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How Teaching Empathy to First-Year Engineering Students Interacts with Engineering Identity

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Abstract

This complete research paper will continue the work of Flanagan et al.'s [5] work-in-progress paper that examined how adding empathy into first-year engineering curriculum changed students' perspectives on the role of an engineer. Engineering design revolves fundamentally around meeting user needs and to offer solutions that meet diverse needs, engineers need to cultivate an understanding of various perspectives. Empathy plays a crucial role in enabling engineers to consider the implications of their design decisions on people thoroughly, and employing empathy can effectively address sociocultural and political aspects of designs. This necessitates its inclusion in engineering classrooms. Flanagan et al. found that through the incorporation of empathy into the curriculum, students begin to think about who they are solving problems for and their role in communicating with those stakeholders and showed a potential shift in the way that they think about who an engineer is and what an engineer does [5]. This paper will further examine this phenomenon by investigating how empathy modules in a first-year class affect engineering identity. If there is a shift in the role of an engineer that the student is identifying with, how does that interact with their interest, performance/competence, and recognition as an engineer? Grounded in the model of empathy in engineering [6] and engineering identity framework, this question will be examined using two established quantitative measures, one for each framework [7,8]. Structural Equation Modeling (SEM) is used to examine any potential direct or indirect relationships between empathy and engineering identity formation using survey data from Fall 2023. Results show a direct relationship between the two constructs with increased strength of relationship from the beginning of the semester compared to the end.

Introduction

Engineering design revolves fundamentally around meeting user needs [1], and to offer solutions that meet diverse needs, engineers need to cultivate an understanding of various perspectives [2]. Empathy plays a crucial role in enabling engineers to consider the implications of their design decisions on people thoroughly [3] and employing empathy can effectively address sociocultural and political aspects of designs [4]. The ability of human beings to be empathetic towards one another and create designs with other people in mind may become even more vital in the age of artificial intelligence. This necessitates its inclusion in engineering classrooms. Flanagan found that through the incorporation of empathy into first-year engineering curriculum, students begin to think about whom they are solving problems for and their role in communicating with those stakeholders [5]. This paper will further examine this phenomenon by investigating how empathy modules in a first-year class affect engineering identity. If there is a shift in the role of an engineer that the student is identifying with, how does that interact with their engineering identity?

Theoretical Frameworks

Grounded in models of empathy in engineering [6] and engineering identity framework [7] this question will be examined using two established quantitative measures, one for each framework [7], [8].

Empathy in Engineering

Walther et al. [6] define empathy as a way of being, an orientation, and a learnable skill for engineers, as shown in Figure 1, this model of empathy was chosen for this study because of its use in the creation of empathic communication modules [9] and its use in the literature exploring student perceptions of empathy [10]. The model draws from engineering education and social work and indicates 5 key components that make empathy a teachable and learnable skill. Affective sharing is the ability to "feel with" someone else. Self and other awareness is the ability to understand the world of others. Perspective taking is the ability to adopt the viewpoint of another. Emotional regulation is the ability to manage one's own emotional response. And lastly, mode switching is the task of applying analytic and empathic mechanisms at the appropriate times [6].

The next supporting area of practice orientation includes four components. Epistemological openness is the ability to value the experiences of others as important sources of information. Micro to macro focus is contextualizing their work from effect on individuals to impacts on global societal systems. Reflective value awareness is recognizing there are ethical issues involved in engineering decisions and each engineer must critically develop their own values. The final orientation of values pluralism is that all of engineering cannot be summed up with a unified purpose [6].

The final area of empathy in engineering is a professional way of being, comprised of three topics with many ties to engineering ethics. Service to society describes a broadening of the traditional ideas of economic development and expansion to include a deeper consideration of human and nonhuman impacts of engineering. Dignity and worth of all stakeholders opens the idea of what is traditionally considered to be a stakeholder to include the natural environment. Engineers as whole professionals questions the assumption that engineers can be entirely impartial in their work, but instead that they bring their own culture, personality, and morality to their work [6].

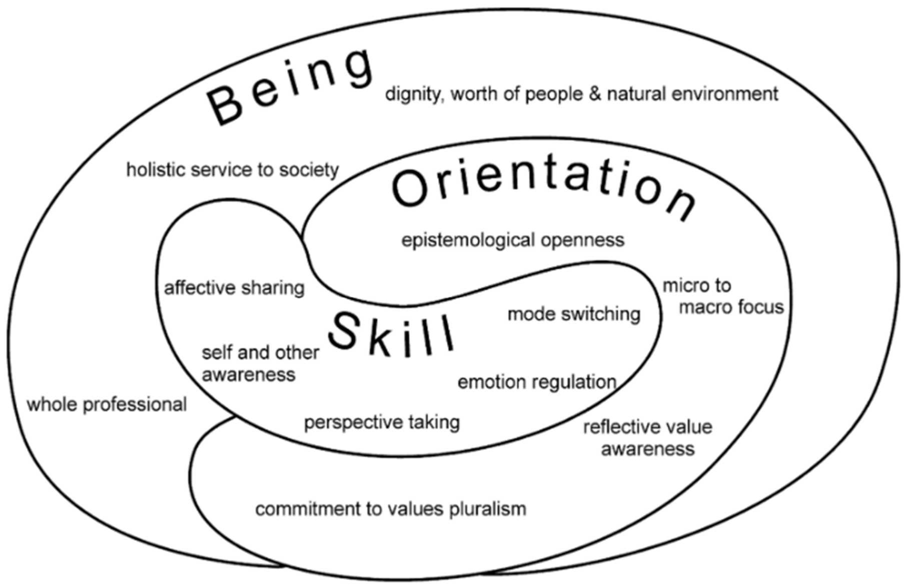

Figure 1. Conceptual model of empathy in engineering [6]

The shape of this conception is meant to convey that the skills, ways of being, and practice orientations are all interconnected, mutually dependent, and supportive of each other without hierarchy or direction. Using this framework, Walther et al. [10] explored how sophomore mechanical engineering students in a design-based course made sense of empathy after experiencing the empathetic communications modules that were also used as the basis of the lesson material for this study. They found that when students actively embrace empathy, it reveals their values and how they view others and themselves as engineers. Further research is needed to continue exploring effective strategies for integrating empathy into engineering curricula in first year programs and to explore the connections students develop in seeing themselves as engineers.

Engineering Identity

Engineering Identity theory has multiple root identity theories. Two root theories are from Multiple Identity Theory by Gee [11] and the General Theory of Self from Stets and Burke [12]. Multiple Identity Theory is being recognized as a certain "kind of person" in a given context. Gee states that there are four types of identity, that are not separate from each other, but interact and relate in complex ways [11]. Carlone and Johnson [13] presented a model of identity for education researchers. They account for the socially constructed nature of identity in the three overlapping dimensions of competence, performance, and recognition. Hazari et al. [14] then built upon the framework from Carlone and Johnson [13] by adding interest to physics identity drawn from Social-Cognitive Career Theory [15]. These dimensions were defined as "(i) interest (personal desire to learn/understand more physics and voluntary activities in this area), (ii) competence (belief in ability to understand physics content), (iii) performance (belief in ability to perform required physics tasks), and (iv) recognition (being recognized by others as a physics person)."

Godwin et al. completed a structural equation modeling (SEM) analysis of engineering identity to predict choice of engineering [16]. Engineering identity was constructed from physics, math, and science identity factors, which followed the Hazari et al. and Cass et al. construction of performance/competence, interest, and recognition factors [14], [17]. A combination of these three identities was chosen because the study was examining major choice in engineering and students have had little engineering exposure at the age of major selection. They found that "while performance/competence [were] important for all domains, without recognition identity formation can be stifled" [16]. Therefore, they showed the path for performance/competence being mediated by interest and recognition. Cribbs et al. [18] found similar relationships between the constructs as Godwin et al. did [16]. They studied math identity across 9000 college students and using SEM found that competence and performance have an indirect effect on math identity mediated through interest and external recognition in math as shown in Figure 2.

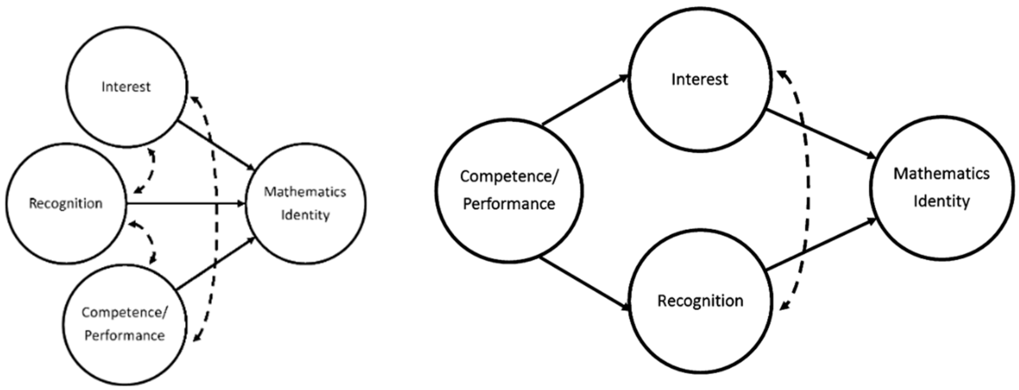

Figure 2. Hypothesized model of mathematics identity (left) to modified structural model after analysis (right) [18]

Godwin published 11 survey items to measure the constructs of competence/performance, recognition, and interest for engineering identity [7]. This allows a quantitative measure of engineering identity for analysis of large data sets of students. The constructs are defined here as: "Performance/ competence beliefs (i.e., beliefs in their ability to perform well and understand concepts), interest in the subject, and feelings of recognition (i.e., beliefs that they are seen as a good student in the subject by peers, parents, and teachers) as being the type of person that can do a particular subject." This is the measure and framework of engineering identity that will be used in this study shown in Figure 3 below.

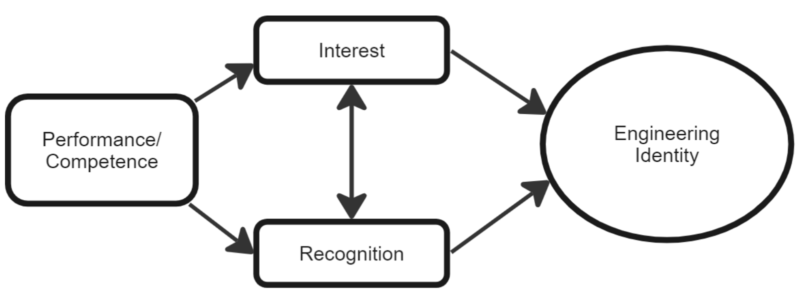

Figure 3. Engineering Identity based on Godwin and later SEM by Verdín et al. [7], [19]

Empathy and Identity Connections

Engineering identity development has been studied in terms of retention [20], [21] and persistence in engineering showing the importance of developing engineering identity [19], [22]. Another related construct is agency beliefs which refer to students' perceptions of their ability to change their world to be a more equitable place [23], [24]. Changing how engineering is taught early on in college to connect to "society" and the "real world" will tie into women's agency beliefs [24]. In perhaps the most expansive quantitative look at identity, critical agency, and engineering choice Godwin et al. [23] examined data from the Sustainability and Gender in Engineering survey (n=6,772). They used SEM to predict first-year students' engineering career choice. They defined "identity as how students see themselves as powerful thinkers and doers of a specific subject and agency beliefs as how students view the world with a critical mindset to advance the world as a more equitable place. (…) Agency beliefs include student beliefs about their own ability to change the world through their actions and career" [23].

They found that "students who believe they can make a positive change in the world and in their own lives and who have strong self-beliefs about their role as physics and math people may choose engineering careers at significantly higher rates in college than if they do not have critical engineering agency beliefs" [23]. They found that women had weaker associations between their physics and math identities but had significantly stronger links to their agency beliefs than men [23]. They were able to account for 20.2% of the variance in engineering choice with Critical Engineering Agency. "The implication is that efforts to recruit women that solely focus on building their physics, math, or engineering identities will be less effective than those that also emphasize their empowerment – or, at least, their perceived empowerment – in changing their world through engineering" [23]. This provides additional theoretical backing for the inclusion of empathy into engineering curriculum from the onset and the following is a hypothesized framework for the interactions between empathy in engineering and engineering identity, shown in Figure 4.

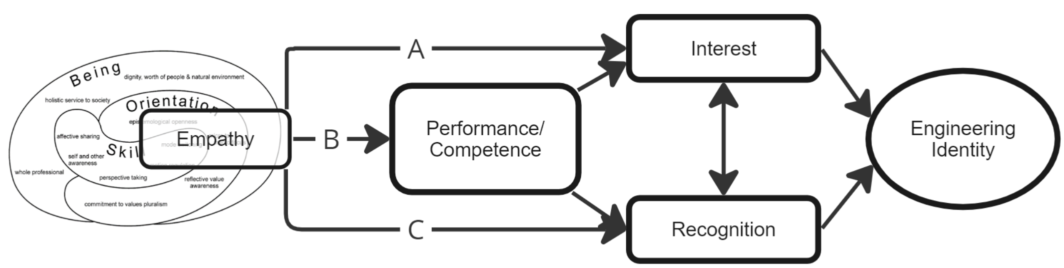

Figure 4. **Hypothesized Model of Interactions Between Empathy in Engineering and Engineering Identity**

In this model, there are three potential paths for empathy to interact with engineering identity. If the role of an engineer contains empathetic skills in the student perceptions, the students might connect it to their engineering identity in any of these three ways. Path A, the interest path, is the potential that a student may be interested in the specific empathic skills, enjoy that work, and/or want to learn more about empathy in engineering. Path B, the performance/competence path, is the potential that they may feel that they performed well during the empathetic communication exercises and are competent in the material. Path C, the recognition path, students may feel that they are recognized as an empathetic person by their relatives, peers, or by their instructors during the lessons debriefs and exercises. This framework grounds this proposed research in two previously developed frameworks, Empathy in Engineering and Engineering Identity, and will allow for the exploration of how they interact.

Methods

The lesson materials of the intervention are based on the Facilitating Empathic Communication Modules in Undergraduate Engineering Education by Sochacka et al. [9]. At a large Southeastern R1 institution, the lessons were implemented in the Fall of 2022 to an Introduction to Engineering course honors section. They have been continuously improved with input from the course instructors to improve the student experience. The lessons were given again during the Spring of 2023 to three sections of the Introduction to Engineering course, none with the honors designation, and all 20+ sections in the Fall of 2023 to a population of over 1100. The students were given a survey at the beginning and end of the semester for a pre and post-assessment. Students also complete written reflections after each lesson. Student survey results from the Fall 2023 cohort are used for this analysis.

Survey items

There are three factors from Godwin [7] on Engineering Identity: Recognition, Interest, and Performance/Competence, all previously defined. There are four factors of empathy from Hess et al. [8] based on the work of Davis's [25] Interpersonal Reactivity Index (IRI): interpersonal self-efficacy, emotional regulation, perspective taking, and empathic concern. Interpersonal self-efficacy is defined as "the ability to successfully interact with others, including others who may have perspectives that diverge from one's own, and committing one's self to bearing in mind these external perspectives when finalizing a decision" [8] which can be seen as the "self and other awareness" from Walther et al. [6]. Next emotional regulation, "as the ability to regulate emotions when faced with uncertainty and complexity while developing solutions or responses to a problem" [8], which can be seen as emotional regulation on the Walther et al. model [6]. Next is perspective taking, "represents one's tendency to consider the perspectives of another or others in general everyday interactions" [8], also seen as perspective taking in the Walther et al. [6] model. And lastly empathic concern, which is affective conceptualization of others and a focus on the self's internalized emotions "resulting from a relation between self and other" [8], as can be seen as "affective sharing" from Walther et al. [6]. The only missing skill is mode switching. Mode switching is defined as the switching between analytical and empathetic modes required in engineering work, being not purely empathetic it is not included on this measure. Mode switching and the outer layers of Professional Ways of Being and Practice Orientations from the Walther et al. [6] model will be analyzed in future qualitative work. This is summarized in Table 1 below.

The skew and kurtosis were evaluated for each item to ensure that the assumptions of multivariate normality were not severely violated using the benchmarks of an absolute value of skewness of 2.0 or higher and a kurtosis of 7.0 or higher [26], [27]. Then a confirmatory factor analysis was performed on the participants survey responses to ensure loading on to expected constructs of the relevant theories from the literature for this study population [7], [8]. Structural Equation Modeling (SEM) was then used to examine any potential direct or indirect relationships between empathy and engineering identity formation. Analysis was completed in JMP Pro 17.1 [28].

Table 1. Survey Construct Definitions, Number of Items, and References for Engineering Identity (EI) and Empathy (EM)

Factor	Definition	Items	Reference
EI – Recognition	Beliefs that they are seen as a good student in the subject by peers, parents, and teachers as being the type of person that can do a particular subject	3	[7]
EI - Interest	Interest in the subject	3	[7]
EI - Performance/ competence	Beliefs in their ability to perform well and understand concepts	5	[7]
EM – Interpersonal Self- Efficacy (ISE)	Ability to successfully interact with others, including others who may have perspectives that diverge from one's own, and committing one's self to bearing in mind these external perspectives when finalizing a decision "self and other awareness" from Walther et al. [6]	6	[8]
EM - Emotional regulation (ER)	as the ability to regulate emotions when faced with uncertainty and complexity while developing solutions or responses to a problem "emotional regulation" from Walther et al. [6]	4	[8]
EM - Perspective taking	represents one's tendency to consider the perspectives of another or others in general everyday interactions "perspective taking" from Walther et al. [6]	7	[8]
EM - Empathic concern	affective conceptualization of others and a focus on the self's internalized emotions "resulting from a relation between self and other "affective sharing" from Walther et al. [6]	7	[8]

Results

A sample size of 713 was collected of those who consented to be a part of the research study. In model 1, identity was measured as a three-factor model comprised of recognition (3 items), performance/competence (5 items), and interest (3 items). Empathy was measured as a four-factor model comprised of interpersonal self-efficacy (6 items), emotional regulation (4 items), perspective taking (7 items), and empathic concern (7 items). In model 2, the identity items were loaded with interest and recognition as mediators for performance/competence. The results showed that model 1 (pre: ChiSquare = 1551, df = 539, RMSEA = 0.06, CFI = 0.9, post: ChiSquare = 2067, df = 539, RMSEA = 0.06, CFI = 0.9) fit the data better than model 2 which did not converge. This was true for both the pre- and post-time points. Table 1 shows the standard covariance between all 7 latent variables of empathy and identity combined from the post-survey. The significance of all the covariances between each latent construct is shown in Table 2. This measurement model was then used as the basis for the structural model.

Table 2. Standardized Covariances of All Seven Latent Constructs from Pre-Survey Results

Covariances	Estimate	Std Error	Wald Z	Prob>|Z|
Performance Competence ↔ Recognition	0.5623564	0.0326334	17.232556	<.0001*
Performance Competence ↔ Interest	0.6900754	0.0240094	28.741878	<.0001*
Performance Competence ↔ ISE	0.3890895	0.0373337	10.421944	<.0001*
Performance Competence ↔ ER	0.5628462	0.0338294	16.637797	<.0001*
Performance Competence ↔ Perspective Taking	0.3474393	0.0385735	9.0072016	<.0001*
Performance Competence ↔ Empathic Concern	0.2289073	0.0426067	5.3725674	<.0001*
Recognition ↔ Interest	0.5002304	0.0345688	14.470591	<.0001*
Recognition ↔ Interpersonal Self Efficacy	0.3435324	0.0406786	8.4450303	<.0001*
Recognition ↔ Emotional Regulation	0.3974101	0.0410839	9.6731277	<.0001*
Recognition ↔ Perspective Taking	0.3213522	0.0414119	7.7599044	<.0001*
Recognition ↔ Empathic Concern	0.2167221	0.0449303	4.8235168	<.0001*
Interest ↔ Interpersonal Self Efficacy	0.3556982	0.0381743	9.3177522	<.0001*
Interest ↔ Emotional Regulation	0.4375023	0.0381243	11.475669	<.0001*
Interest ↔ Perspective Taking	0.330874	0.0389116	8.503228	<.0001*
Interest ↔ Empathic Concern	0.1942027	0.0429098	4.5258337	<.0001*
Interpersonal Self Efficacy ↔ ER	0.5610365	0.0354283	15.835807	<.0001*
Interpersonal Self Efficacy ↔ Perspective Taking	0.8036376	0.0217581	36.935156	<.0001*
Interpersonal Self Efficacy ↔ Empathic Concern	0.6013129	0.0332318	18.094513	<.0001*
Emotional Regulation ↔ Perspective Taking	0.4575402	0.0392405	11.659883	<.0001*
Emotional Regulation ↔ Empathic Concern	0.1819388	0.0469271	3.8770494	0.0001*
Perspective Taking ↔ Empathic Concern	0.7398457	0.0268914	27.512363	<.0001*

The structural model was built to test the hypothesized model in Figure 4, but performance competence was directly loaded to engineering identity. This model also failed to converge. Then, two structural equation models were built for both the pre-and post-data, shown in Figures 5 and 6 below.

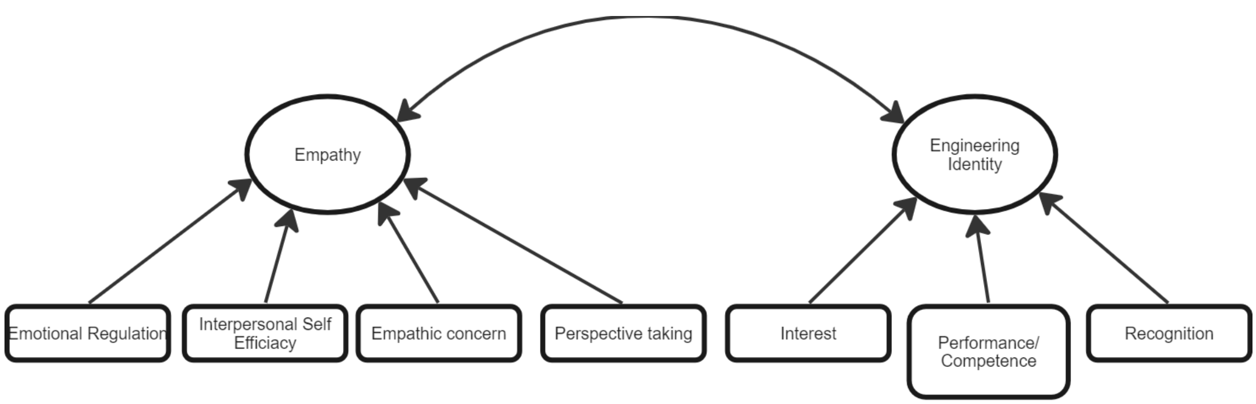

Figure 5. Covariance model of Empathy and Engineering Identity

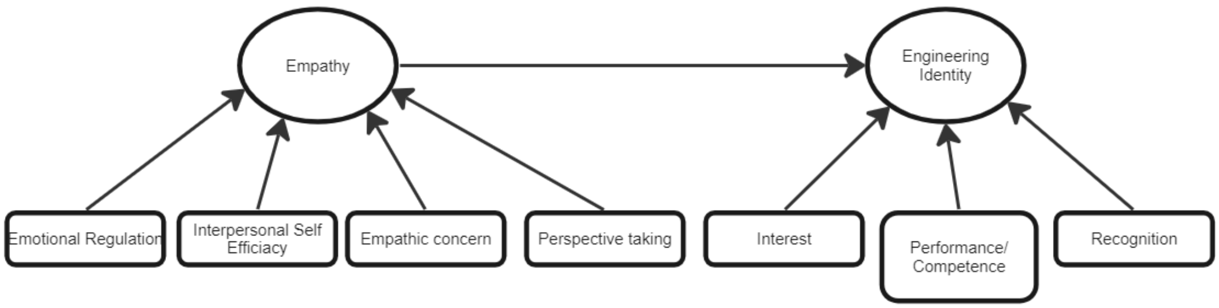

Figure 6. Regression model of Identity by Empathy

These models demonstrate a direct interaction between empathy and engineering identity as opposed to mitigating that effect through each of the identity latent variables. Theoretically, this would mean that students are thinking about empathy as another component of engineering identity as opposed to a component of another factor, such as interest or recognition, as hypothesized. This would make it more similar to agency, as shown by Godwin et al. [23].

For missing data, the method of full information maximum likelihood is performed in JMP to mitigate against potential biasing effects. As the two models are estimating the same number of parameters, there was no difference in the model statistics (pre: RMSEA = 0.063, Chi-Square = 1708.2, p<0.001, post: RMSEA = 0.0655, Chi-Square = 2242.36, p<0.001) between the sets for the pre- or the sets for the post-survey data, but there were differences between the path coefficients. As shown in table 2 below.

Table 3. Path Coefficients between empathy and identity for models in Figures 5 and 6

Time	**Model**	**Estimates**	**Std Error**	**Wald Z**	**Prob > abs(Z)**
Pre	Regression	0.348	0.0739607	4.7035278	<0.0001
Post	Regression	0.649	0.0674463	9.6245542	<0.0001

The regression coefficient increases over the course of the semester, almost doubling in size. Significant covariance indicates that Empathy and Engineering Identity are important predictors of each other, and the significant regression indicates that there is a directional relationship between these two variables. The significant regression estimate indicates that a portion of the variance in engineering identity can be explained by the variance in empathy and that the portion increases over the course of the semester for the studies participants.

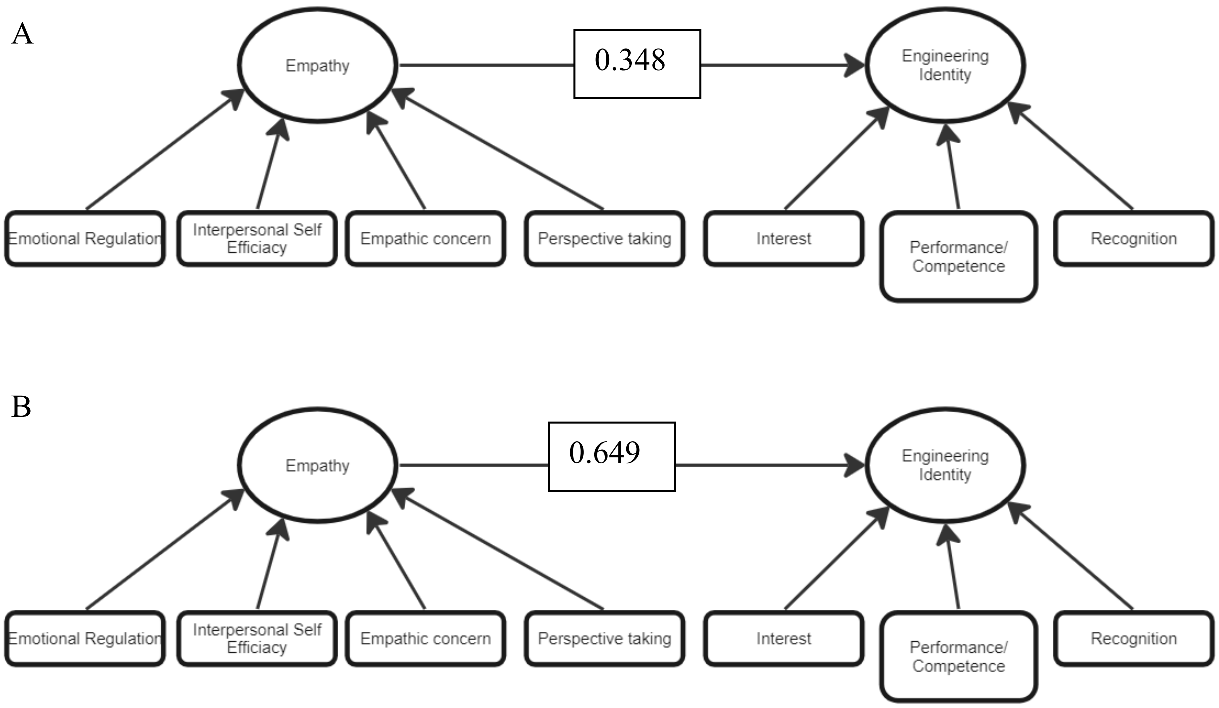

Figure 7. A) Regression coefficient pre-data B) Regression coefficient post-data

Discussions

The results here indicate a different path of the latent observed variables for engineering identity. There was no model where performance confidence mediated by interest and recognition performed better than in direct relation to engineering identity; in fact, the models set up in this manner failed to converge. This finding is a significant deviation from the developed engineering identity theory as described by Godwin and Verdín et al. [16], [19], [23]. It is hypothesized that a contributing factor could be the limitation of this study population to first year engineering students. Further qualitative work will be needed to explore potential underlying factors contributing to this difference compared to previous research.

The regression model always shows a significant estimate (Table 3). There's a noticeable difference between the regression model at the pre-survey and the regression at the post-survey. At the pre-survey time point, approximately 35% of the variance in engineering identity can be explained by the variance in empathy. However, when we moved to the post-survey, that increased to approximately 65% of the variance in engineering identity being explained by empathy. This result could indicate that participants are beginning to see empathy as a component of their engineering identity as they go through the semester.

Given the study population of first year engineering students, for whom a majority of the class in which the modules were implemented is their only class with an engineering designation, this shift is most likely related to what they learned in the class. Outside factors could always contribute to this shift, and additional qualitative work is needed to explore causes further.

Conclusions

Returning to our research questions, *if there is a shift in the role of an engineer that the student is identifying with, how does that interact with their engineering identity?* Empathy and engineering identity are best modeled as a regression relationship where empathy directly relates to engineering identity. Compared to the hypothesized model in Figure 4, this shows a more direct relationship between empathy and engineering identity itself as opposed to being mitigated by recognition, performance/competence, and interest. In that way, it behaves more similarly to agency ("students' perceptions of their ability to change their world to be a more equitable place"), as seen in Godwin et al. [23]. Given the focus within the modules on using engineering for positive societal change, it makes sense that it would behave similarly.

For the practitioner, there are a few pieces to highlight. Over the course of the four empathy modules, students participate in role-play scenarios where one student always represents an engineer. Given the direct relationship found in this study, this appears to be a critical component of the experience, where students get the opportunity to practice empathy while acting as an engineer. While facilitating this experience may be atypical for your classroom, it has been shown here to be effective and beneficial. The facilitating notes found in Sochacka et al.'s handbook are a great place for guidance in getting started [9]. The scenarios can be easily changed to issues relative to your area or discipline, allowing students to see the importance and relevance. With first year students, assigning roles and including pre-work is suggested. This allows time for the students to explore the history and any other relevant character information prior to roleplay participation. The next iteration of the empathy modules planned for Fall 2024 will include more practical engineering example roleplays and less time talking about the skills, taking a more active approach.

As evident from the increased strength of this relationship it does appear that students are experiencing a shift in the way that they think about themselves as empathetic people and engineers. Given the inclusion of specific lesson days devoted to the topic, this is likely to have played a major role in the change. More research will be needed to understand this relationship in greater detail. Future work will include qualitative analyses to understand the student's perspective on the relationship between empathy and how they see themselves as engineers.

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