Do students' resource-usage patterns vary across institutions? Implementing a pedagogical innovation in an undergraduate engineering course

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Abstract

Context

Effective reform of engineering education necessitates the widespread implementation and dissemination of pedagogical innovations globally. However, to ensure the successful propagation of these innovations, we need to better understand the adaptations that they undergo when adopted at a new institution, and the extent to which they differ from the original innovation. This includes understanding the student experience with the innovation.

Purpose or Goal

This study examines the propagation and adaptation of Freeform, a learning environment for teaching an undergraduate dynamics course developed at a large Midwestern university in the United States. Specifically, our goal is to understand how students at an adopting institution used Freeform's learning resources. Our research questions are: 1) What are the students' archetypical patterns of resource usage at the adopting institution? 2) In what ways do those patterns differ from those of students at the original institution of Freeform?

Methods

We conducted a model-based clustering analysis to answer our two research questions. The analysis was conducted on survey data from 50 engineering students at the Freeform adopting institution. This data articulated how frequently students used nine different resources of the Freeform ecosystem.

Outcomes

Our analysis identified 4 resource-usage patterns in the Freeform adopting institution in comparison to 9 patterns for students at the institution where Freeform originated. In the Freeform adopting institution, the most frequent resources that students utilized were Teaching Assistants (TAs) and other students who were not enrolled in the course. This contrasts with the original institution where students relied mostly on the course lecturebook and their classmates.

Conclusion

This study highlights the importance of taking into consideration the differences across institutions when propagating pedagogical innovations such as Freeform. Our results suggest that instructors should anticipate those differences so that the adoption and onboarding process can be optimized for success.

Keywords— pedagogical innovation, help seeking behavior, resource usage.

I. INTRODUCTION

Pedagogical innovations, when successful, are often propagated outside of their original institutions. During such process, they undergo various transformations to adapt to their new implementation environment. Researchers have investigated the fidelity of implementation of an innovation, (Borrego et al., 2013), with the observation (O'Donnell, 2008) that 'efficacy' of an implementation (the extent to which is resembles the original innovation) is different from its 'effectiveness' (the extent to which it achieves a desired outcome). However, little is known about the efficacy of pedagogical innovations from students' perspectives. That is, to what extent students' experiences of a pedagogical innovation differs across institutions.

In this paper, we examined the propagation efficacy of a pedagogical innovation called Freeform with a focus on students' experiences. Specifically, we ask two research questions 1) What are the students' archetypical patterns of resource usage at the Freeform adopting institution? 2) In what ways do those patterns differ from those of students at the institution in which Freeform originated?

II. BACKGROUND

Freeform, the pedagogical innovation that we are studying in this paper, is a pioneering approach to teaching Dynamics. It started in 2008 within Purdue University's School of Mechanical Engineering as an instructional environment integrating elements of Active, Blended, and Collaborative (ABC) pedagogical techniques. The goal of developing the Freeform ecosystem was to enhance both conceptual understanding and problem-solving abilities in the field of engineering mechanics. To this end, Freeform designers curated a range of both in-person and digital learning activities and resources grounded in ABC learning research (Rhoads et al., 2014).

The debate around the value of these ABC approaches and resources seems to have settled with the general conclusion being that each adds value over a more traditional lecture-based format. In fact, a consensus in the literature demonstrates the

effectiveness of active learning practices in the engineering classroom (Freeman et al., 2014). 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 (Freeman et al., 2014; Means, 2014). In addition to active and blended learning, collaborative learning has also been demonstrated to have a positive influence on student success (Means, 2014) in traditional, online, and blended instructional settings (Fatos et al., 2006; Jeong & Chi, 2007; Means, 2014). Taken together, Freeform's evidence-based ABC strategies offer a powerful set of instructional tools to support and enable student success.

The name 'Freeform' embodies the educational philosophy underpinning this instructional innovation, granting both educators and learners the latitude to tailor resources according to their specific needs. For example, the Freeform platform includes a bespoke 'lecturebook' (Rhoads & Krousgrill, 2013), conceived to not only support but also integrate active learning activities within the very fabric of the course curriculum. Each Freeform course is further enriched by a dedicated online blog, serving as a centralized portal for academic materials. This virtual platform augments blended learning experiences by offering threaded conversations on coursework and incorporating illustrative video examples. As found in previous studies (Kandakatla et al., 2020; Zadoks et al., 2017), this comprehensive array of methodologies and resources offers considerable decision-making autonomy to both instructors and students in their interactions with the Freeform educational framework. For instance, in our previous work (Evenhouse et al., 2023), we found that many students used the lecture example videos to clarify questions that arose during lecture. Others reported reading the lecturebook as a means of better preparing for class, or using the online discussion forums to further clarify dynamics concepts or problem-solving processes.

III. METHODS

This mixed-method study employed an explanatory sequential design where student survey data was collected first followed by student interview data to further explain the quantitative results.

A. Data collection

The participants to this study were sophomore engineering students enrolled in Dynamics at a large public university in southeast United States. The sampling frame for this study was 107 students enrolled in Dynamics in Spring 2022 out of which 57 consented to our research study. These 57 students were asked to complete a survey at the end of the semester about their study habits, help-seeking behaviors, and resource usage in the class. This study focuses on a subsection of the survey that probed students about their resource usage in Dynamics. The subsection asked students how frequently they used each of the class resources. The response options were verbatim, and in the order in which they appear on the survey): at least once per day, 3–6 times per week, 1–2 times per week, 1–3 times per month, 1-3 times per semester, and never. The nine resources included

in the survey question are listed in Table 1 along with their descriptions and their median responses for both the adopting and original institution. Seven students submitted incomplete responses to the survey and their responses were, therefore, discarded rendering our final sample to 50 students.

In addition, we conducted semi-structured interviews with seven junior students in mechanical engineering at the adopting institution who took Dynamics. Each interview lasted around 90 minutes and consisted of several questions organized in five categories: Experiences in Dynamics, relationship, and sense of community in class, use of technology, course structure, course comparison to others.

B. Data analysis

We conducted a model-based cluster analysis using the *mclust* package in R (version 3.3.2) to determine the students' archetypical patterns of resource usage across all the nine resources described in Table 1. Model-based clustering offers two main advantages over frequently employed techniques such as K-means. First, it evaluates multiple shapes for the clusters, not only spherical or circular like in K-means. Second, model-based clusters can overlap since they are calculated based on a vector of probabilities corresponding to the alignment of a student's behavior with that of the other students' behavior in that cluster. In the absence of any a priori knowledge about the shape of resource-usage clusters, we opted for model-based clustering. Following Stites et al., (2019) methodology, we conducted a parametric analysis on 14 different clustering shapes with a number of clusters ranging from one to 10. Our selection of the best fitting model was based on the Bayesian Information Criterion (BIC), a likelihood criterion that penalized models with increased complexity. The combinations of shape and cluster-number that recorded the top three BIC values were identified as the most plausible models. The variations in BIC values among these three top cluster models were marginal, less than 0.5% apart, which prompted us to evaluate the three models based on their differences in the number of distinct, qualitative patterns of resource usage. The most parsimonious model which corroborated the qualitatively unique resource-usage patterns was the four-cluster model and was therefore chosen as the final one.

To gain deeper insights into the reasons behind students' specific resource utilization patterns, we undertook what Merriam (2009) described as a fundamental qualitative investigation using data from student interviews. The primary objective of this qualitative research was to discern the distinctive behaviors that characterized each cluster's resource usage. We used the emergent themes of our qualitative analysis not as findings per se but rather as supporting elements to better characterize the different clusters.

Following this methodology, we were able to identify the archetypical resource usage behaviors of students at the adopting institution. We then compare those behaviors to those of students at the original institution based on results previously published (Dridi et al., 2022). This study was conducted in

accordance with the ethical standards of Purdue University and was approved by its Institutional Review Board (IRB). All study participants provided informed consent prior to participation.

IV. RESULTS

A. Macro-level comparison

Table 1 shows a comparison of the resource usage median frequencies between the adopting institution and the institution where Freeform originated. A comparative analysis reveals noteworthy patterns among students' resources-usage preferences. Students at the original institution demonstrate a proclivity for structured, formal resources, notably the lecturebook and the course blog, with median usage frequencies of 3–6 times per week and 1–2 times per week, respectively. These resources appear to be integral components of their learning strategy. Conversely, students at the adopting institution are less frequent users of these core resources, with the lecturebook being accessed 1–2 times per week and the course blog only 1–3 times per semester.

The usage of online solution videos is consistently moderate across both institutions, indicating that students adopted blended learning, which aligns with Freeform ethos. However, the most striking difference emerges in the realm of interpersonal interactions. Students at the adopting institution are more likely to consult both peers outside of class (i.e. not enrolled in Dynamics) and instructors during office hours, with median frequencies of 1–2 times per week and 1–3 times per semester, respectively. This contrasts sharply with the original institution, where students seldom consult peers outside of class (i.e. not enrolled in Dynamics) and never attend instructor office hours.

Interestingly, while the original institution shows a higher frequency of collaboration with classmates—a core Freeform resource—students at the adopting institution engage less frequently with classmates, reporting a median frequency of 1–3 times per semester.

TABLE I

A DESCRIPTION OF THE NINE RESOURCES INCLUDED ON THE END-OF-SEMESTER SURVEY AND THE MEDIAN FREQUENCY WITH WHICH STUDENTS USED THE RESOURCE FOR ADOPTING AND ORIGINAL INSTITUTIONS

Learning Resource	Description	Median Frequency Adopting institution	Median Frequency Original institution
The lecturebook	Combination of a workbook and concise textbook; students write notes and solve problems directly in book.	1-2 times/week	3–6 times/week
Online solution videos	Screencasts of the instructor solving a problem; every lecturebook example and homework problem has a solution video.	1–2 times/week	1–2 times/week
Peers outside of class	Peers who are not currently enrolled in Dynamics but have taken it previously	1–2 times/week	Never
Help room	A dedicated help room staffed over 40hours/week with undergraduate- and graduate-student TAs	1–2 times/week	1–3 times/semester
The course blog	''Blog'' most often refers to the discussion forum but could also be interpreted as the course website.	1-3 times/semester	1–2 times/week
Instructor – In class	Could include questions before, during, or after class.	1–3 times/semester	1–3 times/semester
Instructor- Office hours	Office hours were usually 1 hour long, 2–3 days/week.	1–3 times/semester	Never
Non -course online resources	Could include online videos, online example problems, or online tutoring websites.	1–3 times/semester	1–3 times/semester
Classmates	Group quizzes in class; virtual or in-person collaboration outside of class.	1-3 times/semester	1–2 times/week

B. Cluster analysis of survey data

1) Model selection

The cluster model that had the highest BIC (-14,330) had four clusters, and the models with the second and third highest BIC values (-14, 451 and -14. 490) had three and five clusters

respectively. Thus, the four-cluster model was chosen as the most parsimonious model. To measure the goodness of fit of the four-cluster model we examined the uncertainty associated with the cluster classification of each student. For the four-cluster model, almost half the students had an uncertainty of less than 4% and approximately 80% of the students had an uncertainty of less than 30%. In the institution where Freeform

originated, our previous work showed the existence of nine clusters displaying unique archetypical resource usage patterns (Dridi et al., 2022). The difference in number of clusters suggest that students in the adopting institution resorted to a more targeted usage of the Freeform resources in comparison to a more diffuse usage in the original institution. Such difference in usage pattern might be reasonably attributable to cultural features specific to each context that shaped students' resources-usage behaviors.

2) Characteristics of resource-usage patterns

Figure 1 describes how students in each of the four clusters used Freeform resources. As expected, students did not use one specific resource over the others but instead combined multiple resources into an academic plan that they thought would meet their learning needs. All students across the four clusters, used consistently at least one of Freeform core resources, i.e., classmates, lecturebook, online videos, and the course blog. In contrast, students at the institution where Freeform originated (figure 2) consistently used at least two of the core resources. In the adopting institution, we note a consistent pattern across all students consisting of frequently using the help room (1-2 times/ week or more) while rarely resorting to classmates (less than 1-3 times per month). In stark contrast, students at the original institution frequently relied on their classmates (at least 1-2 times/week) and barely used the help room (less than 1-3 times/ month).
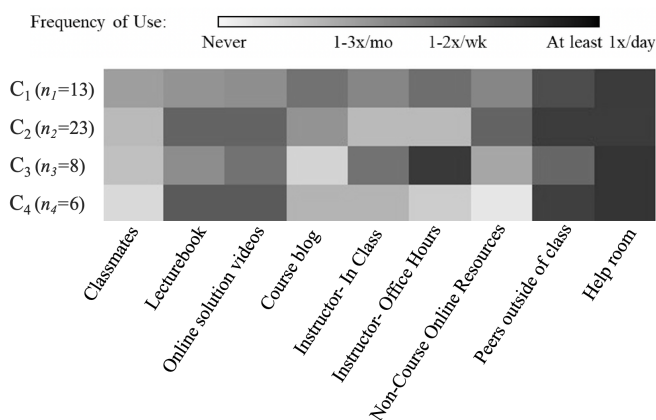

Fig. 1. Clusters of average resource usage frequencies at the adopting institution

A closer look at each of the four clusters at the adopting institution reveals distinctive features among clusters. Students of cluster C_1 used on average the course resources the most frequently. In addition, they displayed a more diversified usage pattern compared to the three other clusters. Conversely, students in cluster C_4 used the course resources the least frequently while displaying a concentrated resource usage pattern around the lecturebook, watching online solution videos, reaching out to peers outside of class and finally using

the help room. Students of cluster C_2 displayed a similar resource-usage pattern but with a more focused usage on additional online resources such as the course blog and non-course online resources such as Youtube videos. Students of cluster C_3 seem to prefer interactions with the instructor team over their peers. In fact, students in that cluster are the only ones who used instructor office hours frequently. Conversely, they are the ones who used the least their peers whether in class or outside.

These archetypical resource-usage patterns in the adopting institution differ notably from those of the original institution. In our previous work focused on the original institution of Freeform, we established that collaboration was a distinctive trait in students' resource-usage strategies (Dridi et al., 2022). Such collaboration was particularly salient in students' reliance on their peers in class as a major resource. However, students in the adopting institution approached collaboration differently as they relied more heavily on their peers outside of class. It seems though that the survey respondents might have interpreted "peers outside of class" not as students who previously took Dynamics but rather as interacting with their classmates outside of class. In fact, our interviews with the students at the adopting institution revealed that using the mobile group messaging app GroupMe was a constitutive feature of the students' culture at the adopting institution. This might explain why we see low usage of the course blog across the four clusters. Keeping in mind that the survey was distributed post pandemic, it is also reasonable to assume that a new culture of out-of-class online communication between students had become the norm. In addition, the students whom we interviewed made note of low attendance in class which was also confirmed by the course instructor. In such case, students might not have known each other and therefore had to turn to students who had previously taken the course for support.

Another notable difference between the two institutions resides in how frequently students at the adopting institution sought help from the instruction team (both the instructor and the TA team). In the original institution, our previous research revealed an avoidance mechanism from students towards the instructor and a perceived hierarchal power differential that might contribute to such avoidance (Dridi et al., 2022). In contrast, students from the adopting institution appear to be more comfortable reaching out to the instructor either in class or during office hours as well as to the TA team. This is reflected in our interviews with the students of the adopting institution who expressed a strong alignment with the instructor teaching and pedagogy. In addition, the interviewed students described the TA team as being a key factor in their success in class and recommended future students of the course to abundantly use that resource.
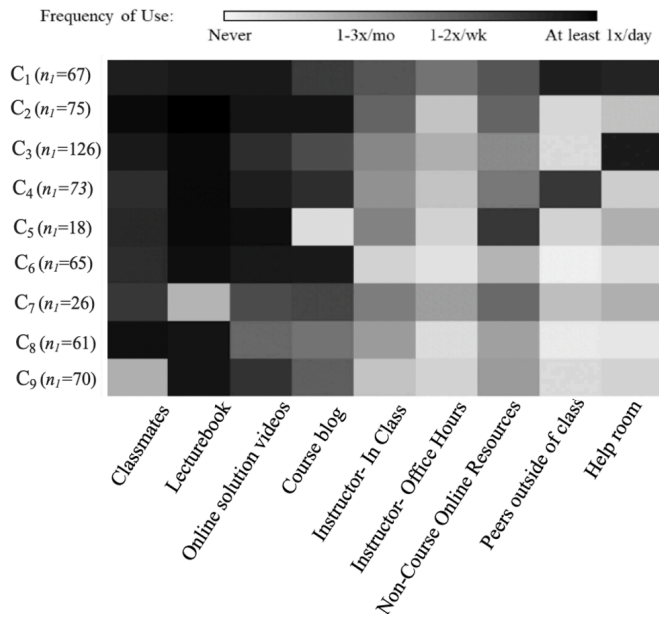
Fig. 2. Clusters of average resource usage frequencies at the original institution.

V. Discussion and Future Work

In summary, our analysis uncovered four main findings related to the archetypical resource-usage across both institutions. Students at the adopting institution 1) displayed fewer archetypical resource-usage patterns (i.e., a smaller number of clusters), 2) used Freeform core resources less frequently across all the clusters (i.e., average usage frequencies, 3) collaborated more with their peers who had previously taken the class, and 4) interacted more frequently on the instruction team (i.e., instructor and TAs). We offer two types of hypotheses to explain these four findings, namely contextual and cultural potential factors.

In terms of contextual factors, we noted that students mentioned in the interviews not being aware of the availability of online videos as one of the resources at their disposal. Since these videos offered solutions to typical homework solutions, it is fair to assume that students resorted to the help room more often to understand how to solve problems. Furthermore, it is also important to recognize that the Freeform implementation and associated data collection at the adopting institution was conducted post-pandemic, while our prior research study at the original institution happened pre-pandemic. This element might help contextualize the observed shift in students' resource-usage pattern in the context of the Freeform ecosystem.

In terms of cultural factors, we noted that students at the adopting institution felt closely supported by the instruction team and found the office hours with the instructor particularly helpful. This could be indicative of student-centric culture among faculty with an orientation towards in-person consultation with members of the instructional team. In addition, students' orientation towards help-seeking and

collaboration from students who previously took the course in the adopting institution suggest a distinct collaboration culture compared to the original institution where students had notable preference towards interactions with co-enrolled students.

National or societal cultures play a pivotal role in determining the dynamics of the classroom. One of the most significant aspects is the relationship between students and authority figures, such as instructors. In many Western cultures, there is a focus on egalitarianism, promoting open dialogue between students and teachers. Conversely, in many Asian or African cultures, there is a pronounced hierarchical structure, where teachers are seen more as figures of reverence, and challenging their perspectives might be viewed as culturally inappropriate. This cultural gradient can have profound implications for pedagogical innovations. For example, an innovation that encourages students to openly critique and question instructional content may thrive in a culture that values open dialogue. However, the same innovation may require substantial adaptation in a culture where such behaviors might be viewed as confrontational or disrespectful.

Both contextual and cultural factors point to the inevitable adaptation of pedagogical innovations to local characteristics of the implementation institution. Therefore, it is important for both pedagogical innovation designers and implementers to consider the idiosyncrasies of propagation settings before rolling out those innovations.

In previous work, we described how cultural consensus theory (CCT) can be used to characterize the unique cultural characteristics of both faculty and students. We also explored how those cultural dimensions converge or diverge with the design ethos of the Freeform ecosystem. In future work, we will use a CCT-based analysis to explore how student cultural characteristics explain their resource-usage patterns. Specifically, we will conduct a clustering analysis of the same students' sample using the cultural consensus analytical framework we developed previously (Berger et al., 2021) and assess to what extent the cultural clusters overlap with the resource-usage ones.

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