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Exploring the Role of Data Proficiency in Shaping Engineering Identity

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Abstract

This study investigates the relationship between data proficiency and engineering identity formation among undergraduate engineering students. While prior research has examined various aspects of engineering identity development, the specific influence of data proficiency on identity formation remains understudied. Through semi-structured interviews with 52 undergraduate students across nine engineering disciplines, we explored how different facets of data proficiency influence the components of engineering identity. Our findings reveal that the dynamic between information literacy and data application plays a central role in shaping engineering identity and other aspects of data proficiency. This relationship is particularly strong in "professional data application" tasks (such as labs and projects) compared to "technical data application" tasks (such as homework assignments). The study found that a robust connection between information literacy and data application positively influences students' competence, recognition, and interest levels. Conversely, when information literacy lacks connection to data application, it can negatively impact engineering identity formation. These findings have important implications for engineering education, suggesting that curricula should intentionally incorporate data application experiences throughout degree programs to foster both data proficiency and engineering identity development. The results also provide insights into how different types of learning experiences contribute to students' professional identity formation through engineering education.

Introduction and Background

Engineering education today faces the challenge of equipping students with both technical knowledge and the ability to interpret and work with data. The increasing complexity of engineering problems and the rapid growth of available data have made data proficiency essential [1]. Equally important is fostering a strong engineering identity, which influences students' persistence and career paths [2]. While much research has explored engineering identity—focusing on competence, recognition, and interest [3]—less attention has been given to how data proficiency impacts these identity components. This understanding is critical as engineering programs optimize curricula to prepare students for a data-driven profession.

Engineering identity is a dynamic construct evolving throughout students' academic experiences, encompassing technical competence and a sense of belonging in the engineering community [4], [5]. Key factors include performance/competence beliefs, interest, and recognition from peers and mentors [6]. Meanwhile, data skills have become crucial for engineering graduates [2], though integrating data science into engineering curricula varies across institutions [9]. Recent studies [1], [7], [8] have begun exploring the link between data proficiency and engineering identity, but further research is needed to clarify how specific data skills influence identity formation. Understanding how students' abilities to acquire, process, and apply data affect their self-perception as engineers is vital for curriculum development. The interplay between theoretical knowledge and practical application in data proficiency is also a critical area of investigation. Preliminary evidence suggests that how students engage with data may be as important as the data skills themselves [9]. This aligns with broader research on experiential learning in engineering education, which emphasizes the value of hands-on, contextual learning experiences [10], [11].

This paper, representing the second phase of a larger study, investigates how different aspects of data proficiency influence engineering identity among undergraduate engineering students across various programs. The qualitative phase explores this relationship, with the quantitative phase building on its findings. By examining this intersection, the study aims to contribute to engineering education literature and inform curriculum design and teaching strategies. The findings could help educators better support students' development of both data proficiency and engineering identity through well-designed educational experiences.

Theoretical Framework

This section establishes the conceptual foundation for investigating the intersection of data proficiency and engineering identity among undergraduate students. We integrate Godwin's engineering identity framework [6] with data proficiency concepts [8] to understand their mutual influence on engineering education and professional development. Godwin's framework outlines three key constructs of engineering identity: interest refers to a student's enthusiasm for engineering, recognition involves being seen as an engineer by others, and performance/competence relates to confidence in one's engineering abilities.

Data proficiency has become increasingly crucial in the engineering field. It can be broadly defined as the ability to effectively collect, analyze, interpret, and communicate data to solve problems and make decisions[8]. In the context of engineering, data proficiency encompasses skills such as statistical analysis, data visualization, and the application of data-driven insights to engineering challenges. The ability to work with data has become an essential competency for engineers. In the context of this study, data proficiency consists of four facets, which are information literacy, data presentation, data application, and computational thinking. Information literacy is the use of background knowledge and critical thinking to obtain and integrate information, along with knowing how to apply it. Data Presentation involves the use of a variety of visual and non-visual means to review, analyze, interpret, and communicate data clearly. Data Application is one's use of data, along with their own skills, intuition, and proficiency, coupled with the evaluation and validity of the data to make well-informed decisions that yield desired results. Computational Thinking is the use of specific techniques and tools to thoroughly manipulate and analyze data.

This integrated framework guides our research by examining how students' experiences with data shape their engineering identity and, in turn, how their identity influences their data proficiency. Understanding these relationships can inform engineering education practices, fostering both strong engineering identities and critical data skills. We synthesize Godwin's model with data proficiency concepts to explore how these elements co-develop and influence each other, preparing future engineers who are technically skilled and have a strong sense of identity in a data-driven field. Thus, the research question in this study is: ***How do the facets of data proficiency influence the components of engineering identity?***

Methodology

The study was conducted as part of a larger NSF-funded, IRB-approved, mixed-methods research investigating the connections among undergraduate engineering students' data proficiency, motivation, and engineering identity. This exploratory sequential mixed-methods investigation is a two-part project, and this paper presents findings from the qualitative phase of the mixed-methods investigation. Much of the methodology of this qualitative phase is similar to the procedure seen in [8], where a similar and related qualitative study was performed targeting Mechanical and Aerospace Engineering students.

Participants and Recruitment

This study involved 52 participants selected from an initial pool of 177 interested applicants over a two-month recruitment period. The participants represented diverse demographics across gender, academic level, and engineering disciplines. The gender distribution included 26 women (50%), 25 men (48%), and 1 non-binary participant (2%). Participants spanned all undergraduate years, with a relatively even distribution across academic levels. The sample included 11 freshmen (21%), 12 sophomores (23%), 13 juniors (25%), and 16 seniors (31%), providing perspectives from students at various stages in their engineering education.

The participants came from nine different engineering disciplines, with aerospace engineering being the most represented field. Twenty participants (38%) were from aerospace engineering, followed by seven (13%) from mechanical engineering, and five (10%) from biomedical engineering. Ocean Engineering contributed four participants (8%), while Computer Science, Computer Engineering, and Chemical Engineering each contributed three participants (6%). The remaining participants included two students (4%) from Civil Engineering and one (2%) from Software Engineering. This disciplinary distribution provided a broad representation across engineering fields, with particular strength in aerospace and mechanical engineering disciplines naturally aligning with these majors' dominance in the university's engineering population.

Data Collection and Analysis

The thematic analysis of this qualitative study was grounded in the thematic analysis framework proposed by [17]. To refine the interview protocol, we conducted a pilot study with four participants, transcribing and analyzing the data to ensure it effectively elicited the desired information. This process helped us identify and resolve ambiguities, adjust the interview flow, and confirm our ability to capture the intended perspectives. Guided by the engineering identity framework and partially reflecting expectancy-value theory, the protocol was designed to explore key aspects of engineering identity formation and students' expectations and values related to data skills. This theoretical foundation allowed us to thoroughly examine students' learning processes and identity development as engineers. Following the pilot, we moved to full data collection, conducting 45-minute individual interviews using the refined semi-structured protocol. These in-depth conversations focused on participants' experiences in acquiring data skills, developing proficiency, and forming their engineering identity. We used an inductive approach, avoiding preconceived definitions from the literature to access genuine, student-driven perspectives on data proficiency and its value in engineering. Participants were allowed to select their own pseudonyms, and many chose creative names, as will be employed in the findings section.

To maintain a student-centered approach while ensuring clarity, we introduced definitions of data proficiency and provided academic examples only later in the interviews when necessary for deeper exploration. This strategy allowed students to express their interpretations and experiences in their own terms while preserving the authenticity of their voices. By prioritizing their perspectives, we gained valuable insights into how they understand and experience engineering identity formation. The audio recordings of the interviews were processed through a secure transcription service, with all identifying information carefully redacted before qualitative analysis began. To ensure accuracy, researchers also listened to the recordings to verify that the transcripts faithfully captured both the content and the vocal tone of the interviewees. This attention to tone was important, as the tone in the excerpts used in the results section was consistent with the corresponding audio recordings, adding another layer of reliability to the analysis.

An abductive analysis approach was employed to analyze the interview transcripts, with two coders working collaboratively to interpret the data. This method, which combines deductive and inductive reasoning, allowed the researchers to move iteratively between the data and existing theories, generating new insights and explanations. The coders began with a set of initial codes based on the research questions and theoretical framework but remained open to emerging themes and patterns in the data. They independently coded sections of the transcripts, then met regularly to compare their interpretations, discuss discrepancies, and refine the coding scheme. This process of constant comparison and negotiation helped ensure the reliability and validity of the analysis. As new concepts emerged, the coders revisited previously coded transcripts to apply these insights, ensuring a comprehensive and nuanced understanding of the data. This abductive approach facilitated the identification of key themes such as the information literacy-data application dynamic and its influence on engineering identity formation.

Findings

Analyzing the transcripts of 52 undergrads provided valuable insights that answered the research question and shed light on the interactions between various components of data proficiency and uncovered additional themes. These will be explored in detail throughout this section.

<u>The Information Literacy-Data application dynamic:</u>
The main theme from the analysis is that participants are eager to learn how to apply their knowledge and anticipate opportunities to do so, as this experience greatly enhances their engineering identity. A dynamic between information literacy and data application emerged, with experiences in applying data positively influencing engineering identity. Further analysis showed that data application can be split into two categories: "professional data application," which involves hands-on tasks like labs and projects, and "technical data application," which applies data in theoretical settings like homework. Professional data application had a stronger positive impact on competence and recognition, while technical data application had a lesser impact on competence and no significant effect on recognition. The only negative influence on engineering identity occurred when there was no connection between information literacy and data application.

When Grid Iron (a Mechanical Engineering senior) was asked about the contribution of projects (professional data application) in the development of his data proficiency, his response exemplifies the influence of professional data application on engineering identity.

> ***Grid Iron:*** *Projects? They were beneficial. A lot of the projects that I did were beneficial with the subject matter because it was like, taking what you learned in the semester and then applying it to this project. And there were times when I was a little confused, but that's what the professors are there for. So I can just ask them. But being able to apply what I learned and see it working out in the project, whether it's a design project or it's design, yeah, mostly design projects. For example, design this system to have this much*

amount of yield, and how would you design it, and other such things. It helped me to develop my analytical skills and design skills by myself. It's less handholding in a sense because you're working to your solution by yourself.

Grid Iron connected semester learning with project work, highlighting the development of analytical and design skills through hands-on experience. This reflects a dynamic between information literacy and data application, as Grid Iron emphasized applying learned knowledge to the project. The response, which stresses self-directed learning with the professor's guidance as a backup, shows the positive impact of this dynamic on competence. Similarly, first-year Mechanical Engineering student Bianca Yates expressed that gaining more experience and internships would enhance her job prospects, illustrating how even early in her program, the connection between information literacy and data application is linked to career recognition, as she anticipates these experiences will make her a more employable engineer. With regards to the information literacy-data application dynamic using technical data application, the positive influence on engineering identity is less than that using professional data application, as illustrated by the response of Ethel Shorhoot (a Biomedical Engineering junior) when asked about the contribution of homework assignments to the development of her data proficiency.

Ethel Shorhoot: *[…] because depending on the class, for some of the homework, you have to go through what was said in the lecture. You have to find what piece of data you need to do the homework and answer those questions. […] So you just keep doing examples until you get how to do it. So that would definitely use the textbook. […] Either for example problems, such as for large part of the biomechanics class, the textbook told you how to do the problems. And then it would have practice problems with the answers attached. And then using them for homework as well.*

It is evident that Ethel Shorhoot finds homework beneficial for data proficiency, but her response lacks the confidence seen in Grid Iron's response regarding professional data application. While Ethel uses homework to enhance her understanding, which positively impacts competence, it is less significant than professional data application tasks. This suggests that students see homework as an opportunity for technical data application, but the connection between information literacy and data application is weaker in these tasks.

The influence of the robustness of the information literacy-data application dynamic is also seen in the responses to questions where the participants were subtly asked to demonstrate their intuitive thinking. The accuracy of the intuition responses is dependent on the robustness of this dynamic. This phenomenon is demonstrated by an excerpt from an Ocean Engineering senior called Arnold Johannesburg, when he was asked about the factors that helped him develop his data proficiency.

Arnold Johannesburg: *Yeah, so I think a lot of the labs at this institution, I mean I started with chemistry and taking Waves lab. We do a lot of data processing with MATLAB and making tables to compare data. So it helps to observe results with what you're theoretically supposed to be getting. And so I think just a simple skill of being able to have a percent error with what you're trying to get an output for, and then going back and maybe modifying a coefficient for a variable and then that would change your output and give you a better, percent error. I've been working in the hydromechanics lab and we've had to do a hydrodynamic coefficients altering to try to get more accurate results for sea trial data for* *ships. So little coefficients can make a big difference in being able to define what's a reasonable parameter, as it can change a lot in your outputs.*

The display of high information literacy (as knowledge, evaluation, and data manipulation were exhibited) coupled with the presence of rectifying incorrect parameters, displays a high robustness of the information literacy-data application dynamic, as well as an adequate understanding and accurate intuition of the boundaries of acceptable parameters for ship engineering (as he said little coefficients can make a big difference). From the confident vocal and written tone of this response, it is clear that this also has a positive influence on competence, and even on computational thinking and self-recognition as an engineer, as the accuracy of the intuition was explicitly connected to lab experience (professional data application).

On the other hand, participants with a relatively less robust information literacy-data application dynamic, show an intuitive response that is less confident, As demonstrated by the following excerpt by an Aerospace Engineering Junior called Charles Xavier, when he was subtly asked to display his intuitive thinking.

Interviewer: *So right now if I tell you design a glider, but with the wing of the glider, let it have a drag coefficient of 0.001. What's the first thing that comes to mind?*

Charles Xavier: *I don't know how. If I'm designing a glider and I need that drag coefficient, I'd trial and error, probably look for airfoils online, try to get the shape of it down, then cut it and see if what happens, I guess that would be a starting point.*

Charles Xavier's response lacked confidence and accuracy, showing uncertainty except for a basic understanding that lower drag coefficients are better. He failed to grasp the impossibility of such a drag coefficient, highlighting his lack of accurate intuitive thinking. In contrast, Ocean Engineering graduate Krabaple Willington immediately recognized the impracticality of kicking a soccer ball with a 50,000-kilonewton force, demonstrating more accurate intuitive thinking. Xavier’s response indicated a weaker influence on competence, while Willington’s was more accurate, confident, and reflective of a stronger grasp of the concept.

Another prevalent observation that was made amongst nearly all participants is that the initial level of interest at the start of a program is at a high level for participants who have had professional data application experiences during their high school years, illustrating the positive influence on interest at a freshman level that is dependent on the information literacy-data application dynamic at a high school level. This is exemplified in the following excerpt of a Software Engineering junior, pseudonymned Clarence Hershey, when he was asked about what led him to engineering.

Clarence Hershey: *So my high school had this really nice engineering CTE pathway where we could take a bunch of engineering classes and I did that and that was my introduction to engineering. I also took some AP computer science courses in high school and besides those block programming, Minecraft games, they have you play, that was my first introduction to computer programming and well, I liked that. Came easily, decided I wanted to do that for a career. So I came here for computer science, did that a little bit and I changed my major to Software Engineering earlier this year because I guess that lined up more with what I actually wanted to do as a job.*

Clarence Hershey cited pre-college engineering experiences, like block programming, as key factors in choosing his degree program and switching from Computer Science to Software Engineering, as it better aligned with his goals. This demonstrates the positive influence of a strong dynamic between information literacy and data application at the pre-college level, significant enough to impact his degree choice. Conversely, another excerpt from Charles Xavier, highlights the relatively lower interest levels when such hands-on experiences are absent at a pre-college level. This response was to the same question asked to Clarence Hershey in the previous excerpt.

> ***Interviewer:*** *So tell me about what made you select engineering as a whole?*
>
> ***Charles Xavier:*** *Engineering, I don't know, just always preferred math and science, like to English and history, and then my dad was also in engineering. He works for a very large company, so like I kind of got to go do a lot of bringing kids to workday and see what he was doing. And I just thought engineering would be cool.*

The written and vocal tone of Charles Xavier's response is less confident compared to that of Clarence Hershey, when asked the same question. There was also a lack of any mention of professional data application experiences at a pre-college level, and only mention of vicarious experiences (watching his father at work) causing a low robustness of the pre-college information literacy-data application dynamic. As a result, the interest levels that brought Charles Xavier to pursue Aerospace Engineering is notably lower than that of Clarence Hershey.

It was also seen that participants who exhibited a robust dynamic of information literacy and data application, also exhibited a high level of presentation skills and confidence. This is highlighted in Ethel Shorhoot's answer when she was asked about the best experiences in her program.

> ***Ethel Shorhoot:*** *Yeah, so probably the best one was I presented at a conference back in April for the lab. Me and the PhD student I work with, we presented our research, which was really cool. The second probably has to be just in general, all the labs and introduction to Biomedical Engineering where we got to use all the equipment, thought that was really cool. And also just like working with the simulations in my lab and running those has been really fun.*

Ethel Shorhoot identified presenting with a doctoral student as her best experience. Her strong dynamic of information literacy and data application, highlighted by her preference for professional data application experiences, shows that this dynamic positively impacts data presentation and recognition. Enjoying the opportunity to present alongside a PhD student indicates her recognition as qualified by others.

With regard to data presentation and computational thinking, it was noted in some participants that high levels of data presentation and computational thinking had a positive influence on competence and recognition. They elicited the desire to pursue further education and research. This excerpt from an Electrical Engineering senior called Ivan Intel demonstrates the phenomenon, when also asked about their best experiences in the program.

> ***Ivan Intel:*** *So my best experience so far has definitely been working with fiber optics and communication systems and just how to integrate that into mechanical systems or just like for this semester, I believe I'm taking control systems this semester, and with that it's introducing things like motor systems and integrating that with satellites. So it's just*

interesting how you could obviously combine the two with motors and gears and whatnot into electrical systems. And so far the communication system experience has been my favorite so far, whether it'd be RF or infrared or net visible light. […] So I've already started applying to graduate schools, so I want to get my master's and hopefully go into my PhD to do research.

Ivan Intel was able to detail his favorite aspects of his best project experience (where the potential of interconnected systems was specified) as well as display a desire to pursue further education and research based on his knowledge and data application experiences. This shows a positive influence of information literacy and data application on data presentation and computational thinking, which then has a positive influence on competence and recognition. Shifting to influences on recognition, the analysis reveals that the facets of data proficiency that most strongly influence recognition are data application and data presentation. The below excerpt from a freshman in Mechanical Engineering called Bianca Yates illustrates the importance of data application with recognition, as perceived by the student.

Bianca Yates: *[…] I think that I will have to improve that because it's something as an engineer, you have to contextualize all the data that you're getting, as input in your work and know what you have to do or know what the people need you to do.*

Bianca Yates associates information literacy and the ability of data application and computational thinking with data proficiency and with being recognized as an engineer, as she distinguishes the lack of such experience with her low self-perception of data proficiency. Conversely, another excerpt from Charles Xavier shows the positive influence of data application and data presentation with recognition.

Charles Xavier: *I think definitely specifically going to the regional conferences or whatever, I wrote and presented on research both times. Like freshman, sophomore, open topic. So I got to do whatever I wanted in research and talk about it. And I think that helped, because you are then presenting a technical paper to judges, like a panel of judges as well as anyone who's there at the conference who wants to see it. So it's a little nerve wracking, but I definitely think it's helped me overall presentation-wise, research-wise as well just like as an engineering student.*

Repeated opportunities for research (which involves high levels of the information literacy-data application dynamic) and presenting the research findings in multiple forms had a substantial positive influence on recognition for Charles Xavier, as illustrated by his fondness for repeated presentation opportunities of his research findings throughout his degree program so far.

The analysis also revealed that when data application was disconnected from information literacy, it negatively impacted engineering identity, highlighting the central role of data application in influencing other aspects. This was particularly evident when participants lacked confidence in their engineering abilities or showed more interest in courses with frequent data application opportunities. For example, Kryptonite X, an Ocean Engineering junior, expressed such concerns.

Kryptonite X: *I don't have a lot of hands-on experience with projects and stuff. I've only ever done one. I would say I've learned a lot more working in professor's lab than most... You learn the concepts which are important but I don't necessarily feel confident being at a workplace and really having to do a function."*

Kryptonite X lacks confidence as an Ocean Engineer due to limited hands-on and project experience, which offer opportunities for professional data application. This disconnect between information literacy and data application negatively impacts her competence and self-recognition.

Program-specific influence on recognition:

Data analysis revealed that interestingly, all Biomedical Engineering students emphasized the importance of the recognition element a bit more than students who are in other degree programs. An example of this is in yet another excerpt from Ethel Shorhoot (Biomedical Engineering Junior).

> ***Ethel Shorhoot:*** *So in high school and in middle school and everything, I've always just been really good at math and that's always been my strongest subject. And then in high school, I knew I wanted to go into the healthcare field because I volunteered at a nursing home in middle school and high school and I loved it. I loved working with people. So I wanted something that would somewhat combine the two of those. So that's why I decided on Biomedical Engineering because it allowed me to use those math and science skills while also helping people in the health profession.*

Ethel Shorhoot's course selection was partly attributed to a pre-college volunteer role, along with her engineering aspirations. The strong recognition factor is highlighted by her mention of enjoying working with people and wanting to help people. This emphasis on the recognition element positively influencing interest was not that noticeable in participants who were not in Biomedical Engineering.

Discussion and Implications

This study investigates how data proficiency impacts engineering identity among undergraduate students, highlighting the dynamic between information literacy and data application as the key factor influencing both engineering identity and other aspects of data proficiency. The influence was stronger in professional data application than in technical data application. The study showed that competence was significantly influenced by data application across various engineering disciplines, not just Mechanical and Aerospace Engineering. A deeper analysis revealed that the robustness of the interaction between information literacy and data application depends on the task type, with the presence of data application shaping how it influences other facets of data proficiency and engineering identity. Overall, the findings underscore the importance of this dynamic in shaping student outcomes.

The dynamic between information literacy and data application has a positive influence on other facets of data proficiency (such as data presentation and computational thinking) as well as all components of engineering identity. The component of engineering identity most influenced by this dynamic is competence. The dynamic between information literacy and data application is more robust with professional data application tasks (labs and projects) than technical data application tasks (homework assignments). A robust dynamic positively influences data presentation, computational and intuitive thinking, competence, recognition, and even freshman interest levels if such a robust dynamic is present at a pre-college level. On the other hand, the only negative influence on engineering identity manifests when information literacy lacks any connection to data application that contextualizes information literacy. This clearly highlights the importance of data application to both data proficiency and engineering identity.

Participants have repeatedly mentioned their anticipation of learning from professional data application opportunities. This shows that the participants themselves connect such experiences with competence, as suggested by the findings of [12]. Many participants also preferred learning from lab and project experiences in the presence of someone with more knowledge and experience, such as a professor. They portrayed it as an opportunity to apply what they have learned in a practical setting. From a theoretical perspective, we see all four components of the How People Learn (HPL) framework being engaged [13]. Learning within a group setting provided by lab assignments and projects aligns with the community-centric dimension of the HPL framework, whereas the student's pursuit of knowledge through such experiences specific to the degree program aligns with the learner-centric dimension. The factor of learning through feedback provided by results of lab experiments and projects could align with the assessment-centric dimension of learning. But what is most profound is that the interaction of information literacy and data application aligns most with the knowledge-centric dimension of the HPL framework, as the data application context helps fill the gaps in knowledge and build connections essential for understanding, and the subsequent positive influences on data proficiency and engineering identity.

From an educational perspective, these findings have transferable implications, as it was seen that data application itself seems to be the central component of data proficiency that plays the biggest role in forming and influencing engineering identity. Thus, instructors could design their curricula to judiciously incorporate data application experiences throughout the degree program. A careful use of virtual science lab experiences could be a cost-effective and useful resource for this endeavor, as suggested by the findings of [16].

Conclusion

This study explored how data proficiency influences engineering identity among undergraduate engineering students across various disciplines. Through qualitative analysis of interviews with 52 students, the research found that data application is the most significant aspect of data proficiency, and its impact on other facets of data proficiency and engineering identity depends largely on its interaction with information literacy. Participants emphasized the importance of learning through hands-on experience with professional data application tasks, linking this to their sense of competence, recognition as engineers, and data proficiency. They also sought opportunities for data application, such as in homework assignments, when professional applications were unavailable. These findings reveal a transferable trend in engineering education and offer insights into how data proficiency shapes engineering identity and how data application influences other aspects of proficiency. This research encourages further studies focused on specific programs and components of engineering identity, and suggests that instructors could adapt their curricula to align more closely with students' preferences, incorporating data application tasks as a key instructional element that supports both self-learning and guided instruction.

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