International Journal of Engineering Education Vol. 41, No. 4, pp. 1086–1101, 2025
Printed in Great Britain

0949-149X/91 $3.00+0.00

Early Career Engineering Instructors' Experiences with Freeform – An Innovative Instructional System: Acceptability and Feasibility*

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Even though empirical data from experimental studies is helpful in evaluating the effectiveness of learning technologies, it is equally important to understand the needs and experiences of stakeholders and their perceived effects in order to develop usable, feasible, and sustainable innovative instructional systems. Using guidance from social validity theory, this study examines experiences and perceptions of early career engineering instructors when they adapt the Freeform (Ff) system, which is an innovative instructional system consisting of instructional resources and instructional practices. Our analysis revealed that the goals of Ff for active, blended, and collaborative (ABC) pedagogies and student empowerment somewhat aligned with the instructors' aims and practices in their teaching. The instructors had more positive than negative experiences with adapting Ff. More importantly, the instructors reported that Ff system facilitated teaching activities both pedagogically and logistically and enhanced student learning. In addition, while the most frequently used components of Ff were the lecturebook and solution videos, the frequency of use and helpfulness of the other components varied depending on personal and contextual factors. Moreover, participating instructors' experiences revealed that Ff had the potential to align their instructional approaches with ABC pedagogies. The findings highlight the potential of adapting instructional systems to promote research-based instructional practices and offer practical implications for developing and adapting innovative instructional systems.

Keywords: new instructors; instructional systems; research-based instructional practices; social validity; instructor experiences

1. Introduction

In STEM education, the number of innovative instructional systems to support teaching and learning has been growing since the development of advanced computer technologies and the widespread use of the Internet [1–3]. While some systems serve only the purpose of managing instructional resources, the others aim to promote reformed instructional practices [4–7]. Despite the differences in the focus of the design, most of the systems aim to increase efficiency and performance for both instructors and students. Correspondingly, evidence that supports the effectiveness of innovative instructional systems in enhancing learning outcomes continues to emerge [8, 9].

Several studies show that students learn better when STEM instructors enact reformed instructional practices such as problem-based learning, inquiry-based learning, and active learning [10–16]. More importantly, STEM related careers demand the ability to solve problems collaboratively [17, 18]. Thus, higher education has been promoting the enactment of reformed instructional practices [19, 20]. Furthermore, there were efforts to achieve long term use of effective practices to benefit both instructors and their students [21]. However, reformed instructional practices that actively engage students are not often enacted in STEM classrooms [22–26].

The enactment of reformed instructional practices is often challenging for early career STEM instructors who usually have little or no teaching experience and do not have a well-developed teaching philosophy [27–31]. Further, instructors increasingly face responsibilities to prepare diverse

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* Accepted 18 April 2025.

students not only subject matter content and disciplinary skills but also social skills and life-long learning skills [32, 33]. Achieving the demands of those tasks is often challenging to early career STEM instructors who have neither the professional experience nor the required professional development courses to do so [23, 29, 34]. For instance, Auerbach et al. [27] compared the knowledge used by experienced and early career STEM instructors and found that early career instructors were less likely to notice opportunities for enacting active learning instruction.

Even though empirical data from experimental studies is helpful in evaluating the effectiveness of learning technologies, it is equally important to understand the needs and experiences of stakeholders and their perceived effects to support the development of usable, feasible, and sustainable innovative instructional systems. Since the ways instructors adapt instructional systems determine whether the systems achieve their intended effects, it is important to research how instructors use and perceive the systems. However, there is still a need for a better understanding of instructors' experiences and perceptions of acceptability and feasibility in adapting innovative instructional systems. Thus, this study examines experiences and perceptions of early career engineering instructors when they adapt Freeform (Ff) system, which is an innovative instructional system consisting of instructional resources and pedagogical ethos. The following research questions guide this study.

1. What are the experiences of early career engineering instructors regarding the acceptability and feasibility of Ff?
2. Which personal and contextual factors are relevant to instructors' variability in social validity perceptions and attitudes?
3. Which critical components of Ff are most frequently used by early career engineering instructors?

2. Theoretical Framework

This study is framed by the social validity theory [35, 36]. Social validity consists of three dimensions: the social significance of intervention goals, the acceptability of intervention procedures, and the importance of intervention effects. The *social significance of goals* reflects the extent to which stakeholders perceive innovation/intervention targets or goals to be consistent with their mission, roles, or objectives. The *social appropriateness of the procedures* (acceptability of intervention procedures) reflects whether stakeholders perceive the innovation/intervention to be enjoyable, relevant to school contexts, usable, and/or feasible. The *social importance of the effects* dimension references stakeholder perceptions regarding the nature and types of outcomes influenced by the innovation/intervention, such as student performance, enhanced teaching quality, or other relevant success indicators.

In the context of using innovative instructional systems where instructor attitudes and perceptions about the systems influence the success of the implementation, social validity is particularly important. Once instructors believe that the aim of a system aligns well with their instructional goals, the enactment is feasible in their contexts, and the system enhances student learning, they are more likely to accept it. With guidance from the social validity theory, our study will provide insights for the development of instructional systems to keep the end-users' needs in mind.

3. Methods

This study utilized a collective case study approach to gain in-depth insights into early career engineering instructors' experiences with an innovative instructional system [37, 38]. The case involved several instructors who were in their first five years of teaching; in other words, the bounded case was determined by the instructors' teaching experience. The focus of analyses was both within and across cases to unveil similarities and differences in complex experiences [39, 40].

In this section, we provide an overview of the Ff system and the context of the study. We then describe the data collection, and the methods used to analyze the data that generated findings regarding the acceptability and feasibility of adapting Ff. After that, we include the main limitations of the study.

3.1 Overview of Freeform

Ff is an innovative instructional system developed at a large public university in the Midwestern United States built on the integration of a variety of research-based pedagogical innovations and instructional resources. Regarding pedagogical practices, Ff uses active learning structures, blended learning models, and collaborative learning opportunities to support engineering teaching and learning [41]. In terms of instructional resources, Ff encourages students to leverage (1) a custom-written lecturebook that includes a concise description of the concepts, procedurally-oriented lecture example problems (with associated solution videos available online and linked through the course's learning management system), and end-of-chapter conceptual questions, along with ample white space in which students can write their notes, (2) solution

videos that show how to solve lecture examples and homework, (3) online discussion forum that serves as an asynchronous avenue for students to seek and provide help and exercise their social network, and (4) peers who formally or informally collaborate with them in learning activities [42, 43]. For instructors' use, the description of concepts in the Ff lecturebook is concise, and the availability of solution videos allows the instructor to deemphasize lecturing in favor of conceptual understanding and problem solving. Because of the synergies among the various critical components, Ff should be used as an integrated system.

Ff was developed to afford instructors the freedom to choose discrete pedagogical tactics and approaches to enact active, blended, and collaborative (ABC) teaching and to enhance student flexibility in resource usage. Table 1 shows a brief comparison of Ff and other leading instructional systems. Ff was originally developed for a key gateway course in several engineering disciplines (engineering mechanics – dynamics) and has since propagated to other key courses. Students often find dynamics course to be challenging because the content substantially expands their prior studies in physics in new and applied directions, and because the mathematics involved are sometimes complex. Thus, another goal of Ff was to enhance student success in the course and reduce the rate at which students withdraw or fail. One of Ff's approaches to improving student success was to strengthen their conceptual understanding before applying the concepts. Two designers of Ff taught dynamics to many students throughout their careers (cumulatively over 4000 students) and had a broad knowledge of students' needs. The design intention of Ff was to be flexible and adaptable for instructors and students, which meant the designers and research team held no expectation that instructors would implement exactly the way the designers would. This flexibility provides instructors and students agency to make their own decisions about how to best support student success.

3.2 Research Context and Participant Selection

The study took place at four institutions in the United States; all taught dynamics using Ff. Universities A, B, and C were medium-size teaching-focused institutions, while University D was a large research-focused institution. We selected early career engineering instructors who were in their first five years of teaching as faculty at their institutions. The selection resulted in ten instructors at four institutions. Table 2 shows the participants' pseudonyms and demographics. The selected participants reflect the diversity of early career engineering instructors at institutions in the United States. Some had prior teaching experience in the United States higher education, some had teaching experience outside the United States, and some did not have teaching experience. One instructor, Prof. Morris, had experience with Ff at University D as an undergraduate student and an instructor of record while doing their Ph.D. before starting their faculty position at University C. Four other instructors had experience teaching dynamics without Ff prior to the data collection of this study. Since we did not explicitly ask the instructors to identify their genders and that gender is not a considered factor of our analysis, we use the pronouns they and them for all the participating instructors.

3.3 Data Sources

The project has been funded by two consecutive grants that allowed us to create a unique dataset

Table 1. A brief comparison of Freeform and other leading instructional systems

Feature	Freeform	Blackboard	Moodle	Canvas
Type	Pedagogical and learning resource system	Learning management system	Learning management system	Learning management system
Pedagogical ethos	Active, blended, and collaborative	Not specific	Not specific	Not specific
Target use	Higher education (especially Engineering)	Higher education, corporate	All levels, especially worldwide	K-12, higher education, corporate
Strengths	Deep integration of pedagogy and resources	Institutional scale, analytics	Flexibility, open-source	Ease of use, integrations
Weaknesses	Limited scalability beyond core context	Interface dated	Learning curve, interface inconsistencies	Limited customization
Ease of use (for instructors)	High (within designed use cases)	Moderate to high	Moderate	High
Deployment	Integrated physical and digital resources	Cloud-based or self-hosted	Self-hosted or cloud-based	Cloud-based

Table 2. Participant pseudonyms and demographic

Instructor	Institution	Year of teaching	Exp. with Ff	Exp. with dynamics	Semester
Lee	A	1st	N	N	Fall 2020
Tapia	A	3rd	N	Y	Spring 2020
Chakyar	A	2nd	N	N	Spring 2022
Gonzalez	A	3rd	N	Y	Fall 2015
Pyon	A	5th	N	Y	Spring 2016
Reed	B	3rd	N	Y	Spring 2020
Morris	C	1st	Y	Y	Fall 2021
Collins	C	1st	N	N	Spring 2022
Torres	D	3rd	N	N	Spring 2018
Bouras	D	3rd	N	N	Spring 2017

spanning multiple years and institutions. In this study, we used only data from the instructors' first semester of adapting Ff to control for their (likely) greater acceptability over subsequent academic terms using the Ff system. The data consisted of onboarding interviews, notes of group onboarding meetings, implementation interviews, memos of the interviews, and written reflections. The goal of the onboarding interviews was to collect data regarding the instructors' background information, preferred ways of teaching, views on the dynamics course, and their students. Also, during the onboarding interviews, the Ff team answered instructors' questions about the Ff system and the support we could give. Only for University A, we had notes of a group onboarding meeting that occurred in-person in Spring 2015. The notes recorded the meeting agenda and the instructors' comments while the Ff team covering the Ff system ethos around ABC pedagogies and student empowerment and the available Ff instructional materials.

Implementation interviews were conducted during the first semester of Ff implementation for each instructor, and instructors shared their experiences using Ff, their observations of students' reactions to the resources and the teaching, their decisions about using and adapting Ff approaches and resources, and the effects of adapting Ff on the teaching and learning. Those interviews happened as often as weekly or as seldomly as twice during the semester. The interviews were conducted in person or over Zoom, with a duration ranging from 18 minutes to 62 minutes (around 38 minutes on average). Some of the interviews had memos created contemporaneously by the interviewers that highlighted the key points in the participants' responses and interpretations or comments of the interviewers on the responses. One instructor (Prof. Gonzalez) wrote weekly reflections to share their experiences and thoughts on the teaching of the week.

3.4 Data Analyses

Recordings of the interviews were transcribed by a professional transcription service and then checked and cleaned (if necessary) by the interviewers. Interview transcripts, interview memos, meeting notes, and written reflections were uploaded into Dedoose for analysis. Based on the social validity theory [35, 36], we first set up a set of parent codes under the overarching themes of social significance of goals, social appropriateness of the procedures, and social importance of the effects. We then read each transcript carefully to identify segments of the data that matched the codes (we did not code segments on the interview memos but read the memos before reading the corresponding transcripts to have a sense of the interviews and ensure we did not miss any important responses in the transcripts). While doing the first round of coding, we added and iteratively grouped emerging codes under the a priori codes, and we also created memos for some excerpts that we were not so sure how to code at that moment [44, 45].

More than halfway of completing coding all the data, based on the essence in the codes, our understandings of social validity theory and Ff system, we recognized some patterns in the emerging codes and decided to group and organize them into categories as in Table 3. We kept coding the rest of the data using the codebook. After that, we conducted a

Table 3. Overarching themes and categories from the coding

Overarching themes	Categories
Social significance of goals	ABC pedagogies Student empowerment
Social appropriateness of the procedures	Lecturebook Solution videos Online discussion forum Peers ABC enactment
Social importance of the effects	Effects on instructor Effects on students

cross-case analysis to find the salient shared and unshared experiences of the instructors [46]. The units for this round of analysis were not data files but the sets of excerpts belonging to the emerging child codes. By using this analysis process, we aimed to reveal the acceptability and feasibility of adapting Ff by early career engineering instructors.

It is worth noting that all the effects on instructors are perceived effects reported by the instructors based on their experiences. Similarly, the effects on student learning are perceived effects reported by the instructors based on their observations. In the findings, we include a subsection for effects on students because the social validity theory [35, 36] and the relevant literature show that instructors' perceptions regarding the effects of an instructional system on student learning affect their acceptability of the system.

4. Findings

In the following sections, we describe early career engineering instructors' experiences with the Ff system. The findings are presented by social significance of goals, social appropriateness of the procedures, and social importance of the effects. Within each of the three dimensions of social validity, we highlight both instructors' self-report experiences and their observations of students' acceptability. Overall, the goals of Ff system and instructors' aims for the course aligned quite well, the instructors and their students accepted Ff design, and the adaptation of Ff led to several positive effects on teaching and learning. Table 4 summarizes the findings, with further details provided in the following subsections.

4.1 Social Significance of Goals

4.1.1 Active, Blended, Collaborative Pedagogies

A major goal of Ff was to promote ABC pedagogies. There were some alignments in the goal of Ff and the instructors' aims for teaching dynamics. For example, University A had already established a culture for hands-on learning, which aligned well with Ff's aim to make engineering teaching more active. Like University A, University B's style of teaching was also hands-on, and they wanted to

Table 4. Summary of the findings

Overarching theme	Category	Strength	Weakness
Social significance of goals	ABC pedagogies	There were some alignments in the goal of Ff and the instructors' aims for teaching dynamics	Not all instructors saw ABC teaching as one of their priorities
	Student empowerment	Most of the instructors implicitly shared that they aimed to meet their students' individual needs both in and outside the classroom, which aligned with the goal of Ff to empower students	The instructors did not explicitly discuss student empowerment as one of their instructional objectives
Social appropriateness of the procedures	Lecturebook	Most instructors' experiences with the Ff lecturebook were positive, notably the content and organization of the book appeared to be helpful to instructors and students	Four out of ten instructors revealed that they faced some frustration or confusion
	Solution videos	Generally speaking, the early career instructors appreciated Ff solution videos and reported that their students found the videos to be helpful	Some instructors wanted more videos, especially more videos on practical scenarios
	Online discussion forum	Seven out of 10 instructors reported that their students used the online discussion forums to some extent	A few instructors conveyed that they did not know how to encourage their students to engage in the online discussion forums
	Peers	Some groups of students learned with and from their peers both outside and inside the classrooms	Instructors had limited influence over peer-to-peer interactions (especially outside of class)
	ABC enactment	Instructors' preference and aim of teaching approaches aligned quite well with Ff ethos for ABC pedagogies	There were constraints in making the classrooms more ABC oriented such as time and class size
Social importance of the effects	Effects on instructors	Ff has its potential to shift instructors' approaches to teaching toward promoting productive learning	One instructor reported that they were overwhelmed with the amount of preparation work and felt uneasy, and less confident in their lecture presentations
	Effects on students	There was a high consensus among the instructors regarding the positive effects of adapting Ff for their students such as becoming more active and independent and understanding the concepts better	There were no substantive weaknesses mentioned by the instructors

make their dynamics course more active, "[University B] tends to be a very hands-on place, and dynamics tends to be not one of the most hands-on classes that you tend to get" (Prof. Reed, interview 1). In addition, University B has been aiming to establish a culture of collaborative classrooms and their students started preferring group projects, which required student collaboration and collaborative learning pedagogies, "Students prefer group projects to individual ones" (Prof. Reed, interview 1).

4.1.2 Student Empowerment

Another goal of Ff was to empower students. Through providing a variety of instructional resources and blended learning opportunities, Ff offered students the affordance and flexibility to tailor resource use to fit their individual needs. Our analyses revealed that the instructors did not explicitly discuss student empowerment as one of their instructional objectives. However, most of the instructors did implicitly share that they aimed to meet their students' individual needs both in and outside the classroom. For instance, Prof. Collins said that they ensured students who missed their classes be able to catch up, and one of their supports was to send students the links of relevant Ff videos to watch.

4.2 Social Appropriateness of the Procedures

When first learning about Ff, there were mixed reactions from early career engineering instructors. For example, in the group onboarding meeting at University A, while a few instructors were hesitant to adapt Ff due to their perception of the workload, "it'll be a lot of work," or the instructional approaches, "we will have to change how our mind works, we'll have to connect the dots in a different order. It'll be a different dynamics," others were excited to start, "learn more and maybe incorporate into other courses" (onboarding notes). Based upon interviews conducted in the first few weeks of the semester, most instructors learned that the Ff pedagogical system (including resources and instructional practices) dovetailed with their preferred ways of teaching more than they had anticipated. For instance, Prof. Reed said, "Freeform is taught in the way that I was pretty much teaching statics [a prerequisite course for dynamics], but with even better things that make it shine better. . . In class, it's exactly the way that I like to teach" (interview 1). In addition, several instructors observed that their students had positive experiences with using Ff resources. Below, we present the instructors' experiences with each of the five Ff critical components.

4.2.1 Lecturebook

The most frequently used component of Ff was its lecturebook. Most instructors' experiences with Ff lecturebook were positive, notably the content and organization of the book appeared to be helpful to instructors and students. For example, Prof. Collins liked that Ff lecturebook gave students space to take notes, "I really like having book examples with the video solutions. I think the students are doing very well with that. I also think that having note taking space, essentially, in the book is very helpful" (interview 2). Another example was that Prof. Chakyar specifically liked the lecturebook because it had no 'extra' content compared to many commercial dynamics textbooks from publishers, which can be upwards of 600 pages. Similarly, Prof. Bouras liked that the content was condensed into a few pages with clear objectives. They said, "It's very good. It's very different than classic textbooks in dynamics. So, it has a completely different structure. The thing that I absolutely like about this book is that it just gets to the point" (interview 3).

Some instructors also appreciated the lecturebook's well-organized content, as Prof. Chakyar shared, "the book is much more well organized. For statics [another course], you have to give them [students] a very specific objective and tell them exactly what we're going to learn in a day, otherwise, if they look at the book, they're lost" (interview 2). More importantly, almost all the instructors reported that the content in Ff lecturebook made sense, "I didn't touch dynamics for 12 years perhaps. And I didn't remember anything. And going through that book was really, really easy. It was day and night compared to the book I studied when I was an undergrad" (Prof. Bouras, interview 1). Another positive perspective on Ff lecturebook was that the examples included in the book helped save instruction time, as Prof. Reed said,

> "Things that Freeform has definitely helped is the fact that there're the examples right in the lecturebook. That's definitely helpful because you don't have to be either pulling an example from the book or taking the time to kind of write everything down, you can just pull up the example and say, 'Okay, here's the example,' rewrite the text that they have into variable format. . . It allows you to kind of start more quickly that way" (interview 2).

On the other hand, four out of ten instructors revealed that besides positive experiences with using Ff lecturebook, they did face some frustration or confusion. Prof. Reed thought that some problems in the lecturebook were too abstract and not close enough to real world dynamics problems, or that were not easy to figure out how to solve them, "The

one thing that I've been less appreciative of Free-form is that some of the things seem to be very abstract. It might just be that I don't remember, but there were examples that seemed extremely, extremely abstract" (interview 2). A similar comment on the lecturebook was that Prof. Collins thought the book lacked guidance on how to select the correct method to solve a certain type of problem. In addition, two instructors reported that they had to spend time to get familiar with Ff materials. For instance, Prof. Gonzalez shared that they had to spend time to solve problems before class, "I feel like I am developing a new course because I am spending a lot of time working problems. I am working on all the problems in the workbook plus all the problems in the homework" (week 8 written reflection). Three instructors said that their students needed more time with the basics, so they had to spend more time with the content compared to the way Ff was designed. For example, Prof. Reed shared, "I need to spend more time up front in the basics. I spend more time showing some of the examples, doing more steps in it" (interview 1). Moreover, Prof. Pyon found a few errors in the Ff lecturebook that confused them. For instance, in a conversation with the developer of the lecturebook, Prof. Pyon indicated, "Homework 3.D and I'm just wondering if R, the capital R value should be given or not because I couldn't find numerical value for R, radius" (interview 3). Prof. Pyon was right, R should be given there [the Ff developer responded to the feedback and took notes of the errors].

Regarding instructors' observations of students' acceptability of Ff lecturebook, there were more positive comments than negative reports. Prof. Reed's students liked the examples included in the lecturebook and the solution videos. Similarly, Prof. Chakyar had a very positive perspective toward Ff for their student learning; they said that Ff resources helped more when students learned more complicated dynamics concepts and they particularly liked the overall flow of the lecturebook from particle kinetics to rigid body kinetics. Besides, Prof. Reed shared that the conceptual questions at the end of the chapters were really convenient for students as a way to study concepts for their upcoming tests. Whereas Prof. Gonzalez conducted an anonymous mid-semester survey with their students and learned that the material was hard for them, "The take home message was simply that the material is hard" (week 8 written reflection).

There were three individual and contextual factors that might have influenced instructors' and students' perceptions of Ff lecturebook. First, students' disciplinary background might have affected their engagement with Ff resources and overall outlook on the dynamics course, which in turn might have influenced instructional decisions. Prof. Chakyar and Prof. Tapia said that they had mostly civil engineers in the course; because the civil engineers did not have any follow-on courses for which dynamics was a prerequisite, the instructors seemed to think that the students were perhaps less committed to the course and less engaged with the materials. This perception affected the instructors' decision-making around the selection of the pace, the examples that they went over, the amount of time they spent reviewing, and in particular the complexity of the problems they picked. Second, some students preferred taking notes on Ff lecturebook, but University B switched over to a full rental system for all of their textbooks. Students paid a certain amount to rent all their textbooks, and these should be returned at the end of the semester without notes on them, which caused inconvenience for students who wanted to take notes on the Ff lecturebook. Third, instructors' perspectives on student preference might have affected their acceptability of Ff lecturebook. For instance, Prof. Chakyar thought their students liked practical examples, so they wanted Ff to provide more practical examples. They said, "I think it's really liked by the students, because with all the other courses I teach, I always try to implement practical examples. Students like it a lot. . . they're mechanical engineers, so they want to look and see stuff" (interview 5). Prof. Chakyar also added that their students did not complain about the lack of practical examples, "I just looked at the course evaluation yesterday... The students really liked the way the course was taught and all the examples that were solved in class. There was no comment about lacking practical examples" (interview 5).

4.2.2 Solution Videos

Generally speaking, the early career instructors appreciated Ff solution videos and reported that their students found the videos to be helpful. It seemed that solution videos were the second most frequently used component by early career engineering instructors. A couple of instructors used other sources of videos before adapting Ff, so they got used to sharing videos with students and had no issues using Ff solution videos. For example, Prof. Lee shared, "I used to use a lot of online resources, especially videos. I send students videos. I think that's a very good way to kind of combine different ways of communication" (onboarding interview). Similarly, Prof. Reed had a very positive perception about Ff resources; when asked what resources they thought were particularly useful for their teaching, Prof. Reed said all of them. Prof. Reed also noted that students appreciated that all the resources were

linked on the online discussion forum, and some loved the solution videos. In particular, one of their students told them Ff resources accommodated different learning preferences. Moreover, Prof. Collins noticed that students who came to office hours did work though solution videos, and they said the videos were helping them. Prof. Collins also pointed out that solution videos were very helpful for students when students missed class, "They can send me an email saying, 'What did I miss?' and I can say, 'Go over these examples.' That's been working really well" (interview 4). Similarly, instructors could use solution videos to support their students better. One example of this was the way Prof. Lee used solution videos to answer their students' questions via email; they commented,

> "There is a very big benefit. For example, if a student has a question about certain, let's say homework problem, and they'd not able to come talk to you during office hours, but they want to know how to do that problem. So sometimes it's pretty hard to explain dynamics problems over email. So, one nice thing about Freeform is I can always refer to some of the example videos or solution videos, and so I can send a link to students to tell them 'Okay, you will find the tools you need from this video, you can watch this and try that problem again.' This is very helpful, helps us to give students more in help" (interview 8).

Some instructors wanted more videos, especially more videos on practical scenarios. Prof. Chakyar said, "They [students] probably would have liked more videos explaining more practical scenarios . . . So maybe the next time I teach, I will probably try to create more videos, which would explain the same concepts, but do more of a practical background" (interview 5). Of relevance, a couple of instructors made some solution videos based on Ff videos but added more details so their students could follow more easily. On the other hand, even though Prof. Chakyar made a comment that their teaching had no conflict with Ff system, when asked about their use of solution videos and their students' use of the videos, they said they had never shown Ff videos to their students in class and did not know whether their students used Ff resources or not, except the lecturebook.

4.2.3 Online Discussion Forum

Seven out of 10 instructors reported that their students used the online discussion forums to some extent. For example, Prof. Reed said that their students used the online discussion forum to discuss difficult problems with peers, "I have had students using the course's online discussion forum to discuss some more particularly difficult problems of homework, so they have actually gone to the course's forum and discussed some of the homework problems" (interview 2). Prof. Reed also added that some students asked for help on the course's forum and other students responded by referring to certain solution videos. They noted, "there are a couple of comments on the course's forum where a student has said for this particular problem, check out this video, because this video is helpful in understanding it" (interview 1). Another example was Prof. Lee's statement that they encouraged students to use the online discussion forum when students could not meet each other in person, "I try to encourage students to use [the] online discussion board [forum] because they live in different areas, they may not be able to get together physically. . . that [online discussion] can work very well" (interview 3).

A few instructors conveyed that they did not know how to encourage their students to engage in the online discussion forums. For instance, Prof. Pyon said, "I don't know how to encourage the students to use that website [the online discussion forum] more and more. Sometimes I upload that [materials], but some of the students didn't even know it" (interview 3). Instructors at institutions that had an in-person help-seeking culture, such as Prof. Chakyar and Prof. Tapia, thought the easy access to instructors could certainly affect their students' use of the online discussion forums. They said that their students understood that if their office doors were open, students could stop by with no appointments to seek help. They expected that the online discussion forums might not have worked at their university due to the prevailing in-person help-seeking culture.

4.2.4 Peers

Ff system was designed to facilitate students learning with and from their peers. Our findings showed that despite the instructors' limited influence over peer-to-peer interactions (especially outside of class), at least some groups of students did learn with and from their peers both outside and inside the classrooms. For instance, as previously mentioned, Prof. Reed's students sought help from peers on their online discussion forum to solve challenging problems, and other students responded using Ff solution videos. Aligned with Ff's ethos for collaborative peer learning, in University A's group onboarding meeting, the instructors agreed that they wanted their students to learn with peers because "sometimes students can explain concepts to another student better than a faculty could" (onboarding notes). Correspondingly, Prof. Lee at University A said that they usually had in-class practice sessions where they asked students to learn with and learn from peers, "Hey, find a group of two or three and work on that problem together and discuss, teach each other, ask questions"

(onboarding interview). Prof. Lee also suggested students to study together when students do homework to prepare for exams, "Hey, when you're doing the homework self-prepare exams, find a study group and study together. That's a very efficient way to cover all the topics you may miss if you study by yourself" (onboarding interview). Similarly, Prof. Bouras at University D encouraged students to learn from peers, "I typically give them a group quiz or a group problem without any credit" (interview 1). Prof. Collins and Prof. Morris at University C also gave students many group quizzes as learning opportunities to exchange ideas and address their misconceptions.

4.2.5 Active, Blended, and Collaborative Enactment

In general, instructors' preference for teaching approaches aligned quite well with Ff ethos of ABC pedagogies. Prof. Lee, who had no prior experience adapting Ff, said that their teaching style was already aligned with the ABC ethos,

> "I tend to use a hybrid teaching style. I have combined the traditional and just lecturing with active learning [instruction]. I ask students to go act, read books or watch videos before they come to class . . . I encourage students to collaborate with each other and form small study groups or discussion groups" (onboarding interview).

Prof. Morris, who had experience adapting Ff in their teaching at another institution before the data collection of this study, acknowledged that Ff system might have shaped their teaching philosophy and teaching style. They shared, "My philosophy of teaching is very much an active learning experience" (onboarding interview).

Besides instructors' preferences for ABC, they did aim to enact ABC in their classrooms. Prof. Reed reported that they aimed to make their classes as active as possible, "I try to make things as active during the class period as possible" (onboarding interview). In addition, some instructors used group quizzes to make students collaborate. Prof. Bouras shared that they intentionally designed quizzes in ways that made students work with their peers, "I try to have them work in groups... The quizzes I give them cannot be done by a single person. They have to collaborate. I purposely design them so that one person cannot do them" (interview 1). Prof. Reed also liked giving group quizzes and they reported that the quizzes promoted collaboration among students, "it was a really great way to allow it [collaboration] to happen. So, I think that's something that I want to continue to do in the future" (interview 2). Instructors also used other tactics to promote collaborative learning. For instance, Prof. Collins used some of the conceptual problems in Ff lecture-book to facilitate in-class discussions among students and thought that the problems stimulated discussions that challenged students' intuition and exposed misconceptions they held. Both Prof. Collins and Prof. Morris mentioned several times in the interviews that they often use think-pair-share to make their teaching more active and collaborative.

However, there were constraints in making the classrooms more ABC oriented. One of the constraints was time, "we definitely have a class during which we don't do any activities... Sometimes we just have to catch up and go over a homework problem that was too difficult so there's no time to do anything else" (Prof. Bouras, interview 1). Another constraint was the lack of instructor awareness of practical or appropriate techniques to make classrooms more active, "I've been to that [on-campus] workshop on how to use active learning. I've tried using a lot of these techniques, but they just seem very awkward, very awkward. I mean then they just... I just don't like it" (Prof. Bouras, interview 1).

Class size was another possible constraint to ABC teaching. Prof. Chakyar pointed out that small class size enhanced their ability to make learning activities more interactive, "since the class size was small, there was a lot more interactions . . . I got to speak a lot with students, and then we also happened to talk about a lot of other things other than dynamics" (interview 5). Likewise, Prof. Reed said that their class size influenced their approach to collaborative teaching. They asked students to do a whole class discussion to come up with a solution for a challenging problem. The students engaged in energetic discussions, as they said, "for some students, there was a little bit of waiting for the smart [sic] students to say something, but for the most part it was just a lot of, 'No, I think it's gotta be like this because of this reason'" (interview 2). Prof. Reed loved the way their students worked collaboratively and planned to continue using whole class discussions. They emphasized that they would have not done so if they had more students,

> "Because my classes are small enough, I can do this [whole class discussion]. So, I only had about 20 students in the room, it's not like a [University D] 100 student class, it's a 20-student class. Therefore, having all 20 students work together is not unreasonable or at least allowing them to kind of come to a consensus class-wide" (interview 2).

Another contextual factor regarding enacting ABC teaching that Prof. Chakyar mentioned was the natural progression of the course. Earlier in the semester, their students focused more on listening to concepts and taking notes. The students were

more interactive near the end of the course, "there were a lot more interactions during the end of the semester, which I really liked. They got really comfortable with the course . . . They kind of started questioning the concepts and all that, which is really good" (interview 5).

Interestingly, some early career instructors reported that compared to active and collaborative teaching, it was more challenging for them to make their dynamics course blended because they often needed to mention the online discussion forum and solution videos. Students tended not to watch Ff solution videos unless the instructors reminded them, as Prof. Chakyar said, "I'm not sure if anyone really watches videos every day unless I tell them" (interview 1). And some of the instructors did not remember to often remind students. Prof. Tapia forgot about the resources like the videos. They explained, "I forget to talk about them because I don't look at them as much as I did because I don't need them as much, as I feel more comfortable with the content." And Prof. Tapia suggested themselves and other instructors to review the available resources, "as you use the resources, refresh yourself of what those resources are . . . Just kind of a periodic review of what the resources are and some of the topics that are in there, would be good." This suggestion stemmed from their experience with the usefulness of the resources for blended learning, "I think that they were more useful to my students before, when I was more focused on them [the resources] and talked more about them" (interview 5).

4.3 Social Importance of the Effects

4.3.1 Effects on Instructors

Some instructors noted that Ff has its potential to shift their ways of teaching toward more productive learning. For example, Prof. Chakyar shared that before adapting Ff, they spent a lot of in-class time going through slides they made from a commercial textbook and did not have time to show students how to solve example problems. With Ff resources, where all students had the lecturebook, Prof. Chakyar could tell students beforehand which problems they would solve in class and then went through the problems. More importantly, the change in instructional activities led the instructors to realize what was more productive for student learning, "I realized the more problems I solve, the better it is for students, and this Freeform really helps with that. So, we have a large variety of problems, and also we have the [online video] solutions... And so it really helps" (interview 1).

Another compelling effect of adapting Ff was that the instructors had more time to interact with students and get to know them and know their progress better, as Prof. Gonzalez wrote in their reflection, "I had more time than I anticipated. I contributed this to the short time I spent giving the lecture . . . It provided me an opportunity to interact with the students and gave me an understanding of their comprehension level" (week 2 written reflection). Similarly, Prof. Collins said that using the Ff lecturebook, supported by the online solution videos, increased the efficiency of teaching and learning for both instructors and students because they wrote less (i.e., reproducing figures and diagrams from a textbook) and discussed concepts more.

Additionally, with Ff resources, multiple instructors reported that they did not need to guide students on everything and that Ff enabled them to focus on important competencies like solving problems. For example, Prof. Chakyar stated that they did not spend a lot of time talking about mathematical rules because Ff lecturebook, as well as the online solution videos, covered the information already, "I explain the concepts, and then I solve as many problems as possible. I think students learn better when we solve more variety of problems. So, I just go problem by problem from the textbook [Ff lecturebook]" (interview 1). Later that semester, Prof. Chakyar shared that their students were very positive about the Ff approach, and they would be assigned to teach the course again, "I think I did a good job, at least with dynamics. That's a relief, actually. I think based on the evaluations, I guess I'll be teaching it again" (interview 5). Likewise, at the end of their first semester teaching dynamics, Prof. Lee stated that they had a sense of accomplishment because they succeeded in their first experience as the instructor of record, "I feel a sense of accomplishment. This is officially the first semester I delivered the lecture by myself. I think I'm glad this semester went smoothly, and students are happy. At least I didn't hear any complaints" (interview 16). Another effect of the Ff system was that instructors had more flexibility when they needed a substitute because they could easily adjust the pace of the class prior to the absence.

Although less prominent than other effects in terms of the number of instructors expressing an idea, Prof. Reed shared that they learned from Ff how to create videos for their teaching. They said that two years before adapting Ff, they wanted to start creating example videos for their students, but they were not comfortable doing it and had not taken the time to learn how to create videos. Ff solution videos gave them suggestions and motivation to start creating their own videos, "I was able to more easily understand what can go into making

videos for students, what things can be helpful for students and kind of learning more how to do that'' (interview 2). Prof. Reed also acknowledged that creating videos took a lot of their time, ''it [making videos] created a large workload for this semester in trying to do those things'' (interview 2).

Almost all instructors expressed that the implementation of the Ff system made the process of preparing for classes easier and faster for early career instructors because they knew what they needed to cover in each lesson, as Prof. Collins stated, ''we're all sticking to the same schedule, so I know exactly, and on that note, not just the same schedule, but we're covering the same examples, so going into each lesson, I know exactly what I need to cover'' (interview 3). Ff also helped save preparation time, especially for the instructor who already had experience with Ff. For example, Prof. Morris shared, ''Freeform allows me to have more time on other things . . . Lesson prep and that sort of thing doesn't take as much time as some of my colleagues said their first semester took, because I've taught in the environment before'' (interview 2). Another instance was that Ff reduced the amount of time instructors needed to prepare for the course because they could watch solution videos when they were confused with the steps of solving some problems, ''whenever I'm confused with the procedure, I do watch the videos'' (Prof. Chakyar, interview 2). Similarly, Ff resources supported some instructors in exam preparation.

Moreover, some instructor reported that Ff provided them the resources for animation, homework assignments, solution videos, and visualizing videos so they did not need to reinvent everything. Prof. Reed stated, ''I'm the kind of person where I don't like to reinvent the wheel. If there's something that works, I want to take the working thing and improve it or implement it and see how I can adapt it to my context'' (interview 2). Prof. Reed added that Ff system assisted them in making instructional decisions, ''I don't have to figure out what is a good technique. I don't have to spend time researching what is something useful to add to this particular aspect of the course'' (interview 2).

On the other hand, Prof. Gonzalez wrote in their reflection that they were overwhelmed with the amount of preparation work and felt uneasy, and less confident in their lecture presentations because they did not know the materials well. They wrote, ''I feel like I am treading water most days because I'm only one step ahead of the students. . . I have not had the time to look at the material for future lectures or lay out a plan of action'' (week 9 written reflection). Therefore, they used both Ff materials and their own materials (with which they were more familiar).

4.3.2 Effects on Students

There was a high consensus among the instructors regarding the positive effects of adapting Ff for their students. Prof. Gonzalez stated that their students were more active and independent, ''the nice thing about the Freeform was that the students were able to work until the end of class without me having to stop to provide the solution because the solution is available [as a video] online'' (week 1 written reflection). More importantly, in their reflection a week later, Prof. Gonzalez shared that their students understood the concepts better, ''I noticed that students focused more on the assignment and gained a deeper understanding of the topic'' (week 2 written reflection). Similarly, Prof. Tapia said that they made some typos or mistakes while showing how to solve lecture example problems in class, and their students caught a lot of the mistakes throughout the semester that showed they could follow the lessons well and understood the concepts, ''that's really valuable for them to be able to catch mistakes. That shows that one, they're paying attention and two, they understand the concepts, that the steps are making sense, and they're trying to justify what's going on'' (interview 5). In addition, Prof. Reed reported that their students performed well in a review session for the midterm exam, ''students asked many good questions and had some really good understanding of the content'' (interview 4). Moreover, Prof. Chakyar thought that their students learned better using Ff, ''I mean initially I was very apprehensive [about using Ff], but now I like it. Students learn better when we teach this way'' (interview 2). At the end of the semester, Prof. Chakyar reported that their students earned high scores in the final exam with an average score of 82, ''the students did way better than I expected in the exam'' (interview 5).

Ff also increased efficiencies when students asked for support from the student support centers. Prof. Reed at University B shared that they told their students that they could get help from tutors at the student support center, but then they learned that because the department had different instructors teaching dynamics each year, it was challenging for the tutors to support students, ''apparently because we've had a different faculty member teach dynamics every term that we've had dynamics here, the tutors are lost when trying to help the students this time around'' (interview 1). Further, Prof. Collins said that adapting Ff made all the instructors of dynamics sections at University C use the same materials, same schedule, same quizzes, and teach their sections in really similar ways, so when students needed to seek help from the tutoring center, it was much easier for them to get effective assistance.

5. Discussion

Our analysis revealed that the goals of Ff for ABC pedagogies and student empowerment somewhat aligned with the early career engineering instructors' aims and practices in their teaching. The instructors had more positive than negative experiences with adapting Ff. More importantly, the Ff system did facilitate teaching activities and enhanced student learning. While it seemed that the most frequently used components of Ff were the lecturebook and solution videos, the use and helpfulness of the other components varied depending on personal and contextual factors.

5.1 Instructional Systems Have the Potential to Promote Student-Centered Instruction

Instructors reported that the Ff system made it easier for them and their students to engage in ABC pedagogies and conceptual understanding. Specifically, several instructors reported that Ff system helped them have more time in the classroom to engage with students and promote conceptual understanding. The finding is consistent with prior research showing that innovative instructional systems have the potential to facilitate the enactment of student-centered pedagogies [47–49]. Specifically, Prof. Morris explicitly shared that Ff influenced their teaching philosophy, and Prof. Chakyar said that Ff helped them realize that using a large variety of problems was more productive for student learning. The findings show that Ff enabled early-career instructors to engage in student-centered pedagogies because of the diverse yet complementary instructional resources, ABC pedagogical tools, and overall ethos. The implication here is that innovative instructional systems have the potential to influence new instructors' teaching philosophy and teaching styles and make engineering teaching more student-centered. Given the lack of student-centered instructional approaches enactment in STEM classrooms [22, 23, 25] and the role of student-centered instructional approaches in enhancing student achievement [10,15], the potential of innovative instructional systems to promote student-centered teaching is valuable.

In addition to providing early-career instructors a platform on which to build their student-centered practices, Ff also helped them reduce the amount of time needed for teaching preparation. Given the workload and stress early career engineering instructors might face [27, 31], we assume that saving preparation time would give the instructors at teaching-focused institutions more chance to focus on important aspects of their teaching such as designing and refining classroom activities that engage students in active and collaborative learning. In addition, it is worth noticing that the adaptation of Ff facilitated early career engineering instructors to focus on fostering student problem-solving skills that are highly important for STEM careers [50].

5.2 It is Important for Instructional Systems to Offer a Variety of Components

Early career engineering instructors generally found Ff to be an acceptable and feasible instructional system for teaching dynamics courses. Furthermore, the instructors' social acceptability of Ff's critical components was diverse, some appreciated a certain component while others preferred other components. While most of the instructors expressed many positive sentiments regarding the usefulness of the Ff lecturebook, Prof. Gonzalez was overwhelmed with the process of solving example problems in the book to prepare for their teaching. Prof. Chakyar found that Ff solution videos could help with solving practice problems in the lecturebook. Specifically, they said that whenever they felt stuck, they watched the videos to find the solutions faster. Even though it was unclear why Prof. Gonzalez did not use solution videos to help them; it was clear that the various components of Ff were useful to some instructors. Since the social validity of instructional systems plays a foundational role in adopting decision and sustainable use [51, 52], it is important for instructional systems to offer a variety of components so instructors can adapt in the way that works for their preference and their classroom contexts. Ff accomplished this by providing five critical components (i.e., lecturebook, solution videos, online discussion forum, peers, and ABC ethos).

Besides offering a variety of resources, findings from this study show that a few instructors were not fully aware of how to leverage all Ff resources. Some instructors often forgot to remind their students to watch solution videos and engage in online discussion forums. Given that the instructors usually did not have many resources to serve their teaching, and that blended teaching was not their common experience (all the data were collected prior to the pandemic or during the pandemic), it made sense why some instructors did not devote attention to those components of Ff. Moreover, most of the instructors in this study taught at institutions where students could easily access instructors in-person via office hours. Thus, it is important to offer ongoing support so instructors can leverage available resources that work for them. Furthermore, the findings suggest innovation instructional system developers should ensure instructors understand the intention of the design. Ff was developed to provide instructional resources

and to promote ABC teaching in an integrated and synergistic way, but some instructors tended to use Ff as a set of instructional resources without fully embracing the ethos of ABC pedagogies. To effectively adapt instructional systems in their teaching, instructors need to be familiar with the system, including the system's content and how their students interact and navigate the system [53]. Even though we support instructor-driven adaptation that promotes their expertise and agency, our findings show that most of the instructors did not fully leverage the potential of Ff.

5.3 Keep Personal and Contextual Factors in Mind While Designing Instructional Systems

Our analysis shows that instructor perceptions about the acceptability and perceived effects of Ff varied across contextual factors, such as class size, student background, established culture for collaboration, and student expectations and preferences about content framing (i.e., conceptual versus procedural knowledge). This is similar to findings from some other existing studies [54–56]. While it was clear that the instructors generally perceived Ff to be an effective and promising instructional system, some instructors expressed that the enactment of Ff's ABC ethos was easier with smaller class sizes. The instructors commented that classroom activities that engage students in active and collaborative learning such as group quizzes and whole class discussions worked better when they have 20 or 30 students rather than 100 or more students. Thus, contextual factors need to be taken into account when developing instructional systems. Ff was explicitly designed to be a flexible system that empowers users (both instructors and students) to adapt it to their context. In addition, even within the same institution, the personal preferences of the instructors varied. Developers of instructional systems cannot assume that their systems will be viewed in the same way by all instructors, even within the same context. To optimize success, it is ideal for instructional systems to allow adaptive implementation that makes the goals, procedures, and effects of the system relevant to users' preferences and learning contexts [35, 36].

One approach to designing instructional systems that meet users' needs is to use the guidance from design-based research framework [57] and include users in the design team. Instructors are the ones who know their classroom requirements best, so they can be key partners in the development process. Even though design-based research is time-intensive and resource-intensive, to create systems that work best for instructors, it is recommended to collaborate with instructors to some extent. In other words, in the case where full design-based research is not feasible, instructional system developers should still consider instructors' perspectives on the social validity of the system. One example of a good instructional system that allows instructors to customize their use is the Science Practices Innovation Notebook (SPIN) [5]. On SPIN, instructors can edit available resources or input their own materials for science teaching. SPIN also offers editable scaffolds so instructors can give appropriate support to students.

The broad contexts of institutions might affect the efforts to adapt a new pedagogical system. For example, University B changed to renting all textbooks prevented students from taking notes on the Ff lecturebook, which was designed to provide students the space to take notes. It seems that systematic changes might require modifications of instructional systems. On the other hand, the adaptation of a new pedagogical system might result in effectiveness not only for the department that adapted the system but also for other parts of the university. For instance, the finding shows us that it was more convenient for the student support centers at University B and University C when the instructors adapted Ff. The benefits of adapting instructional systems might go further than the departmental level, and the large context of the institution might need to be considered.

6. Conclusion

This study sheds light on the social validity perceptions and experiences of early career engineering instructors when adapting Ff for the first time during a semester. Overall, the instructors' experiences were more positive than negative for the acceptability of Ff goals, its components, and its effects on teaching and learning. The instructors reported that not only did Ff facilitate their planning and preparation work and increased the effectiveness of instruction in the classroom, but Ff also promoted student learning. Moreover, the instructors' experiences revealed that Ff had the potential to align their instructional approaches with ABC pedagogies. The findings highlight the potential of adapting instructional systems to promote research-based instructional practices and offer practical implications for developing and adapting innovative instructional systems.

Funding – This material is based on work supported by the National Science Foundation, Division of Undergraduate Education under Grant Number 1915574. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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