness between cadets and faculty at USMA: Many members of the faculty are former cadets and current Army Officers. This relatedness allows each cadet to view each faculty member as a role model and potential future self. Following this model, then justifies the value of the independent design project. Working one-on-one with a faculty member provides an opportunity to not just pursue graduate-level work and scholarship opportunities, but to also make advances and fundamental changes towards that imagined future self.

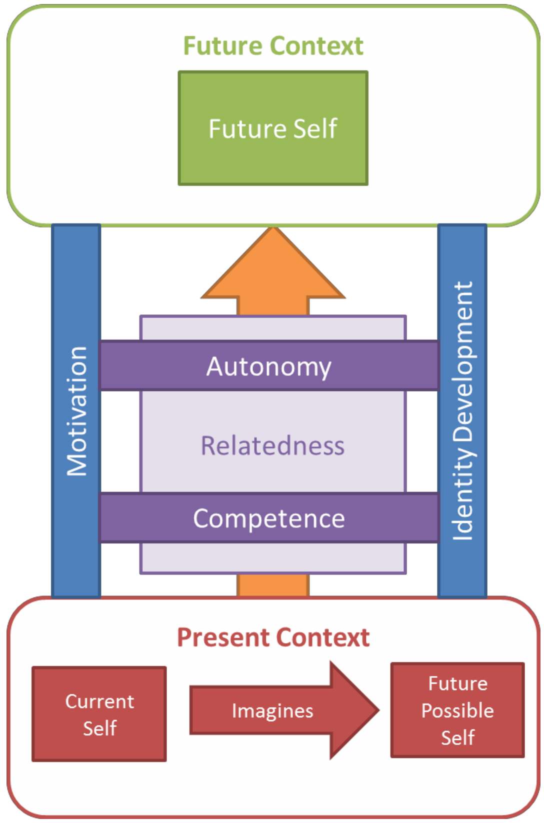


Figure 1: Kajfez's Model of Professional Identity Development [6].

Of note to this study is an account of the author's educational background, ability, and performance to provide context for the remainder of the work. The author attended secondary school in a rural area of southeastern Missouri. He graduated in the top 20% of his class and received several academic awards related to proficiency in STEM subjects. Further elaboration on his introductory STEM education is included in Table 1.

Table 1. The author's formal STEM education at the onset of the independent design project

| Secondary School | 1st Year Engineering Curriculum | 2nd Year Engineering Curriculum |
|---|---|---|
| Calculus | Multivariable Calculus | Probability and Statistics |
| Geometry | Mathematical Modeling and Differential Equations | Fundamental of Engineering Mechanics and Design |
| Trigonometry | Physics (2 terms) | Introduction to Engineering Design |
| Algebra (2 years) | Introduction to Computing and Information Technology | Mechanics of Materials |
| Physics (2 years) | | Chemistry (2 terms) |
| Chemistry (2 years) | | |

As for ability, the author has recorded an IQ of 147 and scores between the 97-99th percentiles on most aptitude exams. His academic performance has not matched this level of ability: he averages a 3.112 GPA and ranks at the 40th percentile among his peers. This average performance can be tied to a disadvantaged background [8], as well as a lack of motivation; the latter of which changed significantly over the course of this study. The author's sense of self and motivation for pursuing the design project were evident during the initial project proposal:

> *"I would like to build and develop a coffee machine that does away with baristas. Essentially, the coffee version of those all-in-one Coca-Cola machines; a machine that can make any number of coffee-related beverages and interfaces with your phone… I should be able to manufacture a working prototype by the end of the summer* [7]*."*
>
> -Kahn, Week 1

Another conversation sparked a measure of cognitive dissonance when the project advisor insisted on scoping the project with the design process as a framework:

> *"It seems like the design process is not a valuable tool. It is only a recent creation. Consider Da Vinci, Jobs, the Wright Brothers, these men got along fine without a single decision matrix. If these great men can forego formal education, and engineering design, why should I waste my time? What value is there in a process that is so stifling* [7]*?"*
>
> -Kahn, Week 1

The advisor then brought to bear an anecdotal account of modern manufacturing practices and the comment that:

> "The design process is not THE answer, it is a framework for getting closer to what is right on the first attempt, then allowing for iteration afterwards [4]."

The author's perception of his future self at the beginning of the study was delineated by an inflated self-concept , evidenced in the excerpts of auto-ethnographic notes [6], [7]. The lack of motivation and competence prevented identity development or progress toward the imagined future self. At the beginning of the study the author's progress towards a future self with an engineering identity was blocked by a lack of the qualities listed in Kajfez's model. Motivation initially stemmed from an obligation to complete course work in the pursuit of graduation and a degree, not as a desire to become an engineer or assume responsibilities related to the engineering profession. Engineering competence was lacking as the author had only just completed the first year of engineering education. The autonomy afforded within a classroom environment was minimal as classes operate at a high tempo with many requirements that are standardized in a way that may have minimized the opportunity for creative or ill-structured solutions. The author also did not have any deep relationships with faculty members or other engineers that could sponsor a degree of identification and relatedness. The sum of these factors set initial conditions that did not favor engineering identity development.

The independent study facilitated an opportunity to change these factors and progress towards an engineering identity. Through working with a senior faculty member at USMA the author was able to eliminate obstacles to engineering identity development. Motivation changed as the author began to understand the value of foundational engineering coursework in relation to solving real world challenges. Engineering competencies increased as a result of being placed in environments such as Pacific Northwest National Laboratories (PNNL), where the opportunity to gain new working skills and practical abilities was facilitated by lab technicians, senior engineers, and a large network of supportive staff. The autonomy implicit in the independent study allowed for wide parameters to work within that fostered novel solutions to engineering design problems. Dialogue with the supervising faculty member as the study progressed allowed for opportunities for the student to gain a better understanding of engineering professionals and the reason certain methodological processes were employed. This in turn brought about the relatedness necessary to engineering identity development.

**Methods**

Records of the experience occurred in the form of auto-ethnographic reflections taken from the participant-observation standpoint, consistent with other auto-ethnographic studies (i.e., [2], [3]). This precedent holds that some value can be garnered from the subjective insights of an individual as described by Patsavas and Caldwell:

> "Because several critical aspects of educational transformation are both subjective and experiential, this "case study" approach is presented as a source of additional information to consider when examining the learning goals and processes associated with developing student capability and interest in the research process [2]."

To present the educational transformation as accurately as possible, and avoid retrospective or other confounding biases, auto-ethnographic reflections were maintained diligently. These auto-ethnographic reflections were recorded weekly, and after specific instances of major development or learning. Excerpts from these reflections are presented in this paper with little editing, except for the purposes of communicating the material in a more cohesive manner.

To ensure the quality of this auto-ethnographic work, the author followed the framework of analytic auto-ethnography, as presented by Anderson [9]. The author was "a complete member of the social world under study." The social world having been that of a student interacting with senior engineers employed in research and academia. The necessary condition of analytic reflexivity was met implicitly as a function of the recorded auto-ethnographic reflections. Within this text, the author has been presented as a visible and active researcher, instead of the invisible bystander that characterized early auto-ethnographic research. Additionally, the stipulation that analytic auto-ethnography requires a commitment to the analytic agenda is met by strict observance of precedents established in other case study approaches. The final tenet of analytic auto-ethnography is dialogue with informants beyond the self. This is an acknowledged limitation of the study. This deficiency can be attributed to the isolated nature of the independent design study, as well as the limited population of student-researchers engaging in auto-ethnographic reflections.

## Results and Discussion

Progress towards the author's engineering future self occurred during an independent study in a series of stages: 1) a realization of competence gaps identified through reflection, 2) competence gap mitigation through the autonomous framework of the independent study, 3) changes in learning behaviors that led to greater motivation, and 4) the catalyzation of engineering student identity development.

### Competence Gap Identification

Within the context of Kajfez's model, the author's identity development and progress towards a future self developed concurrently with the independent design project. This lends credence to Tonso's assertion that "learning is itself conceptualized as a change in identity that comes with participation [10]." Because of the exploratory nature of the independent study project, the author was allowed maximum autonomy. In addition, motivation was elevated because there was only self to blame for failure and in contrast, no theoretical limit to success. Any shortcomings or accomplishments were a direct reflection of ability; the author's sense of competence and self-efficacy were at stake. This success-failure motivation leveled off after the initial weeks of the project. It was later supplemented by a more holistic enthusiasm for the challenge of designing a mechanical system.

Early in the project, the author identified competence gaps associated with the breadth of the project he had undertaken. Despite an ability to grasp theoretical engineering concepts, a lack of hands-on engineering experiences prevented the translation of theory to the physical world. The author correspondingly had difficulty designing a complex system because he was unfamiliar with the physical nature of real-world problem solving.

> *"I could explain how the internal combustion engine worked with minimal difficulty. Gas is injected into pistons that compress, ignite, then fire, creating torque about a shaft that motivates a vehicle. Yet when I was handed a carburetor, the object was entirely foreign to me. I had no idea what it was, or where it physically existed in relation to the engine. My understanding was only metaphysical in nature. I had no practical ability* [6].*"*
>
> Kahn, Week 3

Additional deficits came to bear during later design stages when the need to dimension CAD models of the brewing system. Noticing this deficit in "nuts and bolts expertise or technical competence [10]" the author's motivation to fill identified knowledge gaps through further study increased.

The particular design chosen by the author required a practical ability to incorporate engineering concepts into the machine's design. Specific subsystems required the knowledge of specific fields of engineering that the author was unfamiliar with. For example, in order to design a system to deliver power through the appliance, the author needed an understanding of power consumption, electronic components, and circuit design. In order to configure an optimal brewing system, the author needed to understand how fluids and heat flow, as well as the effect these variables would have on the system's end product. Additionally, the author's attempts to improve on the coffee-making process required further development of fundamental engineering concepts like centripetal force and pressure. In retrospect, these identified competence gaps illuminated the importance of the author's follow-on engineering coursework that would help fill these gaps (Table 2). The lack of engineering competence displayed by the author may suggest that the independent study began too early. However, finding this gap in competence served only to increase the author's anticipation for the forthcoming formal curriculum. In this regard, the author believes that that a key component of middle years engineering education may include a revision of the student's self-concept, toward the further development of an engineering identity [10].

Table 2. Gaps identified in current knowledge and how the curriculum addresses these gaps.

| Knowledge Gaps Identified | 3rd Year Engineering Curriculum | 4th Year Engineering Curriculum |
|---|---|---|
| Power Consumption, Electronic Infrastructure, Circuit Design | Introduction to Electrical Engineering | Controls, Mechanical System Design |
| Fluid Flow Rate, Heat Transfer Rate | Thermal-Fluid Systems I, II | Heat Transfer |
| Brew Time, Coffee Bean Diffusion Rate | Thermal-Fluid Systems I, II; Biology | Organic Chemistry I, II |
| Centripetal Force Generated, | Dynamics, Computer Aided Design | Mechanical System Design |
| Pressure Exerted on Grounds | Dynamics, Thermal-Fluid Systems I, II | Soil Mechanics |

Autonomy Facilitated Competence Development

Additional progress towards the development of an engineering identity was marked by increases in practical engineering knowledge. Having the autonomy to begin working with a project advisor, engineering technicians, and developing a learning behavior of increasing competency through the utilization of multiple sources such as solutions online, professional networking, and in academic curriculum proved to be of immense benefit to the author's engineering competence. Tertiary knowledge of several physical systems arose through spending time in laboratories, working with tools, and studying supplemental materials. There was a direct relationship between many of the systems the author was exposed to and the project's final system architecture.

> *"This afternoon I was working in the laboratory and had to make use of the drill press. As the material I was working with was carbon fiber, I had to adjust both the speed and bit settings. These were tasks I had never done before. The lab supervisor worked with me to make these adjustments and as we peered into the guts of the drill press I observed a v-pulley configuration that I had never seen before. To adjust the speed of the drill press, it was necessary to change the configuration of*

*the pulleys. A similar design could be implemented in the system architecture for the coffee brewing project* [6]*."*

Kahn, Week 7

The exposure to a broad spectrum of engineering as well as the development of professional relationships with senior engineers enabled the author to better understand and relate to the engineering profession. This exposure led to an increase in the relatedness between the author and engineering, a necessary step in the progress towards a future self with a professional engineering identity. The author also exhibited an increased level of production quality due to frequent, thorough feedback from the project advisor. Many of these increases are reflected in the study's final products.

Changed Learning Behaviors

Revising the author's self-concept led to changes in learning behavior. It is common knowledge that engineering and science are much more than being able to solve example problems in a textbook. The author initially approached the design project with the same philosophy he used to prepare for class; just read the book, learn to solve the problems, and finish as quickly as possible. As the project progressed this philosophy proved untenable. For example:

*"I just spent three days trying to reinvent the wheel, literally. I was attempting to craft a CAD model of a textured wheel that would increase friction between itself and the ground. I also tried to build a screw, a perforated cylinder, and a pulley system. I have made no progress.* [6]*"*

Kahn, Week 5

While meeting with the project advisor the author admitted to significant difficulty in making a number of machine components in a CAD program. To which the advisor replied: "why didn't you just look it up [4]?" At this point the author and advisor began searching online for solutions to various problems that had hindered the project's progress. Figuring out how to perforate certain patterns into a hollow cylinder, a problem that the author had spent hours attempting to troubleshoot on his own, now required ten minutes with the assistance of a YouTube tutorial. For some reason, due to stubbornness or another mental block, the author had insisted on a brute force approach to problem solving. This was evidenced in the benchmarking stage of the project, the CAD modeling (as denoted above), and the engineering design calculations. The interaction with the advisor that proved the inefficiency of a brute force approach changed the author's approach to problem-solving. The author began to understand the situated nature of engineering knowledge and myriad of resources available for self-inquiry. As a result, the author's problem-solving ability and tendency to collaborate increased. These increases in ability are cornerstones in the development of an engineer's identity and success [10].

**Conclusion**

Because of the independent design project, meetings with a project advisor, and auto-ethnographic reflections, the author made fundamental progress towards a professional engineering identity. Progress towards an engineering future self could then occur within the context of this study as evidenced by shifts in the author's subjective experience, documented through autoethnographic memos. As a result of this project, the author's motivations shifted from one based on an inflated self-concept, to a collaborative, growth-based pursuit of engineering education. The author's competence increased drastically in several areas of interest to engineering educators: technical competence, technical collaboration, and engineering design. The project provided the author maximum autonomy over the course of its execution. Working closely with a faculty advisor provided relatedness as well as the opportunity for identity development. These improvements satisfied all of Kajfez's requirements to progress towards an engineering future self. This experience thus paved the way towards an improved professional identity for the author. The critical factors that led to these improvements were the revision of an inflated self-concept, the identification of gaps in engineering knowledge, and the development of a more refined engineering identity.

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