Doctoral Advisor Selection in Chemical Engineering: Evaluating Two Programs through Principal-Agent Theory

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ABSTRACT

Background: Little is known about how doctoral advising relationships form, but understanding the inception of these relationships can be helpful to address doctoral attrition. Chemical Engineering programs highly structure this advisor-advisee selection when compared to other engineering programs.

Purpose: This study examines how two programs in Chemical Engineering practice the advisor-advisee selection process from the perspective of their faculty. In particular, our study uses principal-agent theory to address the following research question: *How do two Chemical Engineering doctoral programs manage the advisor-advisee matching process?*

Methods: Through multi-case study methods, we examine faculty perceptions in two large doctoral programs in the U.S. Our coding was informed using Principal-Agent Theory as a framework to help characterize faculty perceptions and develop insight into their interactions with students and the graduate program director.

Results: Our findings showed that faculty perceived control could strongly impact whether they adhere to departmental processes and adapt to the existing practices or if they circumvent the process. Our findings also showed the role of transparency and how such impacted faculty engagement.

Conclusion: We recommend departments consider how they practice shared governance in their departments regarding the advisor-advisee matching process. We also recommend they continuously engage in conversations about processes and practices to surface implicit and explicit practices and perpetuate good community in their academic units. We also present recommendations for using economics frameworks in studying academic processes.

Choosing an advisor is arguably the most critical component to a doctoral student's degree progress and completion (Bair & Haworth, 2004; Barnes et al., 2010; Barnes & Austin, 2009; Devos et al., 2016; Lovitts, 2001; Noy & Ray, 2012; Schlosser & Gelso, 2001; Zhao et al., 2007). Much research has shown that one of the reasons students do not persist in the PhD is a poor relationship with their doctoral advisor (Bair & Haworth, 2004). This importance becomes especially true in STEM due to its practice of the 'science model of advising,' where not only is there typically a high level of interaction between students and faculty (Nettles & Millett, 2006), but the advisor is often a student's teacher, colleague, supervisor, and coauthor (Zhao et al., 2007). When considering that 50% of doctoral students do not complete their doctorate (Council of Graduate Schools, 2007; National Academies of Sciences, Engineering, and Medicine, 2018), we see a clear imperative to understand the formation and development of advising relationships in STEM.

Prior work has developed knowledge on the perspectives that students and faculty have about the advisor selection process (Hilmer & Hilmer, 2007; Joy et al., 2015; Maher et al., 2020; Nettles & Millett, 2006). However, current research tends to be limited by two false assumptions: 1) that the advisor selection process is the same across doctoral degree programs, and 2) that students and faculty both directly choose with whom they will work. Although there is some prior work that challenges these assumptions, further research is needed.

Our initial research in this area has revealed that doctoral programs in engineering tend to provide a shorter time frame for advisor-advisee matching, require fewer preparatory activities associated with advisor-advisee, and have fewer information systems available for students to select an advisor than programs in science and math (Artiles, 2019). A notable exception to the pattern described in the aforementioned study are the doctoral programs in Chemical Engineering, all of which engaged in advisor-advisee matching through a process where the graduate program director essentially brokers advising relationships between the program's incoming students and the faculty. It was this contrast to the dominant practices in engineering that informed the current research effort; a richer understanding of how this matching process is structured in chemical engineering will give us a full view of the formation of advisor-advisee relationships and, as understood from the milieu of its inception, could also provide alternative perspectives and insight as to why students choose to depart from or persist in the doctoral pursuit.

We begin this larger work by examining faculty perspectives on advisor selection processes in two Chemical Engineering programs knowing that the practice of such process is likely to vary by department. This study addresses the following research question: *How do two Chemical Engineering doctoral programs manage the advisor-advisee matching process?* To answer this question, we interviewed faculty in two different Chemical Engineering programs and reviewed the graduate student handbook used in these departments to guide the process. We grounded this work in principal-agent theory (Eisenhardt, 1989) to illuminate the interactions between faculty and graduate program directors. While we argue that the student perspective is also important, the current analysis is limited to the faculty perspective, with the student perspective discussed elsewhere (Artiles, 2019).

THEORETICAL FRAMEWORK

We framed our study in principal-agent theory (PAT) (Eisenhardt, 1989). Economic theories related to behavioral economics, such as PAT, aim to predict human behavior. In the context of this study, PAT can help characterize the existing interactions between faculty and department leadership (graduate program directors). Using PAT overcomes the limitation inherent to many frameworks traditionally used in education which tend to focus on the individual and not the interactions across individuals in a group. PAT illuminates these interactions by establishing behavioral tendencies or 'predictions' as to how individuals will react given a certain set of rules. PAT states that there is a principal who has a task that needs to be completed, and this principal employs an agent to do so. The relationship is governed by a contract negotiated at the beginning of the relationship by the principal and the agent that lays rules for how the agent will engage in that task. This contract details how the agent will complete the task and how it will be assessed for completion by the

principal. It is important to note that although this theoretical framework is often labeled 'agency theory,' it is not related to the concept of agency often found in sociology and education (e.g., such as in O'Meara, 2013) (Baxter, 2001). Rather, it refers to the presence of the agent carrying out the principal's task.

We operationalize PAT for the Chemical Engineering program's practices of an advisor-advisee matching system as follows. Matching is a practice in which students submit a list ranking with their preferred advisors to the faculty member directing the doctoral program (graduate program director). This director then uses this information along with faculty's preferences and funding capacity to develop matches between students and faculty. This system streamlines the advisor selection process across students and faculty and centralizes the final paired matches with the doctoral program, which acts as a mediator. When we consider this practice using a PAT lens, the graduate program director acts as an agent for both the student and the faculty. The student and the faculty (the principals) trust the graduate program director will find them a suitable match, and they make their preferences known to this agent. The handbook – which can be interpreted as the documentation of the contract – states this process as the graduate program director's responsibility. The graduate program director then needs to accommodate various and possibly differing student and faculty preferences, where both groups act as principals. This scenario is known in PAT as the multiple principal dilemma (see *Figure 1*).

In the multiple principal dilemma, the task is being outsourced from two or more parties (principals) to a third party (agent). The multiple principal dilemma has two variations: one in which the principals agree on the outcome and one in which the principals have opposite preferences (Lane, 2012). When the principals agree on the outcome, the largest challenge is which principal will monitor the agent to ensure the contract is completed as agreed. Thus, monitoring the process and outcome is diluted across multiple principals who may or may not enforce its execution. This difficulty can compound the existing challenges common to the outsourcing of the task itself. Sometimes, the agent possesses expertise or information that the principals do not have and is needed for completing the task (Eisenhardt, 1989), creating an information asymmetry that makes enforcement difficult to achieve. Similarly, if the contract is designed strictly to assess the outcome of the agent's actions and not the actions themselves, the principals would have to be in complete alignment with the desired outcome to ensure appropriate enforcement (Lane, 2012). When the principals disagree on the desired outcome, the agent must decide which one contract to fulfill or how to flip-flop across differing desired outcomes leveraging power among the principals. This inconsistency in execution ultimately leads to incoherent policy outcomes and agent behavior (Lane, 2012). This is to say that how the agent reconciles their actions relative to both principals' preferences becomes grounds for inconsistency in the actions of the agent. This inconsistency in the agent's actions can also become ground for implicit principals, or hidden principals, to step in and influence the actions of the agent.
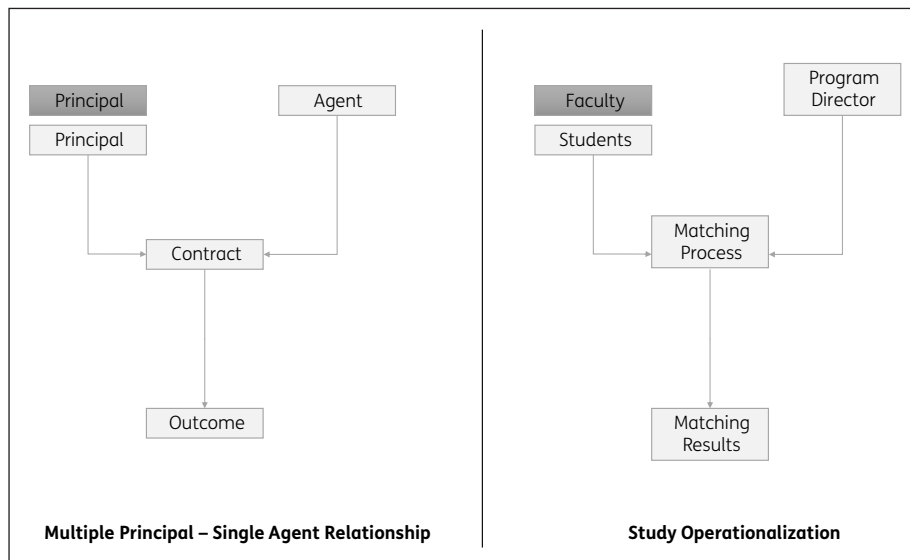

Multiple Principal – Single Agent Relationship **Study Operationalization**

Figure 1 PAT Theory Operationalization with Multiple Principals.

PAT has been used predominantly in higher education research to study the relationship between the government or and higher education administration (Lane, 2012). However, some have focused on the institution's interactions with students. For example, Lozano & Hughes (2017) used PAT to study how student representatives in governing boards act on behalf of the student body's interests. The authors explored whether the representatives truly represented their constituents versus their individual interests when voting on issues and found that students that were elected rather than appointed reported having more pressure from the student peers when it came to voting on issues. While PAT was only loosely engaged in the study, it served as a lens to understand people acting on others' behalf. Another example is work by Dill & Soo (2004), who argued that PAT helps represent the inefficiencies in how students select institutions and courses. The authors demonstrated the students' inability to thoroughly evaluate all of the courses and institutions places them in an information asymmetry that keeps them from making the most rational decision when selecting an institution. As a consequence, these students select an institution based on the information they are available to find and analyze. Thus, they do not operate in a 'free market' because there is too much information to process in order to maximize their benefit. Closer to graduate education, Flora (2007) synthesized the legal arguments on whether graduate students are employees of the university or not through the lens of PAT. The author argued that indeed graduate students act on behalf of the university, particularly when executing teaching assistantships, as they have authority to teach and grade often to their own volition yet on behalf of the institution. Therefore, through the lens of PAT, graduate students indeed act as faculty. Thus, the author argued that they should be honored by the university to receive benefits commensurate with such responsibility.

While research using PAT in higher education exists, there is still much room to grow, particularly in studying interactions between academic programs, faculty, and students. This area holds much promise since there are often assumptions held in these interactions associated with self-interest, information asymmetry, and incentives in which PAT can provide an opportunity to deconstruct human behavior (Lane, 2012; Thaler & Sunstein, 2008). To our knowledge, no study in engineering education has used PAT framework, yet the promise of using frameworks in behavioral economics for engineering education has been previously discussed (Katz, 2019). This study seeks to exemplify this promise by leveraging PAT to understand the relationship students, faculty, and graduate program directors build with each other within the advisor selection process and how the latter reconcile preferences and power differentials across the formers. It is important to note that although these aforementioned relationships are not the same advising relationships that develop later in the doctorate, they do set the context and possibly impact how advising relationships ultimately come to fruition.

LITERATURE REVIEW

To ground our study, we first argue why the selection of an advisor is key in understanding the dynamics of advising relationships from the lens of its inception and specifically why this is key knowledge in the case of STEM doctorates. We then explain how this work builds on existing research on the engineering doctorate. Finally, we demonstrate the importance of the impact individual departments have on doctoral education. We conclude by arguing how our study builds and addresses these arguments.

ADVISOR SELECTION

Research on doctoral education has mostly focused on the dynamics of the student and faculty relationship after students have selected their advisor (Golde, 2005), but not the advisor selection process itself or the doctoral program in which this advising relationship takes place. In an ideal scenario, a student and a faculty member build an advising relationship in which they will both be satisfied and motivated that allows them both to meet their research and degree completion goals. However, it is often the case that this match is less than ideal (Baker et al., 2014; Devos et al., 2016), and both students and advisors are misaligned in expectations for each other within the

advising relationship. Numerous research studies have argued that those students that remain in less than satisfactory conditions are more likely to lose satisfaction with the doctoral pursuit as a whole (Baker et al., 2014; Pyhältö et al., 2015; Zhao et al., 2007), more likely to develop mental health issues (Levecque et al., 2017), more likely to take a longer time to degree (Bair & Haworth, 2004), and are at greater risk of not completing the doctorate (Lovitts, 2001).

To our knowledge, no study has directly examined the advisor selection process itself. However, several studies have uncovered critical knowledge regarding what students and faculty look for in an advising relationship. For example, Joy et al. (2015) found that STEM students mostly focused on funding availability and the area of research when selecting an advisor. As a secondary factor, they considered the personality of the advisor and their ability to help students graduate in a timely manner. The same study showed that faculty members focused on student credentials, such as GPA or standardized test scores, as well as their ability to contribute to research (i.e., the alignment of the student's research interest to the faculty member's desired future research directions). The student findings align with Golde & Dore (2001), who also showed that the larger the number of factors students considered when selecting an advisor, the better their satisfaction with their advising relationship in the long term. Zhao et al. (2007) found that students in the sciences tended to select an advisor based on pragmatic benefit over intellectual compatibility or an advisor's reputation. Regarding the selection itself, a study found that students in counseling psychology value the ability to choose and tend to select advisors with whom they believe they can work comfortably and successfully (Schlosser et al., 2003). The authors found that these students reported being happier than those who were assigned to their advisor.

We can conclude from these studies that although students value the opportunity to select an advisor, the specific factors they consider and the weight they place on such is not always consistent. We can also see a faculty focus on credentials and research interests with little consideration for compatibility. It is important to note that most of these studies did not focus on the advisor selection process directly but discussed the selection process as part of a larger research question. By not focusing on the process itself, critical information for understanding the context in which students find advisors in doctoral programs can be amiss which this study aims to clarify.

DOCTORAL EDUCATION OF ENGINEERS

Emerging research from engineering education has addressed funding and recruitment in doctoral programs, which are often closely linked to advising. A study by Wall Bortz et al. (2020) showed that doctoral programs sometimes adopt non-evidence-based recruitment, strategies in recruitment often obscuring key values for students when choosing a doctoral program. This obscuring of key values early in the doctorate can compound in hindering student success when we take into account the existing gaps in understanding and the general lack of autonomy graduate students experience in discussing and optimizing their doctoral funding (Borrego et al., 2019). These authors also addressed work regarding career placement of engineering PhDs comparatively to other STEM fields (Denton et al., 2019; Kinoshita et al., 2020). Other work within engineering education has looked closely at student development of specific competencies in the doctorate, such as the relation of competencies obtained in the PhD to postdoctoral employment (Berdanier et al., 2016; London et al., 2014; Zhu & Cox, 2015), development of writing skills in doctoral writing (Berdanier, 2016; Berdanier & Zerbe, 2018), doctoral learning environments (Crede & Borrego, 2012), and how having industry experience prior to the doctorate impacts the doctoral journey (Mosyjowski et al., 2017; Mosyjowski & Daly, 2020; Peters & Daly, 2013). While work on doctoral student competencies is important, understanding the formation of advising relationships and the programs in which student development takes place is a critical next step. Our study builds on the existing work specifically by focusing on the doctoral program to understand how they approach the advisor selection process, providing insight into how faculty and graduate program directors assign students. This is particularly important work related to the formation of advising relationships that are critical to student success.

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DEPARTMENTS' INFLUENCE ON FACULTY AND DOCTORAL EDUCATION

A key factor in our study is the departmental context because it influences how the advisor selection process is ultimately practiced (Golde, 2005). Prior work studying departments' influence on the doctoral process has shown that while the doctoral journey is shaped by disciplinary traditions, it is often difficult to separate these disciplinary factors from departmental culture. Specifically, in engineering, Knight et al. (2018) demonstrated that even within engineering, doctoral programs vary widely in their proportions of students' funding mechanisms (e.g., how many students have a research assistantship vs. a fellowship, among other possible mechanisms). Given what has been shown in the literature on the role of funding in the student experience (Border & Barba, 1998; Kinoshita et al., 2016; Torka, 2018), one could conclude that the pursuit of the doctoral degree could vary within the same discipline depending upon on which program a student decides to enroll. Collectively, research shows that both disciplines and departments do indeed impact how doctoral education is managed but understanding the effects of each is difficult to do as separating these influences would warrant studying a phenomenon across multiple institutions within the same discipline. More recent work has begun to question the importance of the context on doctoral education (i.e., the role and impact of the institution, department, program, discipline, policies, norms, etc.), but such work focuses mostly on the direct impact said context has on the student experience paying little attention to the context as the environment in which advisor relationships function (Ferrer de Valero, 2001; Golde, 2005; O'Meara et al., 2014; Sowell et al., 2015; Zhou & Okahana, 2016). The advisor selection process, while influenced by the disciplinary traditions, is often managed by the department under the constraints imposed by both the department and the institution (e.g., resources availability and allocation) (Becher & Trowler, 1989; Ferrer de Valero, 2001; Goldman & Massy, 2001; Joy et al., 2015; Sowell et al., 2015; Zhou & Okahana, 2016) Our study accounts for this difference by examining two departments belonging to the same discipline in different institutions.

METHODS

To examine faculty perspectives on how students are matched to advisors in two Chemical Engineering departments, we employed a multi-case study methodology. Multi-case study methodology allows one to understand an evolving, uncontrollable phenomenon (Yin, 2003) that is bounded in space (i.e., the individual department) and in time (i.e., the professors currently advising graduate students and the advisor selection process currently in place) (Stake, 1994, 2006). We scoped our study to the academic departments, which organizationally house both the faculty and the doctoral programs. Each department represents an individual case, and the units of analysis are individual faculty experiences. These experiences are contextualized through the use of the graduate student handbook. We conducted this study per approved human research subjects research protocols.

CASE SITES

The department labeled as Midwest U is housed in a large public institution with a Carnegie classification of Highest Research Activity (Shulman, 2001). Midwest U's PhD program ranks in the top 15 programs for Chemical Engineering in the U.S. The department labeled Land Grant State also belongs to a large public institution with a Carnegie classification of Highest Research Activity. Land Grant State's PhD program ranks in the top 30 programs for Chemical Engineering in the U.S. Both programs' doctoral student cohorts have an average size of 30 students each year, and they have a similar number of faculty associated with PhD advising, about 30 members. Both Midwest U and Land Grant State reported doctoral student retention ranging from 90–95%, which is well

above the average for doctoral engineering programs as published by the Council of Graduate Schools for engineering programs and Chemical Engineering programs (60%) (Council of Graduate Schools, 2007).

DATA SAMPLE

We analyzed each case using two primary sources of data: 1) interviews with faculty and 2) graduate student handbooks. We obtained the graduate student handbooks from each program's website. The graduate student handbooks include instructions for students and provide the baseline for the process through which students match with faculty.

Individual faculty were invited to participate in interviews for this study through snowball sampling (Patton & Patton, 2002). Faculty were selected to participate based on their experiences in advising and recruiting doctoral students. We specifically sought faculty currently advising doctoral students or holding the title of graduate program director or faculty member who oversees the doctoral program. We aimed to obtain a faculty sample that included a variety of levels (Assistant, Associate, and Full Professors) and research topics to maximize the experiences represented in the interviews. While we recognize that there are often differences in the experiences of underrepresented faculty in each department with regard to both sex and race/ethnicity (e.g., O'Meara et al., 2019; Ong, Wright, Espinosa, & Orfield, 2011), we did not intentionally sample for such differences, nor did we ask participants to self-report gender, race, or ethnic identities. Given the limited diversity in both departments' faculty, reporting on faculty demographic would inevitably identify individuals' participation in this study. This approach is a limitation of our study that future research should meaningfully address.

Table 1 summarizes self-reported participant information. Note that that the sum will exceed the actual total number of participants (6 for Dept A and 7 for Dept B) because the line items are not exclusive. For all programs, we were sure to invite at least one current or recently former graduate program director to have their experiences in arranging the matching process in their departments. We refrain from identifying individual faculty demographics in our results because we did not directly ask for self-identification of some demographic information to preserve the anonymity of our participants, as explained earlier.

FACULTY CHARACTERISTICS		MIDWEST U	LAND GRANT STATE
Faculty by Rank	Former Graduate Program Directors	2	1
	Full Professors	3	3
	Associate Professor	0	1
	Assistant Professor	2	1
Time Working as Faculty in the Department	0–5	2	1
	5–15	0	3
	15+	5	2
Doctoral Students Advised & Graduated	0–5	1	2
	15+	5	4
Currently or Previously Involved in the Graduate Committee	Yes	4	2
	No	2	4

Table 1 Summary of Participant Organizational Status by Department.

The interviews lasted approximately one hour and discussed the process through which students entered the program until they were matched to an advisor. The interview protocol was developed as part of a larger study and the extant literature in the space of doctoral advisor selection (Artiles, 2019). The included interview questions focused on individual participants' experiences in advising and recruiting doctoral students. Sample questions for these interviews are included in *Table 2*, as well as examples of how the questions relate to the theoretical framework.

FRAMEWORK CONNECTION	SAMPLE QUESTIONS
Contract activities and conditions	What is the advisor selection process in this department?
Agent activities prior to contract execution	How does the program promote and facilitate students and faculty to get to know each other?
Principal activities prior to contract execution	How do students and faculty interact prior to matching to an advisor?
Principal awareness of the process	**Faculty:** How does the graduate program director assign students to faculty once they submit their top choices? How do faculty make known their preferences?
Agent inclusion of principal in the process	**Graduate Program Directors:** How do/did you assign students to faculty? How do/did you incorporate faculty preferences?
Constraints to contract execution	Who typically funds your work?
	Are there restrictions on who may be hired as a research assistant through your funding?
Instances where the contract is not executed	Do you receive targeted applications to come work in your group? How do you handle these cases?
	Do your peers accept targeted students into their groups?
Outcome satisfaction	What would you change to the selection process?
	How satisfied are you with this process?

Table 2 Selected Interview Questions and Their Connection to the PAT framework.

DATA ANALYSIS

This analysis was grounded in an interpretivist worldview (Lincoln & Guba, 1985). This approach implies that what participants express to be their perceptions are indeed their reality since these perceptions will drive their behavior (a foundational principle in motivation in theory used in education as shown in Schunk et al., 2014, as an example). Data analysis consisted of three steps: development of case descriptions, applying replication analysis to the cases, and conducting a cross-case analysis.

DEVELOPMENT OF CASE DESCRIPTIONS

Following the case study approach recommended by Yin (2003), the first step was to create a case description for each department. These case descriptions were anchored in the description of the matching process stated in the graduate student handbook and annotations of salient themes from the interviews. We developed an initial set of codes (as shown in the first column in *Table 2*), emergent from these annotations and resulting case descriptions, that consisted of key aspects of the advisor selection process across both departments. These codes were applied across all interviews using Dedoose software, and the resulting excerpts were examined for patterns to find how the different faculty within each case described the different parts of the process and how these descriptions compare. Finally, we conducted a theoretical interpretation of the initial codes using the framework as a lens (as shown in the third column in *Table 3*). This step included identifying in each program which is the agent or person who executed the matching process, who are the principals or person who outsources the matching decisions, and what are the interactions across both of these from the perspective of the interviewed faculty. These operationalizations were developed based on the framework's prior use in the literature.

APPLYING REPLICATION ANALYSIS WITHIN THE CASES

The emerging patterns from both rounds of coding were compared across the participants within a single case, verifying for differences across faculty ranks and involvement in the graduate program. For example, when we found that Midwest U prioritized junior faculty in the advisor-advisee matching process, we confirmed these findings across all the interviews from that institution. This triangulation ensured that the findings here reported are not single instances of the phenomenon in that environment.

INITIAL EMERGENT CODES	OPERATIONALIZATION	THEORETICAL INTERPRETATIONS OF THE INITIAL CODES	SAMPLE QUOTES
Admissions Process	Quotes relating to the admissions process and its influence on student-faculty interactions.	Pre-contract activities that impact contract execution	*We admit a varied pool of students because we want all faculty to have options to recruit for their labs.*
Recruiting Students	Quotes relating to recruiting students after they are admitted to the program.	Pre-contract activities that impact contract execution	*I only begin to recruit students once they are accepted into the program.*
Matching Process Mechanics	Quotes relating to the mechanics of the advisor-advisee matching process.	Contract execution details	*We sometimes prioritize junior faculty's needs for students over student preference.*
Matching Satisfaction	Quotes relating to the faculty's satisfaction with the matching process	Principal satisfaction with the outcome	*I was not thrilled with the match, but it was better than not getting matched at all as I needed someone for the project immediately.*
Veto Match or Back negotiations	Quotes relating to back negotiations led by faculty to either obtain or push away a specific student.	Principal intervention with the execution of the contract	*I was particularly interested in a student, so I took these specific actions to make sure they were matched with me.*
Circumventing Process	Quotes relating to instances where a student circumvents the process completely and enters the PhD program working directly for a faculty member.	Instances where the contract is not executed	*Sometimes we see a student with support from day one by a specific faculty skips the matching process.*
Resource Impact	Quotes relating to the process impacting an individual faculty's resources (e.g., workload, funding, etc.)	Limitations to the execution of contract	*There have been times when I cannot fill the positions I have because the program does not match me with a student.*

CONDUCTING CROSS CASE ANALYSIS

The final patterns that emerged from both rounds of coding were then used to refine the case descriptions and were compared across cases for contextual similarities and differences. To test the transferability of the results, we used replication logic across cases to test emerging themes in the cases (Miles et al., 2014; Yin, 2003). In the example previously mentioned, once junior faculty prioritization was confirmed in Midwest U, we tested this assertion in Land Grant State to determine if it was unique to Midwest U or a more common practice. All the previously described measures are strategies recommended to assure trustworthiness, specifically in qualitative case studies (Creswell, 2013), as they enhance the validity of the study and trustworthiness of the results (Tracy, 2010).

Table 3 Initial and Theoretical Coding Results.

POSITIONALITY

Particularly important in promoting quality, we present our positionalities. The lead author primarily conducted this process with regular engagement with the second author as a form of researcher triangulation enabling the research team to wrestle with researcher positionality and consider implications of such for the research process itself and for the research results. The first author, who was a graduate student at the time of data collection, self-identifies as an underrepresented minority in engineering. She had attended two different graduate programs at the time of data collection and had worked professionally as an engineer. The second author is a white female faculty member who has graduated many doctoral students, served in academic administration, and worked professionally as an engineer. Alongside our interpretivist worldview, these different organizational perspectives and institutional experiences allowed multiple interpretations of the data to be examined. We both believe that human perception drives human action, and thus we interpreted our participants' perspectives as their individual reality. This notion helped examine differing participant accounts of the matching process from the individual vantage points from which our data was sourced.

LIMITATIONS

Like any study, our findings have limitations. First, our study focused on two high-ranked institutions with similar faculty characteristics and experiences. This similarity in institutional traits limits the transferability of our findings to institutions different from our sample. We recommend

readers consider the ways in which these cases resemble their context and exercise judgment in applying the findings accordingly. Second, our sample was predominantly tenured faculty. In the context of our study, this limitation may restrict what we could interpret to be the junior faculty perception of the process and comparisons across this group. However, as senior faculty have more experience in recruiting doctoral students than junior faculty, we were able to obtain more detailed descriptions of experiences in recruiting doctoral students. Further studies could evaluate more, specifically, the assistant professor's experience in recruiting doctoral students. Finally, as explained earlier, our study did not collect faculty demographics for identifiability reasons. Considering much prior research has described how faculty of color and women in engineering may have different experiences, further research should examine how these nuances may impact faculty perceptions of control in processes such as that described herein.

FINDINGS

The aim of this work was to examine how two doctoral programs practice advisor-advisee matching through a PAT lens. We present the case summaries for each department and offer an explicit interpretation in terms of PAT for each. In both scenarios, we identify the principals to be the student and the advisors, while the graduate program director who completes the matches is the agent. The rationale for this role is that the students and faculty have the selection completed by the graduate program director; thus, the graduate program director acts as an agent on their behalf. ***Figure 2*** provides a visual summary of our findings.

MIDWEST U CASE

The matching process for Midwest U consists of students being admitted to the program and is provided funding for the first semester via a departmental source. All students are funded in the same way when they are admitted. Towards the end of September, they are asked to list their top three choices for a faculty advisor. Before students list their preferences, the program holds a series of research seminars and requires students to meet with a minimum number of faculty (such number varied based on cohort size and available funding any given year). The graduate program director collects these preferences and makes matches across all the faculty and all the students in the cohort. The graduate student handbook essentially states the following (exact handbook wording has not been shared to maintain institutional anonymity):

> Each faculty member gives a research presentation to students in the early Fall.
> Students will have 1–2 weeks. after the faculty presentations to arrange and meet
> with faculty members of interest. We require each student to meet with five faculty
> members. After the one-on-one meeting period, students will submit a ranked list of
> their faculty choice. Students are placed in labs by early October. [paraphrased from
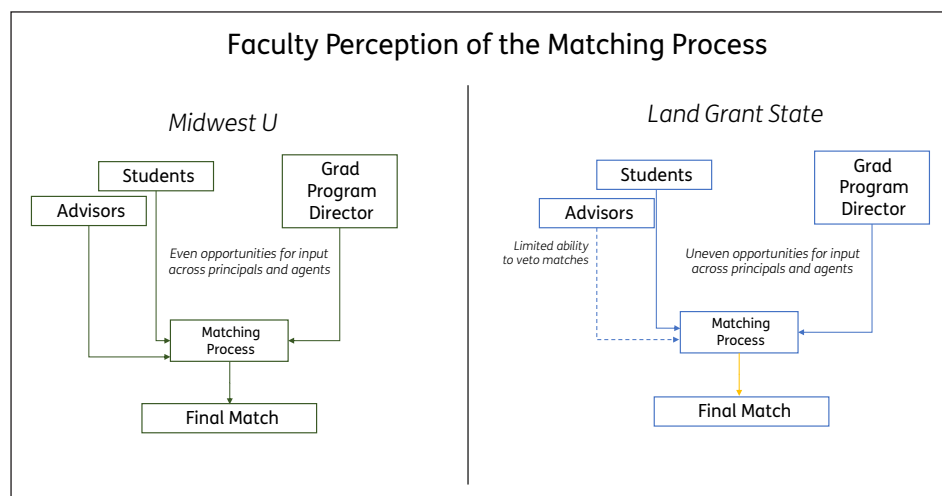> Midwest U Handbook]

Figure 2 Interpretation of the Faculty Perception of the Matching Process using PAT Framework.

This statement is, in essence, the contract that guides the interactions between the principal and the agent. Although all faculty members described a process similar to the one in the handbook, the Graduate Program Director described specific matching prioritization practices that are not listed in the handbook and therefore are perhaps not visible to students and faculty. For example, should more students want to work with one faculty member than available space, the faculty can provide input on who should be prioritized, and those students not selected can be matched to their second choice. It is important to note that faculty in this department was not told which position a student ranked them. They were only told the names of students who had listed them as a possible advisor, and the faculty were satisfied with that information and could use it to request an additional student should there be enough students for all faculty who requested one and they have enough funding to support such student.

The faculty also shared the undocumented practice of taking into consideration the needs of junior faculty as they are less likely to recruit easily:

> So, the graduate chair, in doing the assignments, junior faculty get a higher priority. If you're a brand-new professor walking in, getting a student in your group is vital to your survival. So, they get priority. [...] And this is a community decision. [Full Professor, Midwest U]

Our data also showed that the advisor-advisee matching process in Midwest U is inherently connected to the admissions process. This practice is driven by a program's historical knowledge and experience dictating: 1) that if a program admits too many students interested in a specific research topic, they risk having a more difficult matching process later on because they only have a limited amount of faculty members to advise students researching a specific subject, and 2) the timing of funding availability.

Midwest U attempts to manage this limitation by offering admission to more students than they can accept across all research areas in their department, thus maximizing their chances of having a sizeable cohort of incoming students with diverse research interests. The timing of funding availability also complicates tailoring matches to meet student research interests and faculty-student needs. The program conducts admissions in the early Spring. The results of commonly applied for National Science Foundation (NSF) grants, which most faculty described as their primary funding agency, are typically not known until later in the semester or summer as prominent government funding agencies reach the end of their funding cycles over the summer. This timing gap makes it challenging to match advising capacity in specific research interests and funding availability for students:

> In December when we're making admissions offers. At that time, we often told the faculty how many students do you want? They'll just say, "Oh, no. I don't want students." Then September rolls around, and all of a sudden, they say, "Oh, I have a grant. I need students." [Former Graduate Program Director, Midwest U]

The primary matching criteria used to develop matches was students research interest and advisors' research funding availability. These criteria bring about their own challenges in that students may not actually know their research interests this early in their doctoral journey. The majority of faculty described that while some students come in with a clear idea of the type of work they would like to do, other students are not as aware and would likely be happy with any topic.

> What a student thinks they're interested in as a senior in college applying for graduate school isn't necessarily what lab they want to end up joining. When they get there and get a better sense of what's really happening and get the complete picture of what's available. It's very common for someone to say, "Oh, I want to do something in Life Science," then they end up doing something they didn't even know that existed and was way cooler. [Former Graduate Program Director, Midwest U]

Faculty in this department sometimes had the ability to recruit students that were amid switching research groups. However, they discussed this process as carrying risk in terms of both potentially questionable student performance or possibly ruining a relationship with a colleague:

> You're always a little hesitant to figure out why this person is in the situation they're in and whether that's the type of person you'd want to recruit. But if you find out that it's for legitimate reasons, then it's not a problem, but it's just this extra layer that surrounds people whom it happened to.   [Assistant Professor, Midwest U]

A key distinction in Midwest U is the degree to which faculty perceived being able to have control over their matches. This department had a balance in the decision making between the advising research faculty. When we asked faculty if they thought that they could veto a match made by the program, all the faculty interviewed expressed being able to do so. The following quote shows an example of a junior faculty that declined to accept a student despite financial offers from the department to help support this student:

> There's been times where they say, oh, can you take another student? There's a student that really wants to join your group, and you'd be the best match for them. Then I would just say, well, I actually don't have funding to take another student on. Then they say, okay, well, we can give you a year's worth of funding if you can take this student. Then I can say yes, or I still said no, actually, one year, when the funding would not solve those problems. So, ultimately, through the selection process, professors ultimately have the final say whether they want to take on someone or not. [Assistant Professor, Midwest U]

So ultimately, faculty (even junior in standing) had a choice with whom they worked. They could decide that, even with free funding, they did not want to work with a student for whatever reason. We followed up this question by asking faculty about their satisfaction with the process and whether they would make any changes to the current practice. We found general satisfaction with the process, particularly due to being able to get an assignment with which they were satisfied with. There were no reports of faculty recruiting students outside of the matching process, either themselves or via their colleagues. We also asked faculty how they ensured their research agenda had continuous progress when they were unable to secure student matches in any given year. Although the faculty described having the opportunity to hire students outside of the Chemical Engineering program, they stated it was not as common. In the words of one full professor in this program, "We get great students. What else would I want?"

In sum, we observed this department to have a cohesive process for matching students with advisors and faculty in our sample, having been satisfied with the process and its outcome. We note that not all processes/practices are documented and are thus not all visible to students and faculty.

MIDWEST U THROUGH A PAT PERSPECTIVE

From a PAT perspective, we observe the following at Midwest U. The advisor-advisee matching processes, or contracts, through which students are assigned to advisors are executed in nearly identical manners as the agent (graduate program director) executing the contract (conducting the matching) performs the same actions (documented) and takes into account the same considerations (documented and undocumented) to promote equity across all faculty principals (both senior and junior faculty). The agent also considers the student principals' interests and uses these as the starting point when making the matches. The extent to which parts of the process are not documented shows how the agent has the freedom to make decisions in the execution of the matching process without being bound to any one principal. We also observed the constraints that affect the contract execution, such as connection to admissions, varying student research interests, and funding availability. These constraints start well before the contract execution, and the agents expressed being mindful of such before even beginning the task of matching even when some of these challenges, such as student interests and funding, are not under the control of the departments. Finally, we observe the faculty principals understand the limitations to executing the

contract since the student principals' interests are being taken into account by the agent, but the student principals are not always aware of what may be a successful contract outcome for them; making it challenging for the agent to pursue an optimal matching outcome.

In Midwest U, the agent (Graduate Program Director) works with both principals (students and faculty) to develop an outcome. While the priority is clearly the student preference, the graduate program director does convene with faculty to ensure they are satisfied with the outcome and negotiate the outcome. This allows faculty to have more choice over the students they wish. Consequently, they did not discuss needing to partake in circumventing the process set up by the department or recruiting for students in different doctoral programs.

PAT would suggest that faculty principals that are more satisfied with the outcome of the tasks completed by the agent (Graduate Program Director) are more likely to engage again with the agent to complete a new task than those principals who are not satisfied. Faculty in Midwest U are satisfied with the process and receive students that they like. They also describe themselves as having the freedom to refuse matches. Thus, they adhere to the process when recruiting students and do not deviate themselves or observe their peers deviating from the process.

LAND GRANT STATE CASE SUMMARY

The matching process for Land Grant State was very similar to the one described in Midwest U, but there are some differences that analyzing it through PAT helped us uncover. Students are admitted to the program and funded from a departmental funding source for the first semester. Students then participate in program-hosted seminars about available research projects, interviews with faculty, and towards late October, they were asked to list their top three preferred advisors. The handbook states as follows:

> The Graduate Program Director initially advises incoming students. During the Fall semester, faculty members make presentations about their respective research projects for incoming students. Students then take the initiative to arrange private meetings with individual faculty members to discuss potential research topics. Unless an advisor has already been assigned, each student then chooses at least three potential advisors. Students may also indicate a preference. Advisor Selection is typically completed by the end of Fall semester for incoming Fall semester students whose degree(s) is chemical engineering and by special arrangement for those students who matriculate other semesters. The Graduate Program Director will make final advising assignment decisions based on student preference, faculty workloads, available financial support, and other pertinent concerns. [paraphrased from Land Grant State Handbook]

The faculty described a process that hinges primarily on the students' research preferences:

> All of the faculty get all of the graduate students together over the course of about two weeks for a two-hour session, two nights a week. And they run the faculty through in like 15-minute time slots. And you go in and describe your research program and talk about what students would do in your group, and how many slots you have available, and those kinds of things. Students get a chance to ask you questions. And then, the students get a chance to list their top three choices. And then the graduate studies chair tries to make everybody happy, which is an impossible task. [Full Professor, Land Grant State]

Land Grant State also practiced prioritization for its junior faculty, although this part of the process is not documented and students may not be aware of it:

> One of the things that we really avoid in this department is having very senior famous faculty get all the great students, and then the junior faculty and especially the new faculty end up with nothing. [Former Graduate Program Director, Land Grant State]

This department also noted that the program could not control which admissions offers would later yield to enrollment. Although they did not discuss a specific strategy for managing this concern, they noted sharing the same challenge in trying to tailor admission offers to any given year's advising needs. They described trying to match possible grant funding available to admissions offers:

> We have to try to match our student load with our grant load. So in between, you're trying to guess, "I just submitted a grant last Fall. Is that grant going to get funded? I hope so. [Full Professor, Land Grant State]

Regarding students' research interest, Land Grant State also found that students are typically satisfied with any research topic and sometimes not knowledgeable enough to narrow down on a research area efficiently:

> I would say that 50% of the students are wrong about what they're interested in or could be much more flexible. [Full Professor, Land Grant State]

These quotes show that faculty agree that many incoming students do not have a clear understanding of their research preferences. Consequently, matching students to faculty by research interest is difficult.

At Land Grant State, the faculty did not perceive themselves as having control over their matches. When we asked faculty if they could veto a match made by the department, faculty expressed that they were typically offered to take the student with some financial assistance from the department to help them support such students. However, if they had declined to take on the offered student, it typically came at the cost of not getting matched with any student that year:

> There'll often be a conversation about taking one for the team [by taking a student you don't want]. This is your year to take one for the team. Either you don't get a student at all, or you get one that wasn't even close to a choice for you. [Full Professor, Land Grant State]

Some faculty expressed not being satisfied because they would not always get a PhD student when requested and when they insisted on being matched, the match might be someone not as interested in working with them, and they were told in what position a student had ranked them:

> They'll come to the advisor and be like, "We know this person didn't list you at all, but you're their fourth choice, and would you be willing to take this student if maybe we threw in a free year T.A. or something." Like great, a fourth choice. But [the student] have to go to somebody." [Full Professor, Land Grant State]

In this quote, we see that faculty at this institution were told what position students had ranked them in. While this information may not enhance the final results of the match, the previous quote shows that it does influence how faculty ultimately perceive a student that may have expressed an interest in their work when they were not the student's first selection.

Faculty at this institution were more likely to discuss alternatives for recruiting students outside of Chemical Engineering. For example, one faculty described recruiting students who were changing research groups. These faculty also discussed using their joint appointments with other departments to recruit students in other departments when their home department of Chemical Engineering could not match them to a PhD student. However, the mismatch in the recruiting timeline for both programs made this task very difficult:

> I have difficulties because the [secondary appointment] program you have to match before you're accepted [in the Spring previous to initial enrollment]. So, I have to come to [secondary appointment] and say, "I'm going to take Suzy." Well, I'm usually hoping to pick up a Chem-E student because that's my primary appointment. By the time I realize [ChemE matches] failed, all the students in [secondary appointment] have been

admitted. I either have to take the [secondary appointment] student straight out of the beginning, and there's no Chem-E chance, or I have to gamble on Chem-E and hope for the best. [Assistant Professor, Land Grant State]

Faculty here also described more instances of either themselves or colleagues circumventing the process altogether. Neither department mentioned an explicit prohibition of faculty directly recruiting students. However, some of them discussed on more than one occasion in which they directly recruited a student that they had engaged with through work at some point or another before their commencing graduate school. Many of the faculty interviewed referred to certain colleagues with international connections and those who gained some form of research notoriety as often circumventing the matching process:

> Every now and then you'll see a student coming in from … And it's typically one of my Chinese colleagues who has a student through a colleague who they either have a research collaboration or a strong personal relationship that this faculty member is actually bringing that person in on research grants directly into their lab. All they're worried about is getting the student accepted into the graduate program. They're not using any departmental funds to support that student […] or anything like that. So, faculty members can do that. That's basically like hiring a graduate student directly. [Full Professor, Land Grant State]

While the faculty were not completely satisfied with the status quo of advisor-advisee matching, they were mostly unable to articulate a better process through which to find students and completely rejected a laissez-faire recruiting approach without departmental intervention such as those practiced in most other engineering programs. They believed the system currently in place was the best to help all students succeed. When asked about whether they would like another version of the process, they responded:

> [I like that] you get to meet all the students that have been admitted. The frustrating part is with the ranking (of faculty), I may really like a couple of students, but because they don't rank me in first place, they're not going to be in my lab. I mean, in an ideal world, a department would sponsor the student for, say, the first year […] That way, after they get there, there's a little more time to get to know them. [Assistant Professor, Land Grant State]

In sum, faculty were not likely to follow a different process despite their dissatisfaction often because it meant students had the best chance of finding an advisor, even if it came at a cost to them as faculty. Again, not all processes/practices were documented or visible to students and faculty.

LAND GRANT STATE THROUGH A PAT PERSPECTIVE

Similar to our prior case, we find that there is a contract that guides the process, but the agent also makes considerations for student interests and faculty standing when executing the contract. These considerations were not all documented in the contract. We also observed constraints on the process, such as balancing student research interests in any cohort and funding availability which limit the contract execution.

Unique to this case, we see that the agent not only sides with the student but also limits the faculty perception of control despite the faculty being also a principal in the matching. PAT would suggest that faculty principals that are more satisfied with the outcome of the tasks completed by the agent (Graduate Program Director) are more likely to engage again with the agent to complete a new task than those principals who are not satisfied. Faculty in Land Grant State indeed report this as they describe taking actions that circumvent dealing with the agent rather than monitor or regulate the actions of the agent to promote their individual satisfaction. They do not believe that they obtain the students they need by using the pre-established process. Thus, being unsatisfied with the process outcome (and its limitations on a faculty member's recruiting), these faculty

resort to recruiting students outside of the pre-established process for the department or even outside the program's confines.

MULTIPLE PRINCIPAL DILEMMA

When considering these cases in light of the multiple principal dilemma, we observe two unique challenges. While there are two distinct variations in the multiple principal dilemma (where outcomes align and where they do not), the challenges we note are associated more with determining if desired outcomes are met, which is the step necessary before determining alignment. The first challenge is that of goal alignment between principals, which we observed across both departments. We infer from the faculty interviews that students' desired outcome is to be matched to their top choice, but they have no way to appeal a match. Conversely, the faculty members' desired outcome is to match with a student (less emphasis was placed on matching to any specific student), but they provide input to the Graduate Program Director while the choices are being made, and depending on the department, possibly even veto a match. In PAT terms, this lack of student control places the students in a position of less relative power than faculty, which can compound when the students' and faculty's goals are not aligned. This challenge was equally present for both cases examined above.

The second challenge is the challenge of the information asymmetries between the principals and the agent that limit the ability to assess the outcome. In Midwest U, the Graduate Program Director did not share what rank students assigned to each faculty. Faculty were only told that a student had listed them as a preferred match, and faculty did not request more information. Conversely, Land Grant State did share this information with their faculty, and we found instances where this information influenced how faculty perceived their match with a student (e.g., "this student ranked me fourth, so they probably don't really want to work with me"). In PAT terms, the information asymmetry between the agent and the principal can limit the principal's ability to assess whether the outcome is acceptable.

DISCUSSION

This study examined how two different Chemical Engineering programs manage the advisor-advisee matching process from the perspective of faculty and, using PAT understand how the processes differed. Specifically, we examined how faculty and Graduate Program Directors interact when undergoing this process through a theoretical perspective. Our results showed that both programs herein described a somewhat similar matching process, including the student experience with the matching, how junior faculty are prioritized, and the challenges posed by fluctuating student interests and the timing of grant submission results. However, how faculty perceived the matching process as executed by the Graduate Program Director was different across the two departments, as was faculty perception of control over the matches. This perception of control over entering the advising relationship out of their own volition can be critical since it can influence how the relationship between the student and the faculty begins and develops (Joy et al., 2015).

As examined through PAT, and specifically the PAT multiple principal dilemma, our results reveal two key insights. The first insight comes from the problem of enforcement; both departments lack the student possibility to appeal, making students the principal with lesser power to control the outcome. This power differential should not pose a problem for the student should their outcome preferences match those of the faculty. Prior research in advisor-advisee matching has shown students and advisors look for varying characteristics in their match and the prioritization of such vary across individuals (Joy et al., 2015; Zhao et al., 2007). Thus, unless students and faculty have candid conversations about whether they both want to work with each other, their goals in being matched may not be aligned. Should there be misalignment in the final results of a match, there could be a possibility for an advising relationship to begin under a negative undertone (Devos et al., 2016).

The second insight comes from the challenge of information asymmetries between the principals and the agent. In Midwest U, faculty were not informed about their ranking, whereas in Land Grant State, the specific ranking position a student assigned to a faculty was shared. Per PAT (Eisenhardt, 1989), transparency between the principal and the agent should lead to higher efficiency in their transaction. However, we observe in Land Grant State that this additional information impacts how faculty perceive student matches and how the lack of this information does not make for less satisfactory matches in Midwest U. Thus, our findings counter traditional notions of transparency and suggest that some information asymmetries may be more beneficial than harmful (Bhargava & Chen, 2012). It is important to note that beneficial asymmetries are highly contextual to this scenario. Research in doctoral education has often discussed how transparency between students and faculty can be beneficial to student decision making even within advisor selection (Joy et al., 2015; Sowell et al., 2015; Wall Bortz et al., 2020). Although transparency in advisor selection processes can help reduce attrition (Golde, 2005) and increase overall satisfaction (Joy et al., 2015), care should be placed when assessing which contexts merit information asymmetries, and frameworks such as PAT can help in that assessment.

IMPLICATIONS

The main implication for research of this study is the additional insights obtained in the use of an economics framework to study faculty and departmental process. Our findings showed that faculty behavior indeed adhered to the principles set forth by the PAT framework. Further, by using such a framework, we obtained richness in interpreting what faculty were doing and why they acted the way they did, as well as how the actions of leadership impact faculty reactions. This adherence shows that ultimately faculty are rational human actors making predictable economic rational decisions based on the incentives available to them, similar to those we might make were we in the same situation. Thus furthering the use of economics frameworks such as PAT in studies of academic contexts can provide further understanding to human behavior in such and even the ability to predict how people will act in such scenarios (Shapiro, 2005).

Collectively, the findings show that the intended consequences of current practices can have negative impacts on process engagement and outcomes. We found that faculty appreciate the structured process put in place to help students find an advisor, but the management of such a process can impact faculty engagement. Departments, graduate program directors, and faculty could review their current practices to identify and rectify potential points of disengagement. This might require departments to first fully document what they actually do to make the complete process visible to all engaged in the process. This clarity can help all faculty understand the rationale behind the decisions being made as well as make visible to the students the constraints faculty work around when matching, in particular the role of funding availability as a matching driver. Regarding outcomes, our findings showed how a process—whose intent is to foster equality among students—could create unequal circumstances between students and faculty. Considering that this initial matching process sets the foundation for advising relationships, programs could consider ways to mitigate the impacts of this process in light of the power differentials in advising relationships.

The unintentional consequences could also lead to challenges in assessing the outcomes and effectiveness of matching, mainly if the primary assessment criterion is satisfaction with a match. Such a definition is problematic because when individuals circumvent the process or exert their power to obtain their desired match results, the outcome could be assessed as satisfactory despite the system not functioning efficiently or effectively. Departments could engage in a formal assessment of matching processes which may mean starting by explicitly delineating outcomes and the steps of the process that will promote those outcomes, essentially engaging in a backward design process, such as Wiggins & McTighe (1998) outline for good course assessment.

CONCLUSION

In conclusion, this study showed that although the process of matching students and faculty in chemical engineering may seem similar from a surface-level view, department-specific nuances can vary the process broadly. It was through the faculty members' viewpoints and the lens of PAT that we were able to deconstruct the specific interactions and find further insight into such. We recommend departments consider how they practice shared governance in their departments and continuously engage in conversations about processes and practices to surface implicit and explicit practices and perpetuate good community in their academic units.

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The authors have no competing interests to declare.

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