Learning beliefs of engineering faculty and their students: How might alignments and misalignments affect educational change initiatives?

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Abstract*— This research paper describes and compares the learning beliefs of faculty and students at an engineering college. The ways faculty and students conceptualize learning, including their epistemological beliefs and views on 'effective' pedagogical strategies, play an important role in how they interpret and engage in curricular change. Despite the importance of both faculty and student learning beliefs to educational reform, only a few studies have considered teacher beliefs alongside student beliefs. This study seeks to address this research gap by characterizing the learning beliefs of 35 instructors and 136 students at an undergraduate engineering school, and by exploring potential effects that within-groups variation and between-groups differences may have on educational change efforts. Variable-based analysis of quantitative survey responses reveals significant differences in the ways students and faculty conceptualize learning and learners. Compared to engineering undergraduates, instructors more strongly endorsed process-oriented conceptions of learning such as self-regulation, active knowledge construction, dynamic ability, and social or collaborative learning. The student group showed more variance in their learning beliefs than the faculty group, suggesting a pedagogical alignment among faculty that does not exist for students at the school. Given research that suggests instructors adopt pedagogical practices that reflect their beliefs, and studies that show engineering students prefer learning environments that align with their conceptions of learning, the findings highlight tensions that may arise as faculty and students engage with new curricula, non-traditional pedagogies, or transformative learning approaches. The findings suggest that, on average, engineering undergraduates might more readily accept traditional pedagogical approaches or curricular designs that are aligned with conventional views of teaching and learning. This highlights a need for developmental programs and pathways that enable faculty and students to critically reflect on and work to transform their learning beliefs.

Keywords*— *conceptions of learning, learning beliefs, institutional change, instructional change, teaching philosophies

I. Introduction

Successful educational reform is not simply a matter of selecting and implementing evidence-based pedagogies, adopting cutting-edge curricular models, or addressing physical or staffing resource concerns. Beneath the visible aspects of change, e.g., revised program goals, renovated learning spaces, funded industry partnerships, and flashy marketing materials, lie more personal and often deeply embedded individual identities, beliefs, values, and assumptions about the educational experience [1,2,3]. Depending on how the proposed change aligns with the existing beliefs or values of individuals or groups, educational change initiatives may prompt powerful synergies that fuel the change effort, or significant tensions that threaten to disrupt or derail the effort [4]. Successful change efforts enable individuals and groups to gain an awareness of different identities, beliefs, values, and assumptions at play in the system, and support critical self-evaluation, openness, collaborative discourse, and a gradual shifting toward new perspectives that are aligned with the proposed change. The learning beliefs held by faculty and students, including how they conceptualize roles of teachers and learners and their views on effective learning processes, are important variables in engineering educational change initiatives. Alignment or misalignment in beliefs may contribute in powerful ways to the success or failure of course or program level innovation.

II. Background and Literature Base

A. *Learning Beliefs and Conceptions of Learning: Definitions and Frameworks*

The educational research community generally accepts that instructors' beliefs about learners, learning processes, learning domains, and learning environments influence their behaviors and practices [5,6,7]. At the same time, teacher beliefs represent a "formidable," "messy construct" that is "steeped in mystery" [5] and inconsistently defined, operationalized, and measured. Definitions of learning beliefs span a diverse range, from practical principles and action strategies, to implicit or explicit learning theories, to broad views on the role of schools in societies or ideologies about the purposes of education [5,8].

Drawing on what some researchers refer to as 'conceptions of learning' [9] or 'conceptions of teaching' [10], this investigation frames learning beliefs as individuals' views of knowledge, students, and learning processes. The conceptions of learning literature provides a rich collection of concepts and frameworks based on qualitative and quantitative studies. For example, based on their review of prior research, Samuelowicz and Bain [10] proposed a five-level classification of conceptions of teaching as: (i) supporting student learning, (ii) changing students' conceptions or understanding of the world, (iii) facilitating understanding, (iv) transmitting knowledge, and (v) imparting information. They further characterized different dimensions of these conceptions including the directionality of teaching (i.e., teacher to student transfer versus a two-way cooperative process), teacher versus student control, outcomes from knowing more to knowing differently, and knowledge as curriculum-bound subject matter versus actively constructed understanding [10].

Kember and Gow [11] mapped various conceptions of learning held by university faculty to two distinct teaching orientations – knowledge transmission and learning facilitation – each with specific beliefs, values, goals, and classroom behaviors and interactions that affected the quality of student learning. In a later review article aimed at reconceptualizing teaching conceptions research, Kember [12] described two broad orientations as teacher-centered/content-oriented and student-centered/learning-oriented, with more specific teaching conceptions organized along a spectrum under the two broad categories. The extreme teacher-centered end of the spectrum is described as "imparting information," with teachers as presenters, content defined by curriculum, students as passive recipients of information, teaching as information transfer, and knowledge as possessed by the teacher [12]. The extreme student-centered end of the spectrum is described as "conceptual change," with teachers as change agents, teaching as development of persons and conceptions, students responsible for development, content constructed by students, and knowledge as socially constructed [12]. In the middle of the spectrum lie mixed roles for teachers, interactive teaching processes, and students as active participants within an instructor's framework for content and knowledge [12].

Research exploring conceptions of learning from a student perspective has yielded similar frameworks. Early work by Trigwell and Prosser [13] distinguished between students' *surface* approaches to learning based on memorization and knowledge reproduction, and *deep* approaches to learning based on understanding and meaning. Marshall et al.'s [14] investigation of students' conceptions of learning in an engineering context applied an expanded framework of five different learning conceptions, ranging from Conception A: Learning as memorizing definitions, equations, and procedures, to Conception E: Learning as a change as a person. In their cross-cultural study of high school students' views on learning and learning processes, and with intent to further shift discussions beyond the simple surface learning versus deep learning categorizations, Purdie and Hattie [9] identified six general conceptions of learning as: (i) gaining information, (ii) remembering, using, and understanding information, (iii) a duty, (iv) personal change, (v) a process not bound by time or place, and (vi) social competence. Vermunt and Vermetten's [15] Inventory of Learning Styles emphasized the importance of regulation strategies, specifically external versus self-regulation, alongside conceptions of learning such as passively reproducing versus actively constructing knowledge, and learning in isolation versus learning in cooperation with others. Vezzani et al. [16] distinguished between reproductive conceptions of learning, or "learning as a reduction of deficit knowledge through individual effort," and co-constructive and cultural process conceptions of learning.

This study makes use of a learning conceptions tool by Bolhuis and Voeten [17] that situates many of the previously explored dimensions of conceptions of learning within the context of educational innovation. More specifically, the tool was designed with the goal of understanding learning conceptions in order to promote instructors' process-oriented teaching and students' self-directed learning in secondary education. As such, the Bolhuis and Voeten conceptions of learning instrument incorporates five different dimensions: (i) teacher-control versus student self-regulation of learning; (ii) knowledge as reproduced or transmitted versus knowledge as actively constructed; (iii) learning as an individual versus social endeavor; (iv) fixed versus dynamic views of intelligence; and (v) intolerance versus tolerance for uncertainty in learning [17]. The transmitted versus constructed knowledge and individual versus social learning dimensions are informed by much of the early work in conceptions of learning [e.g., 10,11]. The self-regulation dimension may be traced to learning conceptions work by Vermunt and Vermetten [15], as well as models from self-regulated learning (SRL) theory [18,19]. The fixed versus dynamic ability dimension draws on Dweck and Leggett's [20] theory of intelligence as fixed or malleable. Together, the five dimensions are intended to provide an indication of the extent to which instructors might endorse or engage in student-centered, active learning-oriented educational innovations [17].

B. *Importance of Learning Beliefs to Educational Innovation and Change*

Engineering programs designed for significant or transformative learning are often based on non-traditional pedagogies that situate students at the center of the educational experience and integrate learning goals and processes that may be unfamiliar to many engineering educators, e.g., social learning, internalized regulation, learner agency and autonomy, active experimentation, and conceptual change [21,22,23]. Such approaches may place unfamiliar cognitive, motivational, social, and behavioral burdens on faculty and students, and require fundamental shifts in how individuals conceptualize "effective" teaching and construe their roles as learners [24].

Research illustrates that educators adopt pedagogical approaches that are aligned with their epistemological views [7,25] and that instructors' beliefs about effective teaching and learning affect how they interpret and engage in curricular innovations [24,26,27]. Trigwell et al. [6] illustrated that regardless of whether teachers believe that learning is information transmission or that learning is conceptual change, instructors' intentions translate logically to the pedagogical practices they adopt in the classroom. For example, instructors with positivist epistemological beliefs gravitate toward lectures, exams, and passive student roles; and teachers with constructivist beliefs adopt more inquiry-based and interactive discussion activities [25]. Kember [12] developed a model that illustrates how conceptions of teaching give rise to curriculum design and teaching approaches, which in turn influence students' learning approaches and outcomes. This model acknowledged the importance of departmental or institutional factors in shaping teaching conceptions and practice but suggested that the interactions between teacher conceptions and student learning may be greater at the individual instructor and course level [12].

Any change initiative – individual, departmental, or institutional - that significantly pushes existing curricular and pedagogical boundaries will likely require individuals to change their practices and behaviors and shift their beliefs about learners and learning. Research suggests that congruence between teaching conceptions and teaching behaviors or strategies is necessary for change, and that initiatives focused on activities or strategies alone are unlikely to be successful [7]. As with any significant or transformative learning process, however, critically examining and evolving one's learning beliefs can be a disorienting process undoubtedly accompanied by a sense of tension, dissonance, instability, and uncertainty for most people [23,28].

Instructors' sense of tension and instability with shifting beliefs may be exacerbated by students' response to the proposed curricular or pedagogical change. Research shows that students' learning beliefs affect their learning approaches, engagement, and outcomes in important ways [14,29,30,31,32], as well as their perceptions of and responses to different learning environments, whether traditional or innovative [29,33]. Dissonance between students' conceptions of learning and instructors' pedagogical approaches can lead to high levels of student dissatisfaction [15], conflict, and withdrawal [34]. Congruence between beliefs and practices, on the other hand, can lead to student appreciation and learner transformation [34].

Research suggests that while belief changes are often difficult, significant transformations are possible, especially when interventions are supported by skilled facilitation, practice with implementation, personalized support and guidance, and collaborative reflection and discourse [28,34,35,36,37].

C. *The Present Study*

Despite the importance of both teacher and student learning beliefs to educational reform, only a few studies have considered teacher beliefs alongside student beliefs. Most of the research on learning beliefs focuses on secondary school settings or the professional development of student teachers for K-12 settings [e.g., 25,38]. Work that concurrently examines faculty and student learning beliefs in college-level engineering or computing programs is sparse. This study seeks to address this research gap and expand the educational change dialogue by considering college instructors' beliefs alongside those of their students. The study characterizes the learning beliefs of 35 instructors and 136 students at a small, private engineering school, and explores the potential effects that within-groups dispersion and between-groups differences may have on educational change efforts. The analysis makes use of quantitative data from the Learning Inventory [17], an instrument designed to measure teachers' beliefs about external versus internal regulation, reproductive versus constructive knowledge, individual versus social learning, and fixed versus dynamic ability.

III. Methods

A. *Participants and Study Environment*

Participants in the study were 35 faculty and 136 students at a private undergraduate engineering college in the U.S. In its marketing materials, the college emphasizes a culture of collaboration, innovation, and experimentation, and an academic approach focused on hands-on engineering, lifelong learning, entrepreneurship, and identifying and solving complex real-world problems. The college's courses and curricula reflect a wide range of pedagogies, from conventional lecture-based classes to project-based learning and interdisciplinary courses that are taught by teams of faculty from technical and non-technical disciplines.

Faculty study participants included 32 full-time faculty representing approximately 70 percent of the school's full-time faculty, and 3 part-time faculty representing about 30 percent of the school's part-time instructional staff. The faculty group comprised 16 men, 16 women, and 3 individuals of non-binary or self-defined gender identity. By rank, the faculty group included 3 instructors, 8 assistant professors, 11 associate professors, and 13 full professors.

Student study participants were undergraduates enrolled in engineering major degree programs at the college. The respondent group represented approximately 40 percent of the total engineering degree-seeking undergraduates and included 53 men, 75 women, and 8 individuals of non-binary, self-defined, or unspecified gender identity. By year of study, the student group included 35 first-years, 37 sophomores, 39 juniors, and 25 seniors.

The research protocol used in the study was reviewed and approved by an institutional review board (IRB) for the protection of human subjects. All study participants provided informed consent via a web-based form.

B. *Instrument, Data Collection, and Analysis*

Faculty and student beliefs about teaching and learning were assessed using the Learning Inventory [17], an instrument designed to measure teachers' beliefs about external versus internal regulation, reproductive versus constructive knowledge, individual versus social learning, fixed versus dynamic ability, and tolerance for ambiguity. This study made use of the teachers' conceptions of own learning portion of the Learning Inventory instrument, which included 22 items based on two opposite statements about the same topic, one more aligned with traditional teaching and more aligned with learning process-oriented teaching aligned with self-directed learning principles and teacher-as-facilitator roles.

The Learning Inventory uses a four-point scale that asks respondents to "quite agree" or "agree somewhat" with either of the opposite statements. Bolhuis and Voeten's [17] confirmatory factor analysis (CFA) of Dutch teachers' conceptions of learning suggested that the five factors measured by the Learning Inventory could be satisfactorily distinguished, but that correlations among the five factors were quite high.

Data were gathered via web-based surveys. The faculty and student surveys included the same quantitative measurement, deployed during the same academic term (spring semester, 2019). The five-factor structure of the Learning Inventory survey was verified by confirmatory factor analysis (CFA), with comparative fit index (CFI), Tucker Lewis index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR) selected as model fit indices. Given the relatively small sample size, acceptable fit was defined as SRMR < 0.08, RMSEA < 0.08, and CFI and TLI > 0.90 [39,40]. Group-based descriptive statistics were calculated for all subscale variables. Normality of the faculty and student response distributions was analyzed using the Kolmogorov-Smirnov (K-S) test. Statistically significant differences between faculty and student responses were

TABLE I. DESCRIPTIVE STATISTICS FOR AND COMPARISONS OF FACULTY AND STUDENT GROUPS

Conceptions of Learning: Learning Inventory Subscale[a]	Faculty (N=35)		Students (N=136)		Mann-Whitney *U* Test Results		
	M	***SD***	***M***	***SD***	***z***	***p***	***Effect Size r***
External to Internal Regulation (4 items)	3.41	0.58	2.70	0.59	-5.56	<.001	0.43
Reproduced to Constructive Knowledge (4 items)	3.58	0.42	3.10	0.55	-4.55	<.001	0.35
Individual to Social Learning (5 items)	3.76	0.33	3.43	0.43	-4.51	<.001	0.35
Fixed to Dynamic Ability (4 items)	3.87	0.21	3.72	0.33	-2.43	.015	0.19
Intolerance to Tolerance of Uncertainty (5 items)	3.35	0.56	2.75	0.54	-5.03	<.001	0.38

[a.] Note. Conceptions of learning measured on a 4-point scale (1=quite agree with left, 2=agree somewhat with left, 3=agree somewhat with right, 4=agree somewhat with right)

determined using the Mann-Whitney *U* test. Effect sizes were calculated as *r* using the standardized *z* values from the Mann-Whitney *U* test, a method proposed by Cohen for non-parametric data [41]. Pearson correlations were calculated to examine associations among the study variables.

IV. RESULTS

The CFA suggested that the Learning Inventory five-factor model fit was acceptable ($\chi 2$=259.94, df=199, CFI=.92, TLI=.91, RMSEA=.045 [.027,.058], SRMR=.065), with fit values similar to those for the five-factor model reported by Bolhuis and Voeten [17]. As such, the five-factor model for learning beliefs was accepted without further modifications.

Descriptive statistics for all study variables are shown in Table I. Individual faculty and student responses and group means are illustrated in Fig. 1. Correlations among the learning conceptions subscales for faculty and students are shown in Table II. The K-S test indicated that the faculty and student responses on all subscale measures differed significantly from a normal distribution. As such, it is useful to consider the data in the form of individual response distributions shown in Fig. 1, where, for example, the skew in faculty responses toward positive values is apparent. Given the non-normal response distributions, the Mann-Whitney *U* test was used to determine statistically significant differences between the faculty and student group responses (Table I).

Results suggest that most faculty at the engineering school endorse conceptions of learning consistent with process-oriented teaching and student self-directed learning. Faculty at the school strongly align with malleable or growth-oriented views of intelligence [20], and beliefs that people learn better in social, cooperative, and collaborative settings. Most faculty report epistemological beliefs consistent with constructivist learning theory. Generally, faculty endorse internal regulation

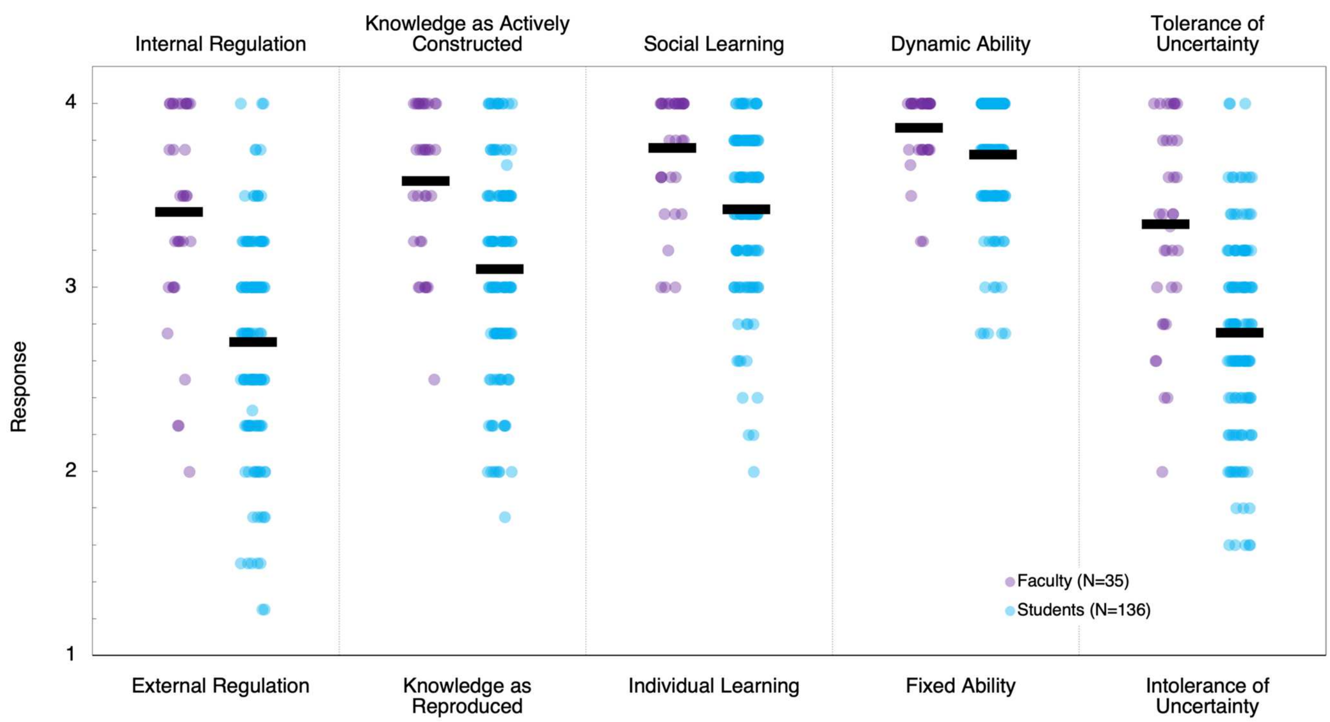

Fig. 1. Faculty and student conceptions of learning at the engineering school. Individual faculty responses (N=35) are shown in purple, and individual student responses (N=136) are shown in blue. Mean values for each group are shown in black.

TABLE II. BIVARIATE CORRELATIONS FOR SUBSCALE MEASURES OF THE LEARNING INVENTORY. FACULTY RESPONSES (N=35) ARE SHOWN ABOVE THE DIAGONAL, AND STUDENT RESPONSES (N=136) ARE SHOWN BELOW THE DIAGONAL.

Conceptions of Learning	1	2	3	4	5
1. External versus Internal Regulation	--	.69**	.56**	.35*	.66**
2. Reproductive versus Constructive Knowledge	.48**	--	.60**	.28	.48**
3. Individual versus Social Learning	.39**	.60**	--	.30	.32
4. Fixed versus Dynamic Ability	.19*	.35**	.37**	--	.26
5. Tolerance Of Uncertainty	.63**	.37**	.38**	.21*	--

**Correlation is significant at the $p < 0.01$ level. * Correlation is significant at the $p < 0.05$ level.

over external regulation and express a high tolerance of uncertainty in learning, although individual faculty responses in these two areas show more variation compared to the other subscales.

Results from the group-based comparison reveal significant differences in the ways students and faculty conceptualize learning and learners. Like their faculty, the undergraduate engineering students strongly endorse dynamic views of intelligence. Students also express moderately strong beliefs in the value of social learning over individual learning. Compared to instructors, however, engineering students at the school report more traditional conceptions of learning across all measured constructs. The differences between faculty and students are most pronounced on the external-internal regulation and tolerance of uncertainty measures. Mann-Whitney *U* test results indicated that, compared to their faculty, students at the school endorse internal regulation (self-regulation) at significantly lower levels ($z = -5.56$, $p < .001$) and view uncertainty in learning as less tolerable, desirable, or valuable ($z = -5.03$, $p < .001$). Relative to faculty, students also reported significantly lower endorsement of constructivist knowledge beliefs ($z = -4.55$, $p < .001$) and social learning ($z = -4.51$, $p < .001$). Effect size is small for the fixed-dynamic ability measure, and medium for all other conceptions of learning measures [41]. The student group showed more variance in their learning beliefs than the faculty group, suggesting a pedagogical beliefs alignment among faculty that does not exist for students.

Correlational analysis of the faculty responses revealed significant moderate relationships between instructors' beliefs about external versus internal regulation, and beliefs about reproductive versus constructive knowledge, individual versus social learning, and tolerance for uncertainty in learning (Table II). Faculty beliefs about learning regulation showed a weak but significant correlation to ability beliefs. Faculty views on knowledge also showed moderate relationships to beliefs about individual versus social learning and tolerance of uncertainty. Student correlations followed a similar pattern to faculty correlations, with the strongest relationships appearing between beliefs about regulation and knowledge epistemologies, between regulation beliefs and tolerance of uncertainty, and between regulation beliefs and individual versus social learning beliefs. Compared to faculty, students showed slightly weaker correlations between learning regulation beliefs and other study variables, and slightly stronger correlations between their views on individual versus social learning and beliefs about learner ability and tolerance of uncertainty.

V. DISCUSSION AND IMPLICATIONS FOR EDUCATIONAL INNOVATION AND CHANGE

The results of this study may be examined and interpreted from several perspectives by considering how alignments or misalignments in the learning beliefs held by individuals or groups may play out in the context of educational change initiatives. The findings highlight synergies and tensions that may arise within or between faculty and student groups, as they engage with new curricula or pedagogies in their learning environment and institutional context.

A. Faculty-Institutional Alignments and Misalignments

It is no secret that many faculty hold strong beliefs about teaching and learning. Research shows that the beliefs instructors hold translate directly to their pedagogical practices, provided their skill level and institutional context allow for a self-determined beliefs-to-action translation. When instructors are afforded autonomy in the design and implementation of curricula and pedagogies, their choices tend to reflect their learning beliefs. For example, Trigwell and Prosser [7] showed that for university science teachers, conceptual change intentions were associated with student-focused strategies such as self-direction and discussion, and information transfer intentions were associated with teacher-focused strategies such as lectures and exams. Berger et al. [42] illustrated moderate to strong relationships between constructivist beliefs and autonomy-supportive classroom practices, and direct knowledge transmission beliefs and externally controlling practices.

In certain academic settings, instructors equipped with skills and experience may freely select and implement pedagogical strategies based on their beliefs. Under these conditions, the academic programs at the school may proceed in a status quo manner, without any notable disruptions in individuals' beliefs-strategies system. Faculty beliefs and pedagogical choices do not always exist in a vacuum, however, and instructors' teaching practices may be significantly influenced by institution- or department-level factors. As Norton et al. [43] suggest, "teaching intentions reflect a compromise between teachers' conceptions of teaching and their academic and social contexts." Disciplinary norms, pedagogical training and experience, departmental goals, institutional vision, pressure from colleagues or students, and a host of other contextual factors may influence what faculty believe about teaching and learning, and how they approach curriculum design and learning.

As described above, the institutional context for this study was an engineering school with non-traditional pedagogical goals including *collaboration*, which aligns with social learning beliefs, *lifelong learning*, which implies internal regulation, dynamic ability, and constructive knowledge, and *complex real-world problem solving*, which implies a tolerance for ambiguity. While the data show that most faculty at the institution are well-aligned with these process-oriented, student-centered learning beliefs, at least a few faculty hold views on learning that lie well outside of the group average, particularly with regard to external versus internal regulation and tolerance for ambiguity. In short, most faculty appear to endorse the college's aspirations for the engineering learning experience, and some do not.

It is interesting to consider what individual faculty may experience on the ground during educational change initiatives, as the institution encourages faculty toward non-traditional pedagogies that are consistent with the institutional goals. In these situations, individually held beliefs that at other schools may be comfortably concealed or expressed only within isolated classes, may be forced into the open during curriculum design discussion or program assessment meetings. Thoughtfully developed belief structures that enable individual faculty to justify their pedagogical choices and resist change in a typical institutional setting [35] may be less effective at a school that is actively striving to revolutionize its departments or programs. Success of any educational innovation depends, at least in part, on alignment of the proposed change with instructor beliefs [37]. As such, this institution may need to build systems and structures that promoting awareness of learning beliefs, enable long-term positive shifts in learning beliefs, support agency and self-efficacy in change initiatives [44], and avert disengagement or burnout of individual faculty [45].

While administrators' conceptions of learning were not measured in this study, it is worth reflecting on how alignments or misalignments between faculty and administrators' beliefs could affect educational change initiatives at the college. The school's academic leaders are responsible for articulating and implementing the school's strategic vision and educational goals, and as such they may play an important role in reinforcing, challenging, or positively influencing faculty conceptions of learning. Alignment of faculty and administrator beliefs would likely reduce anxiety around any proposed educational change and increase the institution's chances of success in educational innovation. On the other hand, depending on factors such as institutional power structures, decision-making processes, extent of faculty agency, and administrative tendencies toward control or support, one might expect discord or instability to arise in situations of mismatched administrator-faculty beliefs [37,44,46]. Without administrators' perspectives, the faculty-institutional learning beliefs picture is incomplete.

B. Faculty-Faculty Alignments and Misalignments

The Fig. 1 data suggest good faculty alignment around social learning, dynamic learner ability, and actively constructed knowledge. Faculty show more variation in their views on external versus internal regulation of learning, and uncertainty in learning. Given these areas of alignment, one can imagine the school's faculty would be able to collaboratively and productively engage in the co-design of team-based learning experiences that nurtured individuals' growth potential and encouraged students to conceive of knowledge as something they actively develop and not a static body of content 'covered' by the instructor. Social constructivist knowledge epistemologies and collaborative pedagogies may serve as faculty rallying points in the educational change process.

In light of research that suggests instructors adopt pedagogical practices that reflect their epistemological beliefs [25], the range of faculty views on external versus internal regulation and comfort with ambiguity in the learning process would likely lead to diversity in the course designs and pedagogical experiences within the engineering programs. At the one extreme, a few faculty may design courses that emphasize high levels of teacher control, in which students sense low levels of instructor autonomy support and have few opportunities for development of self-regulated learning skills. At the other extreme, a larger group of faculty might strive to design and facilitate highly self-determined and self-directed learning experiences, such as open-ended projects that engage students in setting their own goals, developing learning strategies, finding resources, monitoring and controlling their progress, and self-reflecting and self-evaluating [18,19].

The variation among faculty is unlikely to create individual anxiety or interpersonal conflicts, except perhaps in curricular situations where faculty must negotiate or set aside their own beliefs as they engage in practice. This may occur if faculty are compelled to work on a teaching team with colleagues who hold significantly different learning beliefs. In a new course design scenario, for example, faculty may be able to collaboratively imagine and create experiences that reflect different individual beliefs, provided the team interactions are not adversely influenced by faculty power, position, or working style dynamics. Potentially more problematic are situations in which existing courses are assigned to new faculty, with some expectation that the existing courses retain their prior curricular and pedagogical design, and thus the embedded beliefs of the previous faculty designers. Assigning legacy courses to new faculty could be especially challenging if the receiving instructor holds more conventional teaching beliefs yet is expected to facilitate a colleague's non-traditional pedagogy with embodied student-centered beliefs, or if the recipient is a less skilled or experienced faculty member who is still working to develop a coherent learning beliefs-strategies system. Forcing faculty into beliefs-misaligned situations could lead to feelings of exclusion from the change initiative, biased or unjust performance assessments, or student confusion, anger, dissatisfaction, and frustration regarding the learning experience.

C. Faculty-Student Alignments and Misalignments

Alignments or misalignments in the learning beliefs of faculty and students could present the most important and ongoing challenges to educational change initiatives at the college. While faculty and students are relatively aligned in their endorsement of dynamic ability beliefs, they hold significantly different learning beliefs in every other area. Considering research that shows engineering students prefer learning environments that align with their conceptions of learning [33], the findings highlight several areas where substantial tensions may arise as faculty and engineering students engage with new curricula or non-traditional pedagogies. Faculty and students at the school hold different views of knowledge, with students endorsing a more traditional teacher-as-expert view in which learners receive transmitted knowledge in an intact or static form, and faculty strongly orienting toward constructivist epistemologies. Faculty-student beliefs differences are even more pronounced for external versus internal regulation of learning, and tolerance of uncertainty in learning. Misalignments in knowledge beliefs may lead to students' devaluing of open-ended design or ill-defined explorations that are common to inquiry-based or project-based learning. Student responses along the lines of 'they're teaching me the wrong material,' 'I'm not learning engineering content,' or even 'I'm not learning anything in this class' may be expected in these scenarios. Misalignments in regulation beliefs could give rise to student feedback that courses designed for transformative or self-directed learning outcomes are 'poorly designed,' 'not organized or structured enough,' or 'not aligned with my learning style,' or that instructors in these courses 'don't know how to teach' or are 'teaching in the wrong way.'

In their qualitative study of students' reactions to student-centered learning, Lee and Branch [34] examined how alignments or misalignments between student beliefs and pedagogical practices played out in a studio course with a "learning by designing" approach. Students who entered the studio course espousing student-centered learning beliefs reacted with *confirmation* of their beliefs if they enjoyed the self-directed learning experience, or *withdrawal* to teacher-centered beliefs if the course went poorly for them. Students who entered the course with teacher-centered beliefs reacted in several different ways. Some with teacher-centered beliefs showed *appreciation* if they recognized value in or effectiveness of the studio approach. Some disappointed students with teacher-oriented beliefs expressed *confirmation* that they would have learned more in a traditionally structured class. Some students *transformed* their teacher-centered beliefs into student-centered beliefs. While the transformation to student-centered learning beliefs came with conflict, struggles, and challenges, the mismatch in beliefs-pedagogy was ultimately beneficial for individuals' learning outcomes, including self-awareness and confidence [34]. This experience is consistent with transformative learning theory. Entwistle and Peterson [29] emphasize cognitive dissonance and constructive friction as necessary for significant learning, and Mezirow [23] cites the "disorienting dilemma" as the first phase of transformative learning. It could be that the tensions between students' traditional beliefs and the pedagogical experiences offered by faculty members with process- and student-centered learning beliefs set the stage for significant learner growth.

Another concern is students' sense of inclusion in learning processes designed by different faculty, or more broadly in the school's educational change initiatives. Individually, the faculty and students at this institution adopt a diverse range of beliefs about learning and professional identities. On the whole, however, faculty skew toward the self-directed and process-oriented end of the belief spectrum. The Fig. 1 data suggest that in this engineering learning environment, the fraction of students with more process-oriented, student-centered beliefs will have many opportunities to connect with faculty who share similar beliefs, and many opportunities to engage in courses based on non-traditional pedagogies. The most difficult challenges for these students may be the high levels of self-regulation and tolerance for ambiguity expected by many faculty. On the other hand, students on the opposite end of the belief spectrum may often find themselves in learning environments and situations – courses, project teams, instructor interactions – that are grossly misaligned with their existing orientations toward traditional teacher-centered learning. In cases of classroom-level beliefs mismatch, individuals may experience sufficiently high anxiety and dissonance to disengage or withdraw from the learning. A challenge for faculty is fostering a learning environment that acknowledges individuals' current perspectives on learning beliefs, while simultaneously creating the conditions for positive change and recognizing tensions associated with beliefs transformations.

D. Belief Changes are Possible: A Need for Developmental Structures and Processes

The data gathered in this study indicate that the educational innovation aspirations of the institution are well-aligned with the learning beliefs of most faculty, and aligned to a lesser degree with the beliefs of engineering students at the school. The data suggest that a small number of faculty, and potentially large numbers of students, will need to shift their learning beliefs in order to perceive value or a sense of inclusion in the school's ongoing educational change initiatives.

Research shows that positive changes in faculty and student learning beliefs are possible over time and under certain supportive conditions. Levin and Wadmany [47] reported significant changes in teachers' knowledge structures, educational beliefs, and classroom practices over a three-year period of educational change that actively engaged teachers in learning new concepts and procedures, working in cooperative teams, planning interdisciplinary activities, and discussing and reflecting on their experiences. Instructors' beliefs have a major impact on their engagement with professional development and adoption of educational innovations, however, and beliefs must factor into the design of change initiatives [24,27]. Pajares suggests that teacher beliefs are the "single most important construct in education research," and Ertmer [24] refers to research on teachers' pedagogical beliefs as a "vital first step" in understanding how instructors' beliefs influence classroom instruction and engagement with educational innovations. Developmental interventions that thoughtfully integrate instructors' conceptions of teaching and learning may enable faculty and students to gain awareness of the ways educational beliefs affect engagement in educational reform, and more skillfully negotiate their own beliefs as they encounter change-related tensions [46].

Academic leaders could play an important role in developing collaborative long-term processes and structures that help to reveal individuals' underlying values, goals, and assumptions about learning, and that support a gradual evolution of faculty and student learning beliefs in line with institutional goals or aspirations. Complete alignment of all faculty beliefs is likely not possible, and it is certainly not desirable given the critical importance of diverse viewpoints and intellectual freedom in academic environments. Reflective dialogue and awareness raising about learning beliefs, however, may nurture a shared sense of understanding, collective support of educational change initiatives, and the forms of cognitive dissonance and constructive friction that promote thoughtful inquiry and ongoing transformation.

VI. Limitations and Future Work

This study of faculty and student learning beliefs at an engineering college was limited in several ways. First, the quantitative methods allowed for characterization of faculty and student conceptions of learning, but not explanation of learning beliefs. Second, the quantitative measurement tool used in this study was reductionist in nature, and as such it significantly constrained the study's perspective on learning beliefs to a limited set of conceptualizations that may or may not encompass individuals' broader perspectives on teaching and learning. Future research may expand the study approach to mixed methods to enable deeper analysis and extraction of person- and group-level insights. Third, the data for this study were collected at one point in time, thus providing snapshot of faculty and student learning conceptions rather than a longitudinal perspective that may reveal temporal shifts in individual- and group-level beliefs. As discussed above, people's beliefs about teaching and learning may evolve or transform over time, and future work could examine the developmental trajectories of faculty and students, as well as the conditions and processes that support stability or instability in individuals' learning beliefs. Fourth, the study measured faculty and students' beliefs about their own learning, and not faculty members' on-the-ground pedagogical practices or students' responses to different pedagogical approaches. As such, the findings may better reflect espoused learning beliefs or intentions than enacted learning beliefs. Fifth, the study data were collected at a single undergraduate engineering college, with a learning culture and individual learning beliefs that may not adequately or accurately reflect the faculty and student perspectives at other schools. Future work would include different engineering institutions and programs, to broader applicability of the study findings.

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