Characterizing students' subcultures in engineering and their alignment with the adoption of the Freeform pedagogical system

Mohamed Aziz Dridi
MEERCat Purdue, School of Engineering Education
Purdue University
West Lafayette, IN, USA
mdridi@purdue.edu

Ed Berger
MEERCat Purdue, School of Engineering Education, School of Mechanical Engineering
Purdue University
West Lafayette, IN, USA
bergere@purdue.edu

Jeffrey F. Rhoads
MEERCat, School of Mechanical Engineering
Purdue University
West Lafayette, IN, USA
jfrhoads@purdue.edu

Jennifer DeBoer
MEERCat, School of Engineering Education, School of Mechanical Engineering
Purdue University
West Lafayette, IN, USA
deboerj@purdue.edu

***Abstract*—This research-to-practice full paper investigates the alignment of a specific pedagogical innovation, the Freeform pedagogical system, with the student culture(s) of the mechanical engineering department of a small private college (SPC) in the upper Midwest of the United States, we ask the research question: *What are the defining characteristics of the student culture or (sub)cultures in the engineering department where the Freeform system is being propagated?* Based upon interviews with on-campus stakeholders (students, faculty, and staff), we constructed a 64-item survey to characterize the culture of their engineering department. We analyzed student responses using the cultural consensus theory model (CCT), a quantitative method that looks for patterns of responses to cultural statements. Grouped together, these patterns of responses indicate the values of the sub-cultures present within a participant group. Our results indicate that the best fitting model contains two student subcultures: student subculture 1 (SC1) (n = 15) and student subculture 2 (SC2) (n = 60). These two subcultures exhibit differences across a handful of items that focus on the student experience and in particular the sense of connectedness or belonging among students. Members of SC1 seem to be disconnected from both their peers and their instructors, work primarily alone, and seem to struggle to obtain access to academic assistance. SC1 members also feel overworked with (what they perceive to be) low-value-added activities, and they do not perceive alignment between how instructors teach and how they prefer to learn. In contrast, members of SC2 seem to be aligned with the institutional mission, which focuses on faculty-student relationships and learning in the community**

Keywords— Innovation propagation, student cultures

I. INTRODUCTION

One of the reasons that attempts to improve engineering courses fail is that they do not sufficiently align with the local culture of the academic unit. The literature on change in engineering education shows that widespread pedagogical innovation across an academic organization requires the development of a shared vision between the community members, that is faculty, staff [1][2], and students [3][4]. However, instructors often implement pedagogical innovations by requiring students to use a certain set of resources or to engage with a course in a particular way. A currently under-studied element of innovation adoption is the extent to which the innovation aligns with department culture and, specifically student cultures. Our team has been studying the alignment between the adoption of a pedagogical innovation called Freeform and the departmental cultures of multiple engineering institutions across the United States. In this paper, we present our work on characterizing the student culture of a small private college (SPC) in the upper Midwestern region of the United States.

To understand how pedagogical innovations are propagated successfully, we need to characterize the local culture of the propagation setting to assess its alignment with the pedagogical innovation. In our work, our institutional partners (the instructors) made implementation decisions about Freeform, and our research team interpreted those decisions within the local context. In this study, we specifically examined the student culture in order to reveal how a pedagogical innovation is adopted and adapted in pursuit of improved student outcomes. We employed a cultural characterization approach based on Cultural Consensus Theory (CCT) and used it to answer our research question: *What are the defining characteristics of the student culture or (sub)cultures in the engineering department where the Freeform system is being propagated?* Our work provides the engineering education research community with a cultural characterization approach to students' cultures in the context of pedagogical innovations propagations.

II. BACKGROUND AND LITERATURE

A. Freeform: The pedagogical innovation

Freeform is an integrated learning environment that combines the best practices in active, blended, and collaborative (ABC) learning to promote the acquisition of conceptual knowledge and problem-solving skill in engineering mechanics. Freeform started in the School of Mechanical Engineering at Purdue University in 2008 as an attempt to incorporate ABC elements into a sophomore-level dynamics course. This learning environment combines ABC learning strategies with a suite of specially tailored in-class and online learning activities and resources, and student outcomes have been positive [5][6].

The debate about the value of active, blended, and collaborative (ABC) pedagogies seems to be over, with the general conclusion being that each adds value over a more traditional lecture-based format. In fact, an empirical consensus in the literature demonstrates the effectiveness of active learning practices in the engineering classroom [7].

Similarly, blended learning environments, which combine in-class and online learning elements, have been proven to be more beneficial than both in-class and online learning environments [7][8]. In addition to active and blended learning, collaborative learning has also been demonstrated to have a positive influence on student success [9] in traditional, online, and blended instructional settings [8][9][10]. Taken together, Freeform's evidence-based ABC strategies offer a powerful set of instructional tools to support and enable student success.

The name 'Freeform' captures the ethos of this pedagogical innovation in that it provides flexibility and autonomy to both faculty and students in the way resources can be selected, adapted, and aligned to fit the need of each stakeholder. For instance, the custom-written Freeform textbook (the 'lecturebook') [11] was designed to facilitate active learning and infuse active learning opportunities into the infrastructure of the course itself. Freeform classes each have their own online (blog) website, which acts as an information hub, providing students with online resources and facilitating blended learning activities through threaded discussions on homework problems and embedded example videos. As we have detailed elsewhere [12][13], this suite of resources and approaches provides both instructors and students autonomy in decision-making regarding how they engage with the Freeform system.

B. *Propagation context*

SPC is situated in the upper Midwestern region of the United States and is classified as a Baccalaureate College-Diverse Fields (Bac/Diverse). SPC enrolls about 3,200 undergraduate students and maintains small class sizes (typically with a maximum of 30 students). The institution prioritizes face-to-face student-faculty interaction and help-seeking; as a result, during normal business hours students have convenient access to their instructors to seek academic help, advising, and mentorship. We perceive this institution to have a relationship-oriented culture of teaching and learning wherein student-faculty connections are valued and embraced. In past studies of this setting, we observed how the pattern of frequent, in-person student-faculty contact meant that the discussion forum (or blog) of the Freeform system added little value to the student experience. This previous finding epitomizes the importance of "the cultural lens" when characterizing pedagogical innovation adoptions. This culture of in-person help-seeking rendered the asynchronous discussion on the discussion forum unimportant, a strong contrast to the original implementation site whereat the asynchronous blog discussions were lively.

C. *Cultural consensus theory (CCT)*

We use cultural consensus theory (CCT), a person-centered methodology, for discovering and estimating group/subgroup consensus (that is, the 'culture') by analyzing survey data from group members, somewhat akin to cluster analysis [14]. The main assumptions of a CCT model are threefold: First, the model assumes respondents come from a common culture, which means there is a common answer for each response item (assumption 1); Second, the respondents' answers are independent of one another, but they are correlated with the common answer (assumption 2). Third, the model assumes that informants differ in their response bias such that they will be prone to select one of the two responses when guessing (also called the assumption of heterogeneous item difficulty). In our analysis, each one of the three model assumptions was checked, and the results are presented in the next sections.

III. Methods

A. *Survey construction and data collection*

The construction of the CCT survey was based on the same methodology that our research team has successfully implemented in a previous study investigating faculty subcultures at a mechanical engineering department of another university in the Midwestern region of the United States [15].

This approach consisted of constructing the survey items iteratively after careful consideration of multiple streams of qualitative data, such as onsite interviews, focus groups, and field observation with students. In the context of SPC, 13 categories emerged from the interviews as important cultural themes expressed by the students. These key categories were: leadership (12 items), identity (7 items), professional outcomes (6 items), community (5 items), curriculum (3 items), peers (3 items), morale (3 items), change (2 items), membership (2 items), collaboration (2 items), scale (1 item), relationship with faculty (1 item).

Within each of these 13 categories, we created potential survey items based on the data set we collected, and each item was carefully evaluated with regard to the evidence we had already collected. At the end of the iterative process, we ended up with a CCT survey comprising 64 dichotomous (yes/no) cultural statements. We presented this survey to 77 students, who provided their consent to participate in this study in accordance with our institutionally approved protocol. Two students responded to only half of the survey questions and their responses were therefore removed. Each student was invited to indicate their agreement ('yes' response) or disagreement ('no' response) with each cultural statement.

B. *Data analysis*

We analyzed the results of the CCT survey in a two-staged approach. First, we conducted a cultural consensus analysis (CCA) to determine the number of students subcultures. Second, we summarized the cultural statements for which the students' responses from the discovered subcultures were statistically different and formed a narrative description of them.

The CCA was conducted using the *CCTPack* package in R Studio [14]. Our parameter selection for our model was guided by the literature [14][16][17] and a sensitivity analysis was conducted to ensure that model outputs were robust and interpretable. Factor analysis was used to determine variance patterns in response to the survey items and to quantify the extent to which knowledge was shared among students. A cultural consensus was identified when there was a strong pattern of responses across questions and respondents. This does not mean that respondents all answered each question the same way, but rather that their responses have enough of a pattern to suggest that they were drawing upon a shared pool of broader explicit and implicit knowledge when answering the questions [16][18].

Our CCT model complied with the assumptions of the CCT theory introduced in the previous section. Assumption 1 was satisfied, since the student respondents were pooled from the same environment, which in our context includes the physical infrastructure, the faculty, the leadership, the regulations, etc. Assumption 2 which states that respondents' responses are independent was satisfied since we invited the students to participate independently form one another. Finally, we used a posterior check to satisfy the hypothesis of heterogeneous item difficulty

IV. Results and discussions

We collected n = 75 complete responses to the CCT survey and ran a factor analysis on the 75 x 75 respondent matrix which confirmed the existence of two student subcultures. In CCA, the first- and second-factor eigenvalues must have a ratio of at least 3:1 for cultural consensus to exist among respondents [19]. Our results (Figure 1) show that ratio to be 30:4, thus confirming a strong cultural consensus.

A posterior check (Figure 1) of subculture number showed that the scree plot of the actual data (the black line) fell within the distribution of simulated data (the gray lines), and, hence, two subcultures was an appropriate choice. The item difficulty check used the Variance Dispersion Index to validate the hypothesis of heterogeneous item difficulty.

As a final check of model fit, we examined both the Deviance Information Criterion (DIC), which estimates the model predictive error and the sensitivity of subculture membership, to changes in the number of subcultures (Table 1). We found that a two-subculture model has the lowest DIC and is, therefore, the most plausible one.

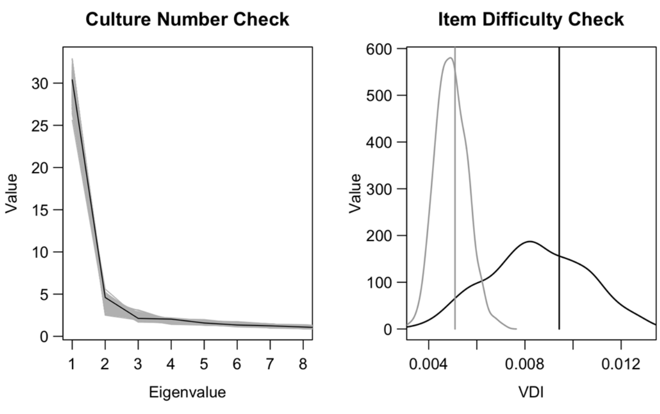

Fig 1. Posterior check of model specification: Number of subcultures based on eigenvalue ratios (left) and heterogeneity check based on Variance Dispersion Index (VDI, right)

The statistical inference estimated that 15 respondents belonged to Subculture 1 (SC1) and 60 respondents belonged to Subculture 2 (SC2). The average respondent cultural competencies for SC1 and SC2 were respectively $\theta_1 = 0.51$ and $\theta_2 = 0.67$, which means that across both student subcultures more than 50% of respondents share the same cultural beliefs.

Such levels of cultural competencies indicate that our consensus model identified strong cultural patterns in the data set. In addition, our analysis revealed that the average guessing biases for SC1 and SC2 were respectively $g_1 = 0.54$ and $g_2 = 0.50$ which indicates that in both student subcultures, respondents displayed a similar cognitive response style (i.e., no inter-group difference in terms of guessing). All of this data further confirmed the existence of two students' subcultures in our sample.

TABLE I. Sensitivity of subculture membership to changes in the number of subcultures explored in cultural consensus theory (CCT) analysis

	Monoculture	**2 subcultures**	**3 subcultures**
# of students in SC1	75	15	11
# of students in SC2	-	60	4
# of students in SC3	-	-	60
Deviance Information Criterion (DIC)	3151.4	2911.9	2994.3

A. Subcultures description

In Table 2, we summarize the cultural statements for which the students' responses of the two subcultures were statistically different using a threshold α = 0.05 and a chi-squared test. The table suggests that SC1 and SC2 have multiple points of disagreement across the survey cultural items. In the next paragraphs, we will interpret the shared cultural features and their differences across the two student subcultures.

1) A strong sense of community but differing views on collaboration

The results show that SPC students have developed a strong sense of community that they share not only between them, but also with staff and faculty. In fact, 97% of the respondents agreed that "*In the engineering department, students, staff, and faculty share the institution's values*". This communal characteristic of SPC, as perceived by both student subcultures, emanates from the caring and tight-knit environment of the institution. This is demonstrated by 91% of students respondents who agreed with the survey item 3 "*Faculty, staff, and students in this engineering department create and value a caring, personalized, and tight-knit community. (St Community)*".

The strong sense of community and the tight-knit environment of SPC as described above did not directly translate into how the students collaborate with each other. There is a significant difference between the two students' subcultures in response to item 2 "*Most students in this engineering department prefer to work individually rather than in groups. (St Collaboration)*" where 87% of SC1 agree in comparison to just 13% of SC2.

2) Different views on academic workload and curricular structure

A consistent theme across the survey items is the perception of a heavy workload by SC1 students, and this appears to be a constitutive cultural feature of SC1 students' identity. The two subcultures had different perceptions about the academic workload at SPC and its impact on their well-being. This theme is instantiated in item 10 "*Students in this engineering department are asked to do too much busy work in their classes. (St Morale)"* where 87% of SC1 agree with this statement, while only 23% of SC2 agree. This does not seem to be an inconsequential complaint from SC1 students since as shown by Item 16, they tend to perceive SPC culture to be strictly binary in terms of academic achievement. Indeed, when asked if *"Students in this engineering department tend to either struggle academically or are high achieving. (St Identity)",* 93% of SC1 students agreed with the question in contrast with 62% from SC2.

TABLE II. PERCENTAGE OF RESPONDENTS AGREEING WITH EACH CULTURAL CONSENSUS THEORY (CCT) SURVEY STATEMENT BY SUBCULTURE (SC1,SC2) AND ACROSS ALL OF THE RESPONDENTS.

	Item	All (%)	SC1 (n=15) (%)	SC2 (n=60) (%)	p
1	In this engineering department, students, staff, and faculty share the institution's values. (St Community)	97	87	100	0.049
2	Most students in this engineering department prefer to work individually rather than in groups. (St Collaboration)	28	87	13	0.000
3	Faculty, staff, and students in this engineering department create and value a caring, personalized, and tight-knit community. (St Community)	91	73	95	0.037
4	This engineering department is an easy place for people to develop a sense of belonging. (St Community)	91	73	95	0.037
5	Students in this engineering department are comfortable collaborating with each other on academic work. (St Collaboration)	92	67	98	0.000
6	The primary job of faculty and staff is to help students in this engineering department prepare for their future careers. (St Leadership/Faculty)	97	87	100	0.049
7	There are so many students in this engineering department that it's hard for faculty to really connect with students. (St Scale)	11	33	5	0.007
8	The course-related workload for students in this engineering department is so high that they have little time for extracurriculars. (St Morale)	64	100	55	0.003
9	The course-related workload for students in this engineering department is so high that they have little time for self-care (such as adequate sleep, or time for leisure activities). (St Morale)	57	100	47	0.001
10	Students in this engineering department are asked to do too much busy work in their classes. (St Morale)	36	87	23	0.000
11	The curriculum in this engineering department imposes too many rules, restrictions, and constraints on students. (St Curriculum)	15	47	7	0.000
12	Ethical issues such as cheating are prevalent among students in this engineering department. (St Identity)	16	40	10	0.015
13	Students in this engineering department have many opportunities to check their understanding of course material and determine if they need extra help. (St Leadership/Faculty)	83	33	95	0.000
14	Faculty in this engineering department rarely implement new teaching methods that align with the learning preferences of the current student population. (St Leadership/Faculty)	35	80	23	0.000
15	Students in this engineering department believe the academic advising at ES is personalized. (St Mentorship)	72	47	78	0.034
16	Students in this engineering department tend to either struggle academically or are high achieving. (St Identity)	68	93	62	0.041
17	Students in this engineering department students rarely seek help with course material. (St Identity)	24	67	13	0.000
18	Students in this engineering department struggle to get help on homework if professors aren't available, especially when students are working after business hours. (St Leadership/Faculty)	37	93	23	0.000
19	Most students in this engineering department struggle to find time to take care of themselves and get enough sleep because of coursework. (St Identity)	68	100	60	0.008
20	Students in this engineering department feel comfortable enough with faculty to reach out to them about employment opportunities. (St Leadership/Faculty)	81	60	87	0.045
21	Faculty in this engineering department can tell when students are not understanding the material and will adjust their teaching style to accommodate struggling students. (St Leadership/Faculty)	64	27	73	0.002

In addition, the perceived heavy academic workload appears to affect SC1 students' well-being and life outside of SPC. In fact, responses to items 9,10, and 19 seem to be all point to the fact that SC1 members feel over-worked, sleep less than they would like, and generally feel that the intensity of their academic work prevents them from spending their time on other pursuits

Item 11 which probes students about the curricular structure gives an interesting perspective to the academic workload challenge. In fact, almost half of the SC1 students (47%) think that "*The curriculum in this engineering department imposes too many rules, restrictions, and constraints on students. (St Curriculum)*" while only 7% of SC2 agree with the item. Thus, it appears that the perceived constraints of SPC curriculum combined with the perceived heavy academic workload places SC1 students in a difficult position and ultimately ends up affecting their broader life.

3) Differentiated views on resource usage behaviors and support availability

SC1 and SC2 members perceive the availability of academic support somewhat differently. Only 33% of SC1 students think that "*Students in this engineering department have many opportunities to check their understanding of course material and determine if they need extra help. (St Leadership/Faculty)*" in contrast with 95% of SC2 who think so. In addition, 67% of SC1 students think that *"Students in this engineering department students rarely seek help with course material. (St Identity*)" in comparison to only 13% of SC2. It appears from these responses that SC1 students' perception of the low availability of resources is translated into a perception that everyone at SPC rarely seeks help with course material.

A similar pattern was found with respect to faculty support. 78% of SC2 students agree that "*Students in this engineering department believe the academic advising at [SPC] is personalized. (St Mentorship)*" while only 47% of SC1 do. The fact that SC1 students do not feel that they are getting personalized advising supports previous findings in terms of their perception of low availability of academic support. This sense of isolation is echoed by SC1 students' responses to item 21 "*Faculty in this engineering department can tell when students are not understanding the material and will adjust their teaching style to accommodate struggling students. (St Leadership/Faculty)*" where a small fraction of SC1 students (27%) agree with the statement in comparison to a larger 73% for SC2 students.

These response patterns in SC1 students suggest that there is a misalignment between what SPC faculty are implementing as a support strategy and what SC1 students perceive to be helpful to them. This finding is reinforced by the responses to item 14 which asks students if "*Faculty in this engineering department rarely implement new teaching methods that align with the learning preferences of the current student population. (St Leadership/Faculty)*". In fact, 80% of SC1 students do not recognize any alignment between faculty teaching methods and the students' learning preferences suggesting that SC1 students do not experience the university environment as student-centered.

V. DISCUSSION AND FUTURE WORK

Our CCT analysis uncovered two subcultures within SPC students' population. Our results suggest that SC2 is a *mainstream* culture both in terms of membership size but also in terms of alignment with the faculty mission. Students in SC2 appear to have a strong sense of educational focus and seemingly can manage their academic workload in concert with their extracurricular life. They do not perceive the curricular structure to be constraining and engage with the engineering program and its community. SC2 students clearly benefit from what they perceive to be a personalized advising style and appear to trust the faculty in their ability to adjust their teaching style to accommodate students who are struggling.

Conversely, SC1 appears to be a counterculture that exhibits misalignment with faculty mission, curricular structure, and students' collaboration. While SC1 students agree that, overall, SPC has a strong sense of community, they have expressed that their experience of academic collaboration was rather limited. Further, at an individual level, they seemingly feel that SPC faculty cannot identify their academic struggles and adjust their interventions to remedy them. Their cultural misalignment is salient and their perception that there is a lack of support in their learning process is unequivocal.

Table 2 shows the mapping of the Freeform ethos onto cultural characteristics. This mapping helps us situate the results of our CCT analysis in the context of the Freeform pedagogical system and identify areas of misalignment with SC1 culture. As can be seen from Table 3, SC1 students seem to access fewer support resources from peers and instructors, and that might make their success in the Freeform classroom somewhat harder to achieve. Future work will critically examine the alignment of the (adapted) Freeform implementation at SPC with the students' cultural features identified in this paper. The goal is to understand, in a more summative way, the instructor experience and decision-making around implementation choices, with a focus on how Freeform promoted student achievement and aligned with SC1 student needs and work habits.

TABLE III. MAPPING OF FREEFORM ETHOS ONTO SC1 CULTURAL CHARACTERISTICS

Freeform element	Freeform cultural instantiation	Comparison with SC1 cultural characteristics
Emphasizes student collaboration	**Collaboration**: General disposition toward collaboration, and clarity on culturally acceptable modes of collaboration (peer-to-peer, student, and faculty, synchronous, in-person, etc.)	• Freeform encourages peer collaboration, so SC1 students may not take full advantage of the collaborative learning elements of the system.
Empowers students to manage their experience	**Trust/Engagement:** Extant level of trust in the learning environment	• Freeform empowers students to manage their learning experience. SC1 students' disengagement might isolate them further in the Freeform environment. Alternatively, Freeform may provide new pathways for engagement.
Focuses on both conceptual and procedural knowledge	**Educational Values:** Relative value placed upon traditional problem solving, viz-a-viz conceptual understanding, socio-technical analysis, or professional outcomes	• SC1 students' disengagement may impede them from making the most out of Freeform educational value. Alternatively, Freeform may provide new pathways for engagement.
Provides a technology mediated, resource-rich learning environment	**Student support:** The extent to which faculty or department prioritize various forms of student support (academic and personal).	• Freeform encourages access to technology-mediated help resources, and the local environment stresses in-person help seeking with faculty. SC1 students seem to not take full advantage of the in-person support available to them.
Offers students multiple flexible paths to success	**Expectations of homogeneity**: The extent to which the faculty expect students to achieve similar outcomes via similar pathways	• Freeform provides agency to students in choosing their own learning pathway: SC1 students might feel empowered to find their own successful combination of learning style and resource-usage in the Freeform environment.
In-class pedagogy glues together all other elements of Freeform	**Faculty attitudes about teaching, learning, and priorities:** The extent to which the faculty culture broadly supports pedagogical endeavors and innovations therein	• Faculty culture is at the core of a Freeform successful implementation, SC1 students misalignment with SPC faculty culture might further increase SC1 students sense of isolation.

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