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How Engineering Faculty Interpret Pull-Oriented Innovation Development and Why Context Matters*

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Faculty development programs often operate as platforms for disseminating pedagogical innovations amongst engineering faculty, but adoption of these innovations into engineering classrooms has been less than desirable. Such issues of low adoption are partially due to the limited opportunity faculty have to pull innovation development towards their unique instructional contexts. However, little research to date has focused on understanding how engineering faculty would interpret such an opportunity to pull innovation development with their own curriculum in mind. The purpose of this study is to investigate a faculty development program wherein engineering faculty collaboratively developed curricular innovations for their mechanics of materials classroom with guidance from research on common student misconceptions. To explore the co-development of innovations, we conducted multiple interviews with the engineering faculty participants throughout the academic year. Participants interpreted this program and their co-developed curricular innovations as providing them with resources they needed to make curricular changes. Findings also demonstrated that faculty adoption of curricular innovations is highly influenced by context. By allowing faculty a greater role in the innovation development process, these contextual issues are more readily addressed. This study provides rich and detailed insight into how certain faculty approach adoption within their own contexts, which can improve faculty development and dissemination of pedagogical innovations in the future.

Keywords: faculty development; adoption of innovations; pedagogical innovations, mechanics of materials

1. Introduction

Engineering education reform efforts have traditionally focused on faculty development programs that disseminate research-based pedagogical innovations to engineering faculty [1]. Faculty development programs are a type of professional development for teachers that often takes the form of workshops, seminars, and/or conferences lasting anywhere from a few hours to several days [2]. These programs aim to increase the awareness of research-based pedagogical innovations amongst engineering faculty and provide them with the training to adopt these innovations in their classrooms [1]. By engineering faculty, we mean teachers or instructors in higher education who teach engineering related courses.

Research-based pedagogical innovations are teaching strategies, materials, and/or resources shown to have positive influence on student learning by educational researchers [1, 3]. Common examples of such innovations are active learning, inductive learning, and hands-on curriculum that often serve as alternatives to lecture-based teaching [4, 5]. Implementation of these innovations into undergraduate engineering curriculum has demonstrated enhanced student learning, engagement, and long-term retention in engineering programs [6]. Existing approaches to faculty development have continued to push these innovations onto engineering faculty in the hopes of increasing their use in undergraduate engineering programs. However, these recommendations are often made with relatively little consideration of instructors' unique contexts and how that might influence implementation in practice [7].

The purpose of this paper is twofold: (1) present a unique faculty development approach wherein engineering faculty can pull pedagogical innovations towards their contexts and (2) understand how the participating faculty interpret such an approach. By *pulling towards contexts*, faculty help guide the development of pedagogical innovations and choose how they wish to adopt them within their curriculum. Therefore, context can be thought of as not only the physical classroom space and course structure where faculty adopt pedagogical innovations, but also as encompassing institution type and size, teaching experience, and what faculty believe to be important in how they develop and adopt innovations within their existing curriculum. This model of faculty development stands in contrast to other approaches that *push* educational innovations onto faculty.

To investigate this space, we collected data from engineering faculty across the United States who participated in an annual, two-day summer workshop over a period of three years. The primary goal of the workshop was to provide space and support for faculty to co-develop innovative educational tools that would improve student engagement in

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mechanics of materials. Research on common student misconceptions in mechanics of materials guided the development process [8]. These innovations went through multiple iterations at each subsequent workshop based on lessons-learned during the academic year. This process led to a set of curricular tools iteratively developed by engineering faculty with their own unique contexts in mind. Following the third workshop, interviews with the faculty participants throughout the academic year explored their perceptions and experiences with adoption of their various curricular innovations. The purpose of this research is to describe those aspects of a pull-oriented innovation development program that faculty perceive as influential in their adoption processes. Thus, we pose the following research question:

How do engineering faculty interpret curricular innovations that they developed and attempted to adopt within their contexts during the academic year?

2. Literature review

Within engineering, educational researchers are often the primary developers of research-based pedagogical innovations. One reason for this is engineering faculty often have other research interests that limit the time and resources they can contribute to education research and developing their own curricular innovations [9, 10]. Thus, innovations in education often emerge from discoveries on student learning by education researchers rather than from emergent faculty issues or experiences in practice [11]. Importantly, the former may not necessarily align with the latter. For example, active learning as a pedagogical innovation in itself and the curricular innovations developed to facilitate active learning, such as clicker questions [12], emerged from research on student learning in interactive and engaging environments [13], but has not always aligned with the technological capabilities that faculty and/or their classrooms possess [2, 7]. A deeper consideration of instructors' situational needs can help inform educational development in ways that leverage and work with existing contexts.

The most common mode of innovation development is characteristic of a push-oriented model, i.e., one in which the *push* of scientific discovery by researchers drives the development of the innovation [14]. The premise being that innovations developed in educational research will in turn create opportunities for improved approaches to teaching and learning in practice. Faculty are then trained on how to adopt these research-based innovations into their classrooms through faculty development programs, such as ASEE's National Effective Teaching Institutes (NETI) and ASCE's Excellence in Civil Engineering Education (ExCEEd) workshops. While participant satisfaction surveys of faculty who attend these and other similar workshops have demonstrated that engineering faculty perceive these programs as improving their teaching [15, 16], there is often little to no direct evidence of faculty actually adopting the research-based innovations they learn about at these workshops [9]. In fact, other survey studies have indicated a significantly greater awareness of these innovations than their actual adoption into the engineering classroom [9]. Thus, these faculty development programs appear to be somewhat successful at disseminating information on research-based pedagogical innovations, but engineering faculty encounter barriers that limit their adoption of these innovations in practice. Herein, adoption means the implementation of these innovations into the classroom with some degree of fidelity to the original intention behind the innovation.

The barriers that engineering faculty face when adopting innovations can vary greatly across their individual contexts. Situational conditions such as class structure and the nature of the course content, along with personal factors and preferred modes of teaching, lead to a variety of factors that influence how engineering faculty perceive innovations and approach adopting them [7, 9]. The push-oriented model of innovation development allows for broad dissemination and frees engineering faculty from having to dedicate their own time and resources towards developing innovative pedagogy and curriculum. On the other hand, it has limited the ability of faculty to *pull* innovation development towards their unique contexts [7, 17]. In contrast to the push-oriented model, a pull-oriented model to innovation development is one where consumers (i.e., faculty) *pull* innovations towards their demands [14]. Rather than research and innovation driving practice, this approach positions practical problems and needs as the driving force for further development. Some of the key differences between the push and pull-oriented models of innovation development in education are presented in Table 1.

This push versus pull dichotomy emerged from economics literature to describe innovation development and dissemination in a wide variety of industries since the mid-twentieth century [14]. The push model is linear, beginning with innovation through peer-reviewed research and then broadly disseminating the innovation to faculty with training and curricular materials through workshops, seminars, and conferences [2, 11, 14, 18–20]. In contrast, a pull-oriented model offers an approach

Table 1. Push vs. Pull Oriented Models of Pedagogical Innovation Development

Push-Oriented	**Pull-Oriented**
Education researchers develop innovations.	Faculty develops innovations.
Developers or administration mandates adoption decisions.	Faculty makes adoption decisions.
Faculty attempt to adopt with their own time and resources.	Faculty attempt to adopt and can request additional resources as needed.

that is inherently more accommodating to the individualized nature of instructional practice [17]. However, to date there have been no explicit applications of pull-oriented models to pedagogical innovations. This has led to engineering faculty having limited input as stakeholders in their own professional development, while still being expected to adopt pedagogical innovations in a wide variety of contexts [8, 17]. Nevertheless, the push-vs-pull model aptly describes the status quo for pedagogical innovation development and dissemination and, importantly, points to the potential for improving innovation adoption through pull-oriented methods.

Pull-oriented models, however, have received considerably less research attention from innovation scholars and economists. This arises in part because human needs are unpredictable, unlimited, and based on individual contexts, making pull-oriented models less suitable for quantitative methodologies [14]. For example, when faculty adopt innovations they adapt them within their contexts, which leads to adoption taking many forms unique to the individual. Sometimes the extent to which a faculty might adapt an innovation (i.e., pull it toward their context) can leave the original innovation unrecognizable [9, 21]. Therefore, investigation into how and why faculty modify and/or go about creating their own curricular innovations could provide a broader understanding of how individual faculty contexts influence innovation development and adoption decisions [22]. The following section presents a faculty development program that provided the opportunity for exactly this type of investigation.

3. Background

The faculty development program took the form of an annual two-day summer workshop wherein engineering faculty and engineering education researchers collaboratively and iteratively developed curricular innovations specifically geared towards mechanics of materials courses. Mechanics of materials—also known as solid mechanics or strengths of materials—is a common sophomore level course for civil and mechanical engineering students that deals with the physical behavior of solid objects, such as steel beams, subjected to stress and strain under various loading scenarios. The engineering education researchers consisted of other engineering faculty and engineering graduate students who conduct research in engineering education.

The program focused on mechanics of materials because the engineering education researchers that attended the workshops had conducted extensive research on a range of critical misconceptions made by students in this area. The nature of these misconceptions is beyond the scope of this paper, but the purpose of the workshop was for mechanics of materials faculty to develop curricular innovations aimed at engaging students in novel ways around challenging concepts. In this way, research-based findings on student learning in mechanics of materials guided the curricular innovations developed at the workshops. (For those interested in the specifics of this guiding research on student misconceptions, additional reading on the topic is available in [8, 23–27].)

The first day of each summer workshop began with a presentation on any relevant new research on engineering student learning specifically pertaining to mechanics of materials. Following this there was a round table discussion amongst the attending engineering faculty and education researchers. During this discussion, the attending engineering faculty were encouraged to share their own classroom experiences teaching mechanics of materials and how their adoption of previously developed curricular innovations went during the past academic year. From this discussion, the attending engineering faculty identified specific contextual needs to help guide the development of innovations and/or iteratively improve existing innovations developed at previous workshops. The remainder of the first day and second day were then for the attending faculty to collaboratively develop their curricular innovations. The innovations developed by the faculty at these workshops were a set of manipulatives and accompanying worksheet activities. Since mechanics of materials often focuses on how solid objects deform, the manipulatives developed at the workshop often took the form of elastic materials, such as foam and/or rubber beams, that are deformable by hand to observe various forms of

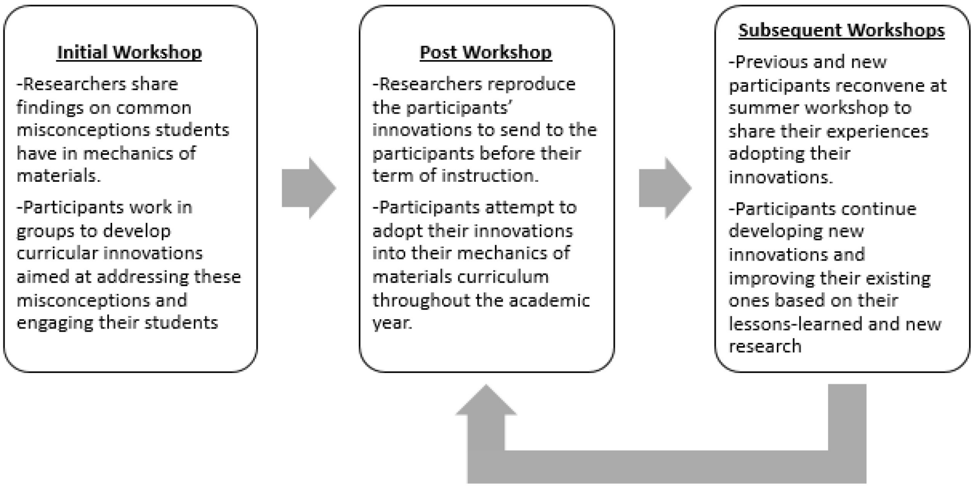

Fig. 1. Main activities at the initial workshop, post workshop, and subsequent workshops.

stress and strain. After the workshop and before the beginning of the academic year, the researchers replicated and shipped any physical innovations created at the workshop to the institutions of the workshop-attending faculty for them to adopt into their mechanics of materials curriculum. Any digital innovations, such as video or worksheet guided activities, were accessible to the workshop-attending faculty through a shared online folder. Fig. 1 presents a general outline of events that took place throughout this series of summer workshops.

The intention of this faculty development workshop was to provide engineering faculty with the opportunity to incorporate their individual needs to pull innovation development towards their contexts. The idea here being that if faculty have greater ownership over the development process and can create innovations they need in their particular mechanics of materials courses, they will be more likely to adopt them. Following the first two summer workshops, the research team facilitated a roundtable discussion among the practitioners to better understand their concerns or limitations to adoption and develop potential solutions for addressing those issues in the upcoming academic year [28]. During the discussion, faculty converged around three primary aspects to improve the adoptability of their previously developed curricular innovations. These included:

1. *Adaptable innovations:* This consisted of being able to tailor existing curricular innovations so that faculty felt capable of adopting them within their own unique contexts. For example, some faculty felt the worksheet activities demanded too much of their class time, and therefore wanted activities that could be readily shortened and/or adopted in tandem with a specific activity.
2. *Student kits:* The participants wanted enough replicas of their previously developed manipulatives to put into each of their students' hands. This led to the creation of a student kit that contained a set of manipulatives. Each participant received a student kit for each of their students before their term of instruction.
3. *An aide:* The participants expressed sometimes needing additional support during the academic year with adopting their curricular innovations. The researchers employed two undergraduate research assistants for the participants to contact at any time if they needed any help or additional materials during their term of instruction. These undergraduate research assistants participated in the development of these curricular innovations and were therefore familiar with their purpose.

These adaptable innovations, student kits, and aides are the most salient aspects of the curricular innovations that emerged from the contexts that the attending engineering faculty expressed. While the manipulatives, worksheet activities, and student kits created are clearly physical curricular innovations, the aides were a human resource that the participating faculty wanted for real-time support during their adoption process. In this way, the aides are another curricular innovation that the participating faculty pulled towards and based on their contexts. Fig. 2 presents some of the curricular innovations developed from the workshops, including the contents of the student kits.

4. Methods

The researchers interviewed the participants throughout the term they implemented the innovations to answer the research question: *How do*

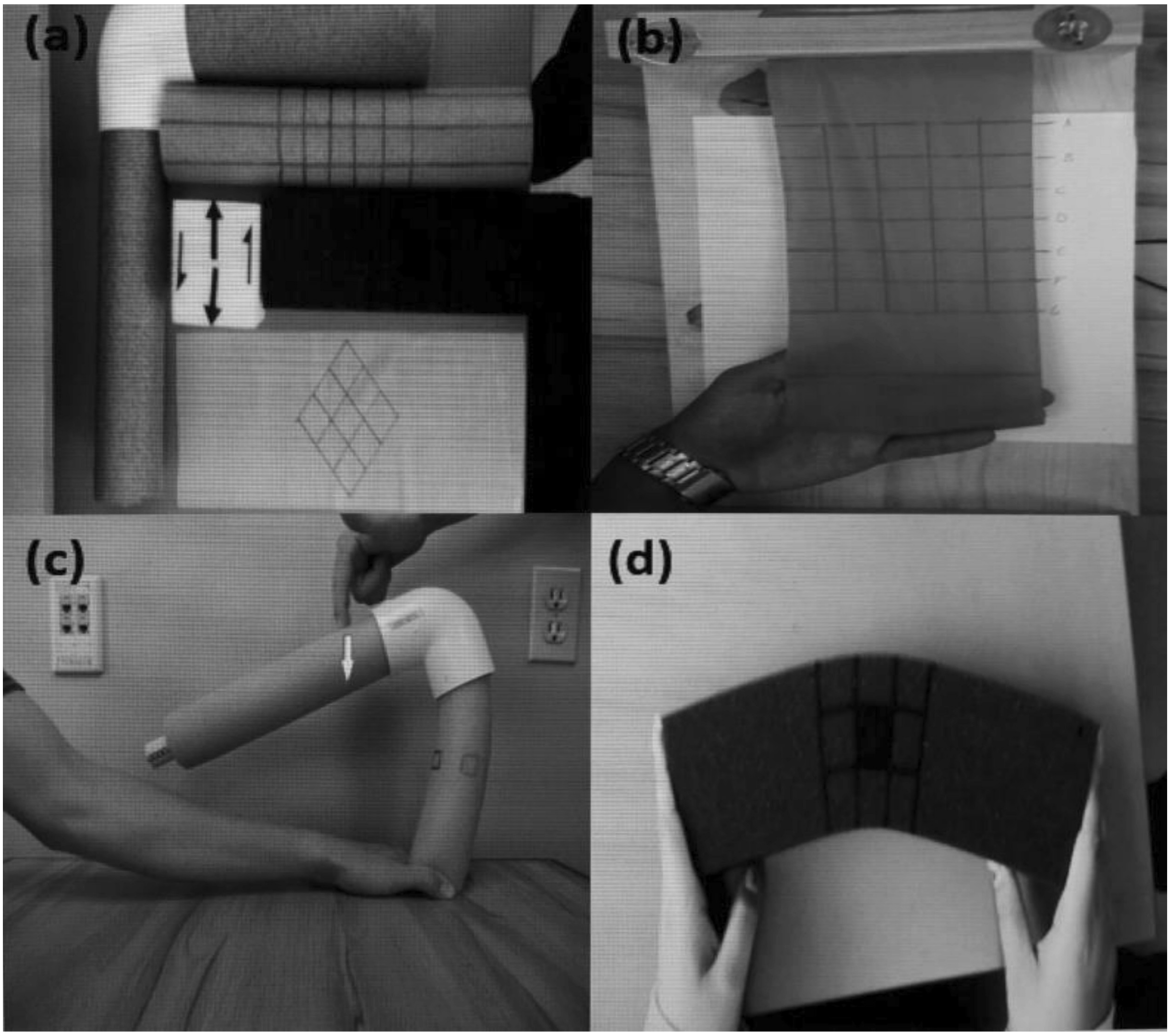

Fig. 2. (a) Contents of student kits, (b) Innovation developed for demonstrating concepts related to axial loading, (c) Innovation developed for demonstrating concepts related to combined loading, (d) Innovation developed for demonstrating concepts related to bending beams.

engineering faculty interpret curricular innovations that they developed and attempted to adopt within their contexts during the academic year? Interviews probed participants' interpretations of their curricular innovations and explored the ways in which their context (i.e., class structure, teaching experience, etc.) influenced these interpretations. Analysis of the interview data went through multiple coding cycles to find and describe common interpretations [29]. Since interpretations are influenced by the contexts in which individuals operate [30], it follows that being able to describe participants' interpretations would provide insight into the role that context plays on the adoption of curricular innovations.

4.1 Selection and description of participants

Engineering faculty were recruited to the summer workshop through emails, conference networking, and snowball sampling via previous workshop participants inviting their colleagues to attend future workshops [31]. Each year the workshop was attended by 15–20 engineering faculty from around the United States. Sixteen engineering faculty attended the workshop where the three curricular innovations outlined in the Background section had been created. Of these sixteen, seven taught mechanics of materials in the academic year following that workshop. Those seven faculty members were purposively selected [32] for this study because they were the only workshop participants who attempted to adopt those curricular innovations in their mechanics of materials classrooms. Background information on these seven participants is presented in Table 2. The names of the participants provided in Table 2 are randomly generated pseudonyms to ensure participants remain anonymous [33].

The small, medium, and large descriptors of the

Table 2. Faculty Participants' Background Information

Participant Pseudonym	Institution Type	Term Length (Weeks)	Class Size (# of Students)	Class (Lab) Hours/Week	Teaching Experience (Mechanics Experience) in Years	Workshops Attended	Other Classes Taught
Justin	Large CC	10	30	5 (0)	6 (6)	3	Intro physics, intro to engr., statics, dynamics, graphics
Elsie	Medium CC	10	30	5 (0)	18 (17)	2	Intro to engr., statics, dynamics, thermo- dynamics, circuits, graphics
Gaby	Small private university	15	35	3 (0)	17 (12)	2	Intro to engr., statics, dynamics, fluid mechanics, surveying, civil engr. capstone
Danny	Large CC	10	25	4 (0)	6 (3)	1	Intro chemistry, intro to engr., statics, dynamics, hydraulics, circuits, graphics, bioengineering
Henry	Small public university	10	30	3 (3)	8 (8)	2	Intro to engr., statics, dynamics, structural design, civil engr. capstone
Leif	Large CC	10	30	5 (0)	15 (2)	2	Intro physics, intro to engr., statics, circuits
Anne	Large CC	10	20	6 (2)	9 (4)	2	Intro physics, mathematics, intro to engr., graphics, thermodynamics

institution type in Table 2 refers to the annual undergraduate student enrollment. A small institution was defined as one that annually enrolls approximately 5,000 or fewer undergraduate students, medium sized institutions annually enrolled approximately 5,000–15,000 undergraduate students, and large institutions annually enrolled more than 15,000 students.

Each column in Table 2 does not necessarily represent the most influential contexts on the participants' interpretations of their curricular innovations. Each column instead serves to represent the contexts that were definable for all of the participants in order to present commonalities and differences in their backgrounds. The participants varied primarily in their institution type, class and lab hours per week, teaching experience, and courses taught.

4.2 Data collection

The researchers conducted semi-structured interviews with each participant at the beginning and end of their term teaching mechanics of materials. We chose interviews because they allow for the interpretations and experiences of the interviewee to be explicit and therefore accessible, knowable, and meaningful [31]. The interviews were semi-structured in that they followed a deliberate interview protocol to guide the interviewer, but also allowed the researchers to probe for new or unanticipated findings based on participant responses [31, 33]. Sample questions from each interview protocol are shown in Table 3. The interviews lasted between 30–90 minutes and were audio recorded for transcription and analysis. A third party transcription service and the researchers transcribed the audio recordings from each interview.

Table 3. Sample Interview Protocol Questions

1st Interview Protocol	2nd Interview Protocol
• Have you implemented similar curricular materials in your previous courses?	• What was your favorite and/or least favorite part about your involvement with this project?
• What are your plans with the demonstration materials we sent you? Which activities do you plan on using and how?	• Is there anything you wish we could have helped you with more or any recommendations for us moving forward?
• Do you think your aide will help in allowing you to meet your goals from the workshop?	• Please explain how your interactions with your aide helped or did not help you implement your curricular activities?
• How do you plan to use the student kits?	• Will you continue to use these materials in future mechanics of materials courses?

We conducted interviews at the beginning and end of the participants' term, not necessarily to observe change, but to allow participants to reiterate previous interpretations or express new ones in order to enhance the validity of our findings [31, 32, 34]. In addition to these interviews, there were other informal means of interactions between the researchers and participants throughout the academic year that helped inform later analysis. This included informal email and phone correspondence between researchers and participants throughout the academic year. Furthermore, the researchers maintained weekly meetings with the undergraduate research assistants who worked as the aides. This was done in order to validate and enhance the reliability of findings in the interview data through triangulation [32] with the aides' descriptions of their interactions with the participants.

4.3 Data analysis

Analysis of the raw text data consisted of multiple iterations of coding. Coding is the process of iteratively constructing categories, or codes, that describe excerpts of text relevant to the research question [35]. The coding process consisted of three cycles. The first cycle consisted of deductively coding the interviews to identify relevant excerpts that referred to *adaptable innovations*, *student kits*, or *instructional aides*. The second cycle then consisted of inductively coding these relevant text excerpts from the previous cycle to generate and operationalize codes that described the participants' interpretations [29]. More specifically, this cycle entailed looking within each coarse category from cycle 1 for dominant themes or common descriptions. The outcome of this phase was a codebook that characterized the different ways faculty perceived the three major aspects of pull-oriented innovation. Finally, the third cycle of coding consisted of deductively applying the codebook to the relevant text excerpts from all of the participants' interviews [29]. The final cycle was carried out with another member of the research team to assess and negotiate the reliability of the operationalized codes and their application to the relevant text [36].

4.4 Limitations

These methods were meant to answer the research question and provide further understanding into how context influences the ways in which faculty interpret their adoption of their own curricular innovations. They are not meant to result in findings that can be generalized to a wider population of engineering faculty or similar faculty development programs. The findings do offer insight, however, into the significance of context on the development and adoption of innovation. These contexts are presented in a way that may provide resonance with other engineering faculty and education researchers, which could help guide current and future faculty development programs. Further, data regarding the frequency counts of code applications were not provided. This was a conscious choice because the generated codes were meant to describe common interpretations but are unable to encompass the nuances of every participant's context. Frequency counts would then be misleading in describing the contextual influences on the participants' interpretations.

While there are multiple example quotes for each code and even more contexts that could be attributed as influential to participants' interpretations, there is obviously not enough space in a single paper to present the richness of each code. Furthermore, while the three primary aspects of adaptable innovations, student kits, and the aide were distinct curricular innovations created by this group of faculty, they all played an integral role in the participants' context. Consequently, the following section describes the participants' interpretations of their curricular innovations by presenting each code with the most salient example of a corresponding quote and brief descriptions of how other participants' unique contexts influenced similar interpretations.

5. Findings

Three interpretations emerged for each of the faculty participants' three curricular innovations, resulting in nine interpretations. The codebook with the operationalized codes describing each of these nine interpretations are in Table 4. The following section goes through each of these codes in more detail with a specific emphasis on how the contexts of the faculty participants' influenced their interpretations of their curricular innovations.

It should be noted that the three primary aspects of adaptable innovations, student kits, and the aide were integral to each other within the participants' contexts. Therefore, the interpretation codes are not always unique to the curricular innovation. For example, the aide helped participants implement their student kits and/or encouraged them to make adaptations to their innovations. In this way, the aide could be interpreted as empowering the participant and/or elevating their enthusiasm. For purposes of organization and concision, each interpretive code is presented and exemplified as a subsection to their respective curricular innovations in the following subsections. Synthesis of overlapping codes across curricular innovations is provided in the following subsections where necessary to

Table 4. Applied codebook with operational definitions

Curricular Innovation	Interpretation Code	Operational Definition
Adaptable Innovations	Preference	Adapting an innovation through choice. This includes making the decision to adopt or not adopt something, or to utilize or not utilize a given resource.
	Personalization	Adaptation that manifests after a preference is made. Therefore, personalization includes adapting the curricular innovations and resources that the faculty participant preferentially chose in any way.
	Empowerment	Empowerment includes awareness of one's own autonomy and ability to pull their adoption process. It also encompasses the self-recognition of being an expert in one's own adoption process.
Student Kits	Enthusiasm	Enthusiasm includes the faculty participants' excitement to use the kits and try new methods of teaching as a result. It also encompasses their perception of the kits increasing their own students' enthusiasm.
	Accommodating for teachers' time and resources	Accommodating includes interpretations of the student kits saving the faculty participants' time and resources by not having to assemble dozens of student kits on their own. It also included how this resource saving effort allowed participants to focus their resources on other areas of their adoption.
	Useful for teachers' engaging their students	Useful in this code includes interpretations of the student kits helping faculty participants engage their students. This included enabling the ability to facilitate more engaging discussions and exploring the technical content of the course in new ways.
Aide	Accountability	Accountability represents action that was taken due to the intervention of the aide that might not have been taken had that intervention not occurred. Accountability includes increasing one's own awareness of their own goals, so that change and adoption efforts are sustained.
	Support	Support represented assistance being provided in resolving barriers of any size. It also represents the comfort of having a designated resource readily available to help.
	Reflection	Reflection includes extended engagement with one's own adoption process. This includes thinking about one's decisions and ways to improve one's curricular innovations and teaching strategies because of communicating with their aide.

provide a more holistic view of participants' contexts.

5.1 Adaptable innovations

The participants initially co-developed their curricular innovations to be adaptable at the workshop but were also reminded that they could and should utilize their innovations in whatever way was most beneficial to them and their contexts. While the participants modified and adapted their innovations in unique ways, there were three common interpretations about their ability to do so. These interpretations of their adaptable curricular innovations were characterized as allowing them to make *preferences* in their adoption decisions, *personalize* their innovations further towards their unique context, and as *empowering* them during the adoption process.

5.1.1 Preference

Preference manifested in a variety of ways across participants, and this is not necessarily surprising as each participant was encouraged to adapt their innovations towards their contextual needs. For example, the following excerpt from Gaby's second interview illustrates how she preferred to adopt the curricular innovations that she was more familiar with and confident in using.

> "I definitely probably trusted [innovations] that were based off things that I'd been doing anyway because I also didn't feel like I had to throw something out to bring that in. It was a tweak of something that I was already doing that I felt was valuable. I guess I understood the . . . I had more confidence because I'd seen what they were." [Gaby, Interview 2]

Here, Gaby expresses her preference to use the curricular innovations that aligned with the way she had been operating her class in the past. Gaby had been using rubber cylinders as an easily deformable manipulative to demonstrate torsional strain and angle of twist. A similar manipulative—a foam pool noodle—with corresponding worksheet activities used to assess students comprehension of angle of twist and torsion-induced shear stress and strain were developed at the workshops. Since Gaby had already been using a similar manipulative in the past, she was more willing to adopt the innovation because it was only a "tweak" of something she had already been doing. Gaby's willingness to adapt an innovation with which she was already comfortable suggests that personal preference can play an important role in one's decision to adopt.

Preferences also influenced the ways in which participants decided to interact with their aide. Some participants preferred not to use their aide to help them adapt their curricular innovations or develop new ones during their term of instruction.

Participants preferred either doing this themselves or having their lab technicians/teaching assistants help them in this way. This shows that regardless of the context of having a lab tech or a TA, faculty seem to prefer not relying on remote support to help them adapt their innovations. Participants expressing their preference for certain innovations over others or in the ways in which they utilized their innovations provided further insight into the contexts that influenced these types of decisions.

5.1.2 *Personalization*

Another way in which participants interpreted their adaptable innovations was through their own further personalization of the curricular innovations they co-developed at the workshops. By creating innovations that could be readily adapted, participants were able to personalize their curricular innovations to make them even more useful within their unique contexts. This is exemplified in the following excerpt from Leif's second interview where he shares the fact that he further personalized a curricular innovation that he already liked:

> "For that [activity], we actually have an experimental setup. We [used] aluminum beams that [. . .] hang under their own weight and bend. Then, we attach masses and they bend more, and the students have to predict how many millimeters deflection [. . .] Then they measure it. [. . .] It's a nice little activity, but I think it was originally done by one of the members of the group and then I just snazzed it up a little bit." [Leif, Interview 2]

In this excerpt, Leif demonstrates that he interpreted their adaptable innovations as something he could personalize, even just "a little bit" to make it more adoptable. In this example, Leif is referring to the amount of class time required using a worksheet activity developed for demonstrating beam deflection. Leif "snazzed" the activity up by adding the experimental setup with the aluminum beams instead of using the foam beam manipulatives. Leif's access to aluminum beams allowed him to personalize the activity within the context of his existing classroom resources to run the activity more efficiently.

In addition to personalizing the worksheet activities, participants also personalized their usage of the student kits based on their contexts. For example, one faculty member had their students use the manipulatives in their student kits during the lab as physical examples for modeling in a CAD program. Both these examples represent how the context of whether a course has allocated lab time or not influences how faculty personalize curricular innovations. Faculty without lab components to their courses need to be able to personalize curricular innovations that can be supplemented into necessary lecture time. On the other hand, faculty with lab components sometimes have other curricular demands for that allocated time, such as CAD training, that they may need to personalize an innovation to supplement as well. Ultimately, course structure and content, as well as faculties' preferred pedagogical approaches influence how and when innovations can be implemented into the classroom, and adaptable innovations allow faculty to personalize their usage of curricular innovations based on these contexts.

5.1.3 *Empowerment*

While faculty were always encouraged to express their autonomy and make preferential and personalized decisions, their adaptable curricular innovations made them more aware of this autonomy. This is exemplified by Gaby's second interview:

> "I felt like I had more license to change. What was given [in previous years] I felt like was to use what was provided and get feedback [. . .] and that was difficult because if I didn't think what was there on the [worksheet activity] made sense I didn't really feel like I could change it . . . I had more of a . . . a little more of a license to just go ahead and tweak this for my class and share back and that made me feel much better about using the material. I did, I took to things and I changed them and I've made it my own style [. . .] so that was really . . . helped me use it more." [Gaby, Interview 2]

In this excerpt, Gaby says she felt she had "more license to change" and modify their curricular innovations towards her own style which empowered her to adopt within this context. For Gaby specifically, she preferred her worksheet activities to look a certain way, and by being able to personalize the worksheet activities to her style, she felt more empowered to use them. Gaby also mentions that making adaptations to their curricular innovations and seeing how that went in her class offered her the opportunity to share her experiences with other colleagues and talk about which adaptations worked and did not work for her. Other faculty expressed similar interpretations of being empowered by being able to guide the iterative improvement of their innovations through their own trial and error and lessons learned. Thus while context is shaped around the individual experience, faculty perceive aspects of their context as being relatable to their peers when they are empowered to iteratively improve and adapt curricular innovations.

5.2 *Student kits*

The student kits were a curricular innovation co-developed by engineering faculty to address the limited reach of previously developed manipulatives. Prior years of the workshop had provided instructors with their own physical demonstrations, but faculty noted that it would be more educationally valuable to provide each student with their own set of physical manipulatives. Each student kit contained a set of manipulatives that the participants frequently used to engage with the course material in a more hands-on way. While the participants did use their student kits in a wide variety of contexts, their general interpretations of the student kits were that they were *accommodating on their time and resources, useful for engaging their students*, and as generating greater *enthusiasm* towards their adoption process.

5.2.1 Enthusiasm

Being able to place manipulatives in each student's hands generated enthusiasm towards adoption of their curricular innovations. For some participants their own enthusiasm was influenced by their perception that the student kits generated more enthusiasm amongst their students. Henry expresses such an interpretation in the following excerpt from his first interview:

> "I've dropped the [student kits] in the middle of each table, and then the students have those to work with as a small group. I'm pretty excited to use the new [student] kits now with each individual student having those. I think it'll generate more enthusiasm." [Henry, Interview 1]

Henry's mechanics of materials classroom has group seating and therefore the student kits appear to have fostered his own enthusiasm by allowing him to take full advantage of adapting the innovations for his classroom environment. Allowing faculty a greater role in the innovation development process helps them create curricular innovations they are more excited to use.

Another way in which this interpretation emerged for participants was that the student kits allowed the faculty participants to adopt their previously developed curricular innovations in new ways that got them enthusiastic about going through the adoption process. This demonstrates that for an innovation to go through multiple iterations of development, faculty need to perceive an innovation as continuously improving and meeting new and emergent contexts in their adoption process.

5.2.2 Accommodating of faculty resources

Faculty are often significantly pressed for their time and sometimes do not have the adequate resources to create all the materials they would like for their classroom. When the participants expressed interest in having student kits for all of their students at the third workshop, the goal became to create enough student kits and ship them to each instructor before their term of teaching mechanics of materials. The participants then interpreted these student kits as being accommodating to their concerns about time and resource allocation. Faculty often operate in contexts that limit their ability to create the necessary curricular materials for them to carry out adoption of curricular innovations. Gaby exemplifies this interpretation in the following excerpt from her first interview:

> "Having more manipulatives is definitely something, like setting yoga bands in every student's hands. I don't have time to sit there and cut pool noodles into pieces and put grids on them. I've done that in the past, I've found the time for it, but it's . . . you do some of that and then you're diminishing mental and time ability to do more. It's having these whole manipulative student kits are fantastic. Every student I have, I care [about], but I can't put those together. It's huge." [Gaby, Interview 1]

This excerpt shows how Gaby interpreted the student kits as accommodating to her time constraints and subsequently enabled her to allocate her time and efforts towards other adoption efforts, such as how she might personalize some of their curricular innovations. Gaby demonstrates here that she cares for her students, but her context of having limited time outside of class to create the resources necessary for her students can limit the impact their curricular innovations can have on her students' engagement.

5.2.3 Useful for engaging students

In addition to being accommodating of faculty resources, the participants interpreted the student kits as being useful for engaging their students. Justin demonstrates in the following excerpt from his first interview how he allowed his students to draw on their manipulatives and explore mathematical concepts in more engaging ways:

> "[. . .] holding the pool noodle and being able to draw that angle of gamma on the actual pool noodle right there we're doing the math, but we're doing it with our hands. Rather than just an equation and diagrams, which is what I used to do in the past." [Justin, Interview 1]

In this example, the pool noodle Justin is referring to is one of the manipulatives provided in the student kit that he uses to represent a column or beam deforming due to certain types of applied loads (e.g., torsion). Justin expressed how having this manipulative from the student kits in each of his students' hands has allowed him to teach some mechanics of materials concepts in a more tangible way than his traditional abstract way of equations and diagrams. Justin interpreted the student kits as increasing students' level of engagement, which then encouraged him to adopt new approaches in his classroom. In addition, Justin is primarily a physics instructor who also teaches early level engineering courses like mechanics of materials, statics, and dynamics. Justin's context as a physics instructor influences his pedagogical approach to engineering curriculum as he tries to align the theoretical mathematics and physics concepts with the engineering representation of these concepts. This context influences the way in which he interprets the ability of the curricular innovations to engage his students in the engineering classroom.

Other faculty participants utilized their student kits to engage their students in discussions and to have them follow along with their own use of manipulatives as demonstrations. A context that influenced this interpretation of the student kit was the pedagogical approach that the faculty used to undertake adoption. Therefore, faculty interpreted their curricular innovations as being accommodating towards engaging their students when they have the resources and ability to adopt in a way that aligns with their context.

5.3 Aide

The participants requested aides to help them with their curricular innovations as they took place. We anticipated faculty would primarily use their aide to assist them in creating additional worksheet activities or sending additional manipulatives as necessary. While some faculty did interact with their aide in this manner, most noted the importance of aides in terms of ensuring *accountability*, providing *support*, and encouraging *reflection* surrounding their adoption of their curricular innovations.

5.3.1 Accountability

Accountability was one of the most common interpretations of the aide, which was surprising because that was not the intention of this curricular innovation. Elsie expresses such an interpretation in the following excerpt from her second interview:

> "Part of the reason why I was incorporating it was because I knew I was going to talk to [my aide]. [. . .] There's accountability there. It's like a workout partner." [Elsie, Interview 2]

Elsie notes how having weekly phone calls made her feel accountable to her goals of incorporating the innovations developed at the workshop, like a workout partner keeping someone accountable to their fitness goals. Since the intention of the aide was not for instilling accountability amongst the participants, their interpretations of them as such seems to reflect their context requiring some source for self-accountability. This demonstrates the importance of following up with faculty and holding them accountable to their pedagogical commitments.

5.3.2 Support

Faculty also interpreted their aide as a source of support when they had questions about implementation. Given participants' involvement in the development of their innovations, one might assume they had a plan for implementation and therefore did not require much support. However, most participants taught their courses more than six months after the workshop, and time lag caused participants to forget some of the details of their innovations. In addition, unforeseeable challenges can emerge within their contexts that can cause significant barriers to adoption if not met with adequate support in a timely manner. In Danny's second interview, he expressed how his aide helped him overcome barriers to adoption:

> "I think knowing that [my aide] was there was also helpful [...] because I feel like any little, tiny barrier can be enough to have people not implement changes. Just making sure that there aren't any barriers available, you're basically saying, 'I have this person and this person will ensure that any assembly blocks are removed,' so I think those are all positive." [Danny, Interview 2]

Here, Danny recognizes that simply having someone available to offer assistance helps support adoption. As mentioned before, adopters are likely to have unpredictable and emergent needs. If these needs are unaddressed, they can become a barrier to adoption. In regard to Danny's context, he was a first time workshop attendee and therefore was less familiar with some of the innovations. His regular contact with his aide provided him with the support to familiarize himself with some of the innovations and their intention so that such a "little, tiny barrier" would not become a barrier to adoption. Having the aides available during the adoption process to respond to authentic needs can make the difference in a sustained adoption effort or an abandoned one.

5.3.3 Reflection

Finally, the continuous engagement the participants had with their aides provided a unique opportunity for faculty to reflect upon their adoption process and keep lessons learned in the forefront of their minds so they could continuously improve and adapt their innovations and adoption process. Anne expresses this interpretation in the following excerpt from her first interview:

> "One of the biggest things is just by having that weekly telephone conversation; it keeps this in the front of my mind and current. [My aide] had some suggestions that have been helpful, and we've talked about the worksheets, and I had the idea of wanting to [share] exams and syllabi, and ran that by her, and she said, 'Great, go ahead and get that started.' That was helpful. That kept the feedback there." [Anne, Interview 1].

In this excerpt, Anne expresses how her weekly phone calls with her aide provided her with feedback that allowed her to reflect with someone about her adoption process to keep her engaged with their curricular innovations throughout the term and how she might be able to share curriculum with the other participants. Such an interpretation seems to have also been necessary for the participating faculty to identify additional adoption needs and continuously make note of how to improve their curricular innovation for the next iteration. The nature of these telephone conversations obviously varied amongst the participants and their contexts, but even when participants did not require any support from their aide, many found their regular conversations with their aide as a valuable opportunity to reflect with someone interested in their teaching.

Some of the participants' context of not having other engineering faculty to engage with at their respective institutions appeared to influence this interpretation. For example, faculty at smaller institutions or institutions with smaller engineering programs often do not have as many other engineering faculty to interact with and discuss their curriculum. This context influenced some of the participants to interpret their interactions with their aide as an opportunity for reflection since they did not perceive this opportunity elsewhere. This further illustrates how the contexts that influence the development of an innovation are not always the same as the contexts that influence adoption of that innovation.

6. Discussion

The interpretations identified above corroborate, expand on, and offer new insight into the literature on faculty development and the adoption of pedagogical innovations. First, the participating faculty's interpretations of their innovations demonstrated that faculty would significantly adapt curricular innovations when adopting within their unique contexts. This corroborates with a previous study that has demonstrated that the fidelity of implementation of curricular innovations varies greatly amongst engineering faculty [21]. Furthermore, even when the participating faculty had the autonomy to select to adopt the curricular innovations that they preferred in their contexts, they continued to adapt and personalize these innovations based on additional contexts. A similar study [37] showed that when engineering faculty had the autonomy to select from a set of existing curricular innovations, the innovations they selected and their fidelity of implementation varied greatly across contexts.

While the findings in this study echo the findings in these two studies [21, 37], the difference is that faculty participants in this study played a role in the development of the curricular innovations they were selecting and adapting. This would seem to demonstrate that even when faculty are able to pull innovation development towards their contexts, they must further adapt their innovations to meet their contexts during adoption and that they may even decide not to adopt. One interpretation of this finding is that engineering faculty are indeed not qualified to develop their own curricular innovations as some literature has suggested [7, 9, 17]. The authors contend, however, that the contexts faculty operate in can change from one adoption experience to the next. Take for example the curricular innovation of the aide. The participants developed the idea for an aide based on their experiences with past adoption and not having adequate support. Once the participants began to utilize their aide, however, many of them depended on their aide for accountability more than for support. A potential explanation for this is that their context had changed because their more adaptable innovations and student kits provided them with the resources they needed in previous years. Therefore, the participants needed less support and could utilize their aide for accountability and reflection as well.

These reflection and accountability interpretations of the aide were particularly interesting. In regard to reflection, another study where faculty developed their own curricular innovations with the guidance of instructional consultants [19] found that when faculty engaged in reflective processes with instructional consultants they were more likely to adopt learner-centered innovations. While the aide was not a professional instructional consultant, they did provide similar benefits of creating opportunities to reflect, which may be why the participants felt more accountable towards their own goals. Instead of an aide or instructional consultants, faculty could be paired at faculty development programs and encouraged to have regular communication with each other throughout the academic year. Therefore, providing faculty with someone to engage with during their adoption process could be an affordable and sustainable way of improving faculty development efforts. Future work should explore the efficacy of such a "buddy-system" program that affords accountability and reflection, especially for engineering faculty that are more isolated at their own institutions.

Finally, one of the challenges with a pull-oriented model and allowing faculty to adapt innovations within their contexts is maintaining fidelity towards the intended use of an innovation. Fidelity and adaptability do not have to be in opposition to one another when it comes to adopting pedagogical innovations. The participants in this study were all able to adapt their innovations within their unique contexts while being able to maintain the original intent for their innovations to increase their students' engagement. Recognizing that innovation adoption can take many forms in the classroom allows faculty to develop innovations that are highly adaptable without deviating from the main goal of the innovation. Development and dissemination of curricular innovations, therefore, should take into account context to better align these innovations with faculty preferences and thereby increase their adoptability.

The authors recognize that the content nature of mechanics of materials may be unique in that manipulatives can be developed to deal directly with how tangible objects can deform. Similar research could investigate how engineering faculty approach innovation development in courses with more abstract concepts, like thermodynamics or circuits, and how the contexts of these courses influence innovation development and adoption. Another perspective for examining faculty development programs that offer pull-oriented innovation development could be through communities of practice [38]. Such an examination could provide further insight into how faculty identity and epistemology evolve throughout the process of developing curricular innovations and becoming more integrated in the education research community.

The primary implications of this research is that aspects of the pull-oriented model can be helpful for bridging the gap between awareness of innovations and their adoption into the engineering classroom. The authors do not mean that all curricular innovations should be pull-oriented, but rather that existing push-oriented models would benefit from allowing faculty an enhanced role in innovation development. Empowering engineering faculty to have a greater role in the innovation development process is not only likely to enhance adoption of curricular innovations into the engineering classroom, but also provides engineering faculty with the opportunity to engage their students in novel ways. This, in and of itself, may be a better way for faculty to engage their students than any single innovation.

7. Conclusions

We sought to understand faculty interpretations of their curricular innovations during the context of adoption. Previous research has documented that engineering faculty are well aware of curricular innovations, but struggle with adoption due to a wide variety of contexts that are not always addressed in the innovation development process. While context can be an unwieldy concept and may be too complicated to understand in a generalizable manner, we found that it does have an influence on how faculty interpret curricular innovations and go about adopting them. Once we set out to engage and listen to engineering faculty during their adoption process without imposing a right or wrong way to adoption, we found that context could be characterized and addressed in a way that is meaningful beyond the individual instructors. Therefore, just because something may never be quantifiable, predictable, or transferable to a larger audience, this does not mean we should abandon trying to understand the individual and their experience in efforts to improve our understanding of complex phenomena. In summary, the faculty participants interpreted their curricular innovations as a way to engage their students and themselves in a manner that addressed their contexts. This made them more prepared for approaching adoption of additional curricular innovations in future courses that they teach.

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