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A Multiple Case Study of Teaching-Focused Professional Development Programs Offered at Three Different Types of US Institutions of Higher Education

Holly Fortener[1], Leilani A. Arthurs[1, 2], Patrick Shabram[3], Pierre Lu[4], Chu-Lin Cheng[5, 6], Stephanie Plaza-Torres[1] & Carly Flaagan[3]

[1] Department of Geological Sciences, University of Colorado at Boulder, Boulder, USA

[2] School of Education, University of Colorado at Boulder, Boulder, USA

[3] Department of Social and Behavioral Sciences, Front Range Community College, Fort Collins, USA

[4] Department of Teaching and Learning, University of Texas Rio Grande Valley, Edinburg, USA

[5] School of Earth, Environmental and Marine Sciences, University of Texas Rio Grande Valley, Edinburg, USA

[6] Department of Civil Engineering, University of Texas Rio Grande Valley, Edinburg, USA

Correspondence: Leilani A. Arthurs, Department of Geological Sciences, University of Colorado at Boulder, Boulder, CO., 80309, USA. Tel: 1-402-617-7229. E-mail: Leilani.Arthurs@Colorado.EDU

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Abstract

Teaching-focused professional development (PD) programs offered at institutions of higher education (IHEs) are uniquely positioned to be levers of change that improve the quality of undergraduate science, technology, engineering, and mathematics (STEM) education in ways that broaden participation in STEM education, workforce development, and career pathways in the United States (US). PD programs and their potential to transform undergraduate STEM education, however, are understudied. This multiple-case study compares suites of PD programs offered at three IHEs in the US: a community college, an emerging research institution, and a research-intensive university. Each suite of PD programs is characterized in terms of program structure, implementation, and potential to transform undergraduate STEM education. The presented results illustrate the existence of a wide range of ways in which PD programs are structured and implemented. A key finding is a suite of PD programs offered at these IHEs has greater potential to transform undergraduate STEM education when embedded in an institutional culture that highly prioritizes the teaching enterprise. Lastly, the results are synthesized into an innovative framework. The framework can be used as a tool to design, implement, and evaluate PD programs so they have greater potential to transform undergraduate STEM education in the US.

Keywords: teaching, professional development, STEM education, higher education

1. Introduction

1.1 Background

"Effective teaching may be the hardest job there is" (Glasser, 1990, p. 14) and, in the United States (US), institutions of higher education (IHEs) have struggled to meet decades-long national calls to improve student learning outcomes and broaden participation in undergraduate science, technology, engineering, and mathematics (STEM) education, workforce development, and career pathways (Carlson, 1959; Hunter, 2019; National Academies of Sciences, Engineering, and Medicine, 2021; National Research Council, 2011; National Science Board, 2007; National Science Board Task Committee on Undergraduate Science & Engineering Education, 1987). One factor that contributes to this situation is the fact that many instructors of undergraduate STEM courses lack formal pedagogical training (Harvey & Knight, 1996; Zimmerman, 2020), even though they are well trained in their STEM disciplines (National Research Council, 2012). Most instructors teach the way they were taught, via traditional lecture (Schwartz & Bransford, 1998; Stains et al., 2018; Watts & Becker, 2008). Traditional lecture alone, however, is insufficient for deep learning (Bransford et al., 2000; Mayer, 2003) and yields poorer learning outcomes compared to active-learning teaching methods (Freeman et al., 2014; Hake, 1998; Schoenfield, 1985; Wieman, 2007).

In the absence of formal pedagogical training to learn about active-learning teaching methods, many instructors interested in improving their pedagogy engage in ad hoc self-directed learning about how to teach. For example, they consult colleagues who teach similar courses (Harrison & McKeon, 2008; Hurst, 2010), read pedagogical literature (Cranton, 1994; Sunal et al., 2001), peruse teaching-related websites, and/or join online communities of practice (Sherer et al., 2003). Instructors also participate in teaching-focused professional development (PD) programs (Bouwma-Gearhart, 2012; Sunal et al., 2001), which are available through on-campus offices, off-campus professional societies, organizations, and other entities (Ebert-May et al., 2011; Manduca et al., 2017; Viskupic et al., 2019).

1.2 Motivation

On-campus PD programs offered at IHEs may foster communities of practice among instructors (Arthur, 2016; Eddy et al., 2022; Nagy & Burch, 2009). As such, these programs are uniquely positioned to be levers of change for improving the quality of STEM education in ways that broaden participation in STEM education, workforce development, and career pathways. Although on-campus PD programs are generally available to STEM instructors, they are understudied (Connolly et al., 2016; McCourt et al., 2017; Luthra et al., 2023). Thus, this multiple-case study helps address this gap in knowledge by systematically comparing three suites of PD programs, each offered at one of three types of public IHEs in the US: a community college, an emerging research institution, and a research-intensive university. Each suite of PD programs is characterized in terms of program structure, implementation, and potential for the combined suite of programs to transform undergraduate STEM education. More specifically, this study aims to answer the following two research questions (RQ):

RQ1. What similarities and differences exist in PD programs offered to STEM instructors at different types of public US IHEs, in terms of their structure and implementation?

RQ2. To what extent are the suites of PD programs offered to STEM instructors at different types of public US IHEs likely to transform undergraduate STEM education at those institutions?

In this study, we define "instructor" as full-time or part-time career faculty who teach undergraduate STEM courses, and graduate student instructors are not included in the present study. Our research questions are investigated through the lens of a theoretical framework. The theoretical framework is based on Borko's 2004 model of a PD system and Futrell's 1995 model of the relationship between PD programs and education transformation. This study's theoretical framework is described in the next section.

1.3 Theoretical Framework

Borko's 2004 model describes a professional development (PD) program as a system, whereas Futrell's 1995 model describes the factors in a PD program needed to transform education. Both models were originally developed for K-12 contexts, and they were adopted for the present study for two reasons. First, similar models were not found for undergraduate education contexts. Second, these models are applicable to undergraduate education contexts, with some modifications. Both models inform the methods used in this study to collect, analyse, and interpret data about PD programs.

1.3.1 PD Program as a System

Borko's model describes a PD program as a system (Borko, 2004). The system has four components: (1) *program type*, (2) *teacher participants*, (3) *facilitators*, and (4) *context* in which the PD program occurs. For the purposes of the present study, three modifications to the definitions of these components are made to account for differences between the K-12 and undergraduate education contexts. First, the *program type* component is based on the activities that the participants engage in during a PD program. Examples of such activities include reflecting on one's own teaching methods, discussing teaching with other instructors, and conducting research on one's own teaching. Second, the *teacher participants* component refers to instructors of undergraduate STEM courses. Third, the *context* component refers to the type of IHE in which a PD program is offered along with associated physical and socio-cultural environments.

1.3.2 Relationship between PD and Education Transformation

Futrell's 1995 model links teacher PD with education reform. It comprises seven PD-related factors that together catalyse education transformation. These factors include: (1) a *local focus* that recognizes local needs and local solutions, (2) *financial resources*, (3) *local leadership*, (4) *long-range planning*, (5) *teachers and PD*, (6) *collegiality* among teachers, and (7) *time* for teachers to participate in PD programs.

Although most of these factors are self-explanatory, four warrant additional explanation in the context of this study. First, the *financial resources* factor in Futrell's model refers to superintendents, principals, and district-level budgets, whereas, in the present study, it refers to the budgets managed by campus administrators, PD program providers, other internal funding sources, and external funding sources. Second, the *local leadership* factor in Futrell's original model refers to school and district leadership, whereas, in the present study, it refers to campus, college, and university leadership. Third, the *long-range planning* factor refers to long-range planning in which PD programs promote STEM transformation in this study. Lastly, in this study, the *teachers* factor refers to instructors (i.e., full-time and part-time career faculty who teach undergraduate STEM courses, and graduate student instructors are not included in the present study).

Both Borko's and Futrell's models inform the methods used to collect, analyse, and interpret the data about PD programs offered at each of the three IHEs examined in this study. Borko's model provides a basis for answering RQ1, which deals with the structure and implementation of PD programs. Futrell's model provides a basis for answering RQ2, which deals with the potential for an IHE's suite of PD programs to transform undergraduate STEM education. The next section further describes how Borko's and Futrell's models are integrated into this study's research methods.

2. Methodology and Methods

The general research approach or methodology for this research is a multiple case study (Gustafsson, 2017; Stake, 2006). A multiple case study is an intensive approach to studying a phenomenon by analysing a few specific cases in detail (Stake, 2006). After each case is analysed completely, the cases can be compared to discover similarities and differences (Stake, 2006). This study focuses on three cases. Each case represents a *suite of PD programs* at a public US IHE during a specific 5-year period (2014-2019).

2.1 Selection of Cases

The three cases include the suites of PD programs offered at a community college (Front Range Community College, with ~21,000 students), an emerging research institution (University of Texas - Rio Grande Valley, with ~25,000 students), and a research-intensive university (University of Colorado at Boulder, with ~34,000 students). These cases were selected because they are representative of the range of possible PD contexts in higher education in the US. As such, PD programs at different types of IHEs could be described and inter-institutional comparisons made. This study analysed PD programs in terms of their structure, implementation, and potential to transform undergraduate STEM education. It was beyond the scope of this study to interview participants, facilitators, and administrators about their experiences with the PD programs.

2.2 Data Collection and Original Database Construction

The primary sources of data about PD programs at these three institutions were three experts knowledgeable about the PD programs at their respective institutions. These experts each have at least ~10 years of experience working with PD programs at their institutions. They all work very closely with PD providers at their institutions and/or are PD providers themselves. They are also collaborators on an inter-institutional project to study PD programs available to instructors of undergraduate STEM courses at a range of public IHEs in the US.

To systematically collect data about PD programs at their institutions, they created the original database in Google Sheets in the style of an Excel workbook with multiple spreadsheets, one spreadsheet for each institution. The original spreadsheet was designed through discussions among all three experts about what to include. They developed column headings that represented key characteristics of PD programs (e.g., information about the facilitators, participants, funding, etc.), which overlap with the four components in Borko's model and the seven factors in Futrell's model. They then populated the spreadsheet for their institution with information about the PD programs offered at their institutions during the five-year period from 2014 to 2019. The information that they input into the database included textual descriptions under each column heading for each PD program.

After the experts inputted information about the PD programs offered at their institutions, a research assistant verified data inputted into the database by looking up information about the programs available online and/or having follow-up email exchanges or *Zoom*-based conversations with the experts to ensure agreed understanding of the textual content. The research assistant and experts worked together from 2020 to 2022 to populate the database, making it as comprehensive as possible.

2.3 Data Analysis and Final Database

After the contents of the original database were set, the research assistant subjected the textual information in the initial database to a content analysis, which involved both categorization of information and systematically counting categorical information (Prior, 2014). The content analysis utilized the four components in Borko's model and the seven factors in Futrell's model as a priori categories into which the existing information could be sorted into main categories (e.g., Borko's *program type* and Futrell's *funding source*). The content analysis also yielded emergent subcategories for these main categories. The result of the content analysis was a final database with succinct and systematic descriptors (i.e., subcategories) for each column heading (i.e., main categories) instead of wordy textual descriptions written in a range of styles (e.g., from bullet points to complete sentences).

To help illustrate the contents of the final database, Table 1 lists, defines, and provides examples for each main category for program characteristics examined in this study. Most of the program characteristics are self-explanatory; however, the *program type* category warrants further explanation because it is associated with several emergent subcategories that require a description. Thus, Table 2 lists, defines, and provides examples for each subcategory of the *program type* category that emerged.

Table 1. Program Characteristics

Category of Characteristics	Definition	Example(s)
Program Type	Based on the activities that program participants engage in.	A workshop is a *program type*. See Table 2 for full list of program types.
Facilitator	The instructor or leader of a program. May also be the designer of the program.	A faculty member runs programs for other faculty members on their campus.
Duration	The period of time program participants are expected to engage.	A program may require meeting every other week over one semester.
Funding Source	Who funds the program. May be internal sources (e.g., Dean, Provost, etc.) or external sources (e.g., federal grants).	A program is funded internally using institutional funds.
Participant Eligibility	Criteria that possible program participants must meet to be admitted into the program.	A program may be restricted to only early-career faculty members.
Participant Pay	Payment for completing a program. May be in the form of additional pay, gift cards, or course credits.	A faculty member is paid overtime during the semester or the summer to participate in a program.
Sustainability	Whether a program continues.	A program was sustained by the end of 2019 or it was not.

Table 2. Program Types

Program Type	Definition	Example(s)
Discuss-and-reflect	Participants engage in self-reflection and discussion of teaching and learning with colleagues.	Participate in a book club to read about how to empower students, participate in an informal discussion about teaching methods.
Education research	Participants receive funds to conduct research on teaching and learning in the context of their courses.	Participant receives an award to fund research on student learning outcomes in a course they teach.
Funded project	Participants receive funding to improve teaching and learning environments.	A department chair receives an award to fund teaching-focused professional development for faculty.
Mentorship	Participants are more/less experienced instructors who give/receive each other advice and develop a support system.	A first-year or early-career faculty instructor seeks teaching advice from a more senior instructor.
Training	Participants attend multiple meetings with scaffolded topics related to teaching and learning over the course of two or more weeks.	Participants engage in a semester-long training about online teaching methods that require participants to meet eight times per semester.
Workshop	Participants attend a one-off single-topic meeting (i.e., single meeting with no follow up).	Participate in a session on how to write a teaching philosophy, participate in a session on how to use rubrics for assessments.

The result of this content analysis was a final version of the database. In the final database, each PD program was assigned a program ID number.

After the final database's categories and subcategories for PD characteristics were set, the data were tabulated as numeric rows and columns for each suite of PD programs at each institution. The quantitative analyses involved descriptive statistics such as counting the frequencies with which each category and subcategory of PD characteristics occurred at each institution and then computing their percentages. These results are described in the next section and in Tables 3-6.

3. Results

All categories that resulted from the content analysis of the original database are listed and defined in Table 1 as *PD program characteristics*. All categories comprised subcategories, which made possible comparisons between the three suites of PD programs (i.e., interinstitutional comparisons). While most subcategories are self-explanatory, the *program type* subcategories are defined in Table 2.

All PD programs were assigned to a PD *program type* subcategory based on their textual descriptions in the original database. Below, text in the original database are included as examples of text that were categorized into each PD *program type* (listed in the order they appear in Table 2).

- Discuss-and-reflect: *"In summer 2018, over 20 [institution name] faculty and staff collaboratively read and discussed [book title]."* (PD program 26)
- Education research: *"The [program name] assists [institution name] faculty in developing scholarly research projects on teaching and learning …."* (PD program 23)
- Funded project: *"[Grants] should … support the goal of increasing the use of evidence-based teaching practice through supporting course redesign or faculty ability to use active learning or effective assessment."* (PD program 28)
- Mentorship: *"… can vary from a quick check in session to a series of planned meetings over the course of a semester."* (PD program 06)
- Training: *"… offers faculty and instructors a chance … to redesign their classes around evidence-based instructional strategies. Participants in the [program name] meet for nine, two-hour sessions over the course of one semester."* (PD program 01).
- Workshop: *"One time event."* (PD program 17)

The *program facilitator* subcategories indicate who facilitated a PD program: faculty, staff, or student(s) from the IHE. The *duration* subcategories include a range of durations for PD programs: one-off meetings, 1-week-long commitment, 2-week-long program, semester-long program, and year-long program. PD program *duration* also indicates how many times participants met for a program. For example, a one-off meeting would only require participants to meet once while the year-long program would require participants to meet many times throughout the program.

The *funding source* subcategories indicate where the funds for a PD program are sourced, such as from the institution, the institution's state, or from federal grants. *Participant pay* subcategories (i.e., yes, no) indicate whether participants were paid to attend a PD program. The *participant eligibility* category has several subcategories that indicate who can attend a PD program (e.g., full-time faculty, part-time faculty, tenure track and non-tenure track). Finally, the *sustainability* subcategories indicate whether a PD program was operating (i.e., sustained) or not operating (i.e., discontinued) at the end of 2019.

The data collected about PD programs offered at the community college, emerging research institution, and research-intensive university are shown in Tables 3, 4, and 5, respectively. These tables include the categories of information that capture how the PD programs were structured and implemented. The data summarized in Tables 3, 4, and 5 are used to answer RQ1.

Although it is beyond the scope of this study to evaluate the potential of each individual PD program to facilitate education transformation on its own, this study investigates the potential that each institution's *suite of PD programs* has to transform undergraduate STEM education. The holistic examination of each institution's suite of PD programs over the same 5-year period yielded the comparative data shown in Table 6. The data summarized in Table 6 are used to answer RQ2.

Table 3. Characteristics of Programs at a Community College

ID	Program Type	Facilitators	Duration	Funding Source	Participant Pay	Participant Eligibility	Sustainability
01	Training	Faculty	Semester-long program	Institution	Yes	FT and PT	Sustained
02	Discuss-and-reflect	Faculty, staff, students	One-off meeting(s)	Institution	No	FT and PT	Discontinued
03	Discuss-and-reflect	Faculty, staff	One-off meeting(s)	Institution	Yes	FT and PT	Sustained
04	Workshop	Faculty	One-off meeting(s)	Institution	Yes	PT	Sustained
05	Workshop	Faculty	One-off meeting(s)	Institution	No	New tenure-track FT	Sustained
06	Mentorship	Faculty	One-off meeting(s)	Institution	No	FT and PT	Sustained
07	Mentorship	Faculty	One-off meeting(s)	Institution	Yes	New PT	Sustained
08	Workshop	Faculty	One-off meeting(s)	Institution	No	FT and PT	Discontinued
09	Training	Faculty, staff	Semester-long program	Institution	NS	FT and PT	Discontinued
10	Training	Faculty	Semester-long program	Institution	Yes	FT and PT required to be certified to teach online	Sustained

Note. ID refers to Program ID. FT stands for full-time faculty. PT stands for part-time faculty. NS stands for not specified.

Table 4. Characteristics of Programs at an Emerging Research Institution

ID	Program Type	Facilitators	Duration	Funding Source	Participant Pay	Participant Eligibility	Sustainability
11	Discuss-and-reflect	Faculty	Semester-long program	Institution	Yes	FT and PT	Sustained
12	Workshop	Faculty	One-off meeting(s)	Institution	No	FT and PT	Sustained
13	Training	Faculty	Semester-long program	Institution	No	FT and PT	Sustained
14	Workshop	Faculty	One-off meeting(s)	Institution	No	FT and PT	Sustained
15	Discuss-and-reflect	Faculty	One-off meeting(s)	Institution	No	NS	Sustained
16	Discuss-and-reflect, education research	Faculty	Semester-long program	Institution	No	FT and PT	Sustained
17	Workshop	Faculty	One-off meeting(s)	Institution	No	FT and PT	Sustained
18	Workshop	Faculty	One-off meeting(s)	Institution	No	FT and PT	Sustained

Note. ID refers to Program ID. FT stands for full-time faculty. PT stands for part-time faculty. NS stands for not specified.

Table 5. Characteristics of Programs at a Research-Intensive University

ID	Program Type	Facilitators	Duration	Funding Source	Participant Pay	Participant Eligibility	Sustainability
19	Workshop	Staff	One-off meeting(s)	Federal	Yes	1st, 2nd, or 3rd year tenure-track faculty	Discontinued
20	Discuss-and-reflect	Staff	Semester-long program	Federal	No	Pre-tenure STEM faculty	Discontinued
21	Workshop	Staff	1-week-long commitment	Federal	No	FT and PT, departmental nomination required	Discontinued
22	Training	Staff	Year-long program	Federal	No	FT and PT, invitation only	Discontinued
23	Education research	Staff	Year-long program	State	Yes	FT and PT	Discontinued
24	Training	Staff	2-week-long program	Institution	Yes	FT and PT in arts and sciences	Sustained
25	Funded project	Staff	Year-long program	Institution	Yes	FT and PT with experience advancing education in their discipline	Sustained
26	Discuss -and-reflect	Staff	One-off meeting(s)	Institution	NS	FT and PT	Sustained
27	Discuss -and-reflect	Staff	Semester-long program	Federal	NS	FT and PT	Discontinued
28	Funded project	Staff	Semester-long program	Federal	Yes	FT and PT in STEM	Discontinued
29	Funded project	Staff	Year-long program	Federal	Yes	FT and PT in STEM	Discontinued

Note. ID refers to Program ID. FT stands for full-time faculty. PT stands for part-time faculty. STEM stands for science, technology, engineering, and mathematics. NS stands for not specified.

Table 6. Comparison of PD Program Characteristics Between Institutions

Category	Subcategory	Community College (n=10)		Emerging-Research Institution (n=8)		Research-Intensive Institution (n=11)	
		#	%	#	%	#	%
Program Type	Discuss-and-reflect	2	20	3	38	3	27
	Education research	0	0	1	13	1	9
	Funded project	0	0	0	0	3	27
	Mentorship	2	20	0	0	0	0
	Training	3	30	1	13	2	18
	Workshop	3	30	4	50	2	18
Facilitators	Staff	3	30	0	0	11	100
	Faculty	10	100	8	100	0	0
	Students	1	10	0	0	0	0
Duration	One-off meeting(s)	7	70	5	63	2	18
	1-week-long program	0	0	0	0	1	9
	2-week-long program	0	0	0	0	1	9
	Semester-long program	3	30	3	38	3	27
	Year-long program	0	0	0	0	4	36
Funding Source	Internal	10	100	8	100	3	27
	External	0	0	0	0	8	73
Participant Pay	Yes	5	50	1	13	6	55
	No	3	30	7	63	3	27
	Not specified	1	10	0	0	2	18
Participant Eligibility	By invitation or nomination	0	0	0	0	2	18
	Part-time faculty	9	90	6	75	9	82
	Full-time faculty	8	80	6	75	11	100
	Tenure track	1	10	NS		2	18
	Early career	1	10	NS		2	18
	Mid-career	NS		NS		NS	
	From specific discipline(s)	0	0	0	0	4	36
Program Status	Sustained	7	70	8	100	3	27
	Discontinued	3	30	0	0	8	73

Note. NS stands for not specified. The total number of programs in the set of PD programs examined for each IHE is included parenthetically. Where percentages for a given category of PD program characteristics exceeds 100%, one or more PD programs were characterized with more than one subcategory.

Notable similarities and differences in each institution's suite of PD programs are presented next. Following the presentation of notable similarities and differences, the Discussion section discusses this study's results in the context of earlier studies. In the Discussion section, the answers to RQ1 and RQ2 are organized according to Borko's components and Futrell's factors. Directions for future research and recommendations are also made.

3.1 PD Program Type

All three IHEs offered a variety of PD program types. The research-intensive university and the emerging research institution offered *education research* type PD programs; however, the community college did not. Only the research-intensive university offered *funded project* type programs. Only the community college offered *mentorship* type programs. The most common type of PD programs offered at the community college and the emerging research institution were *workshops*. At the community college, the percentage of *workshop* type programs were equal to the *training* type programs. At the research-intensive university, the *funded projects* and the *discuss-and-reflect* types of programs were equally most common.

3.2 PD Program Membership and Duration

PD program membership includes facilitators and participants. All PD programs offered at the community college and the emerging-research institution had facilitators who were faculty members, whereas the PD program facilitators at the research-intensive university were all staff members. At all three IHEs, participant eligibility was mostly based on part- or full-time faculty status. Furthermore, all three suites of PD programs hosted participants with mixed disciplinary backgrounds. Only the research-intensive university's suite of PD programs included programs specifically for STEM faculty.

In terms of PD program duration, more than half the PD programs at the community college and the emerging research institution were designed as one-off meetings, whereas less than 20% of the PD programs at the research-intensive university were of the one-off type. One-off meetings are stand-alone single-topic meetings. About a third of the PD programs were designed to be one-semester long. These programs expected participants to regularly attend bi- or tri-weekly meetings and addressed different topics during each meeting. A small number of these programs expected participants to do homework in preparation for each meeting. An even smaller number of these programs provided participants with feedback on their work (either completed during a meeting or as homework).

3.3 PD Program Funding and Sustainability

Funding for all PD programs offered at the community college and the emerging research institution was internal (i.e., funded by the institution), whereas only about a quarter of the PD programs offered at the research-intensive university were internally funded. Most PD programs offered at the research-intensive university were externally funded through grants from government agencies.

Whether and how PD program participants were compensated varied widely. About half the PD programs offered at the community college and the research-intensive university offered participants compensation (i.e., monetary pay), whereas less than a quarter did at the emerging-research institution.

This study shows that PD program sustainability is tightly linked to internal funding. By the end of the 5-year period examined in this study, 100% PD programs offered at the emerging research institution were sustained with internal funding. In contrast, almost 75% of the community college's PD programs and just over 50% of the research-intensive university's PD programs were sustained. Programs that were not sustained at the end of the 5-year period were discontinued.

4. Discussion

4.1 PD Program Structure and Implementation

To answer RQ1, this section discusses the similarities and differences that exist in the suites of PD programs offered at each IHE, in terms of their PD program structure and implementation. To do so, the discussion draws upon and is organized using the components in Borko's model of PD as a system. This study's results and how they are connected to the broader research literature are discussed.

4.1.1 PD Program Type

Comparisons of the PD *program type* category across all three suites of PD programs reveal *workshops* was the most common subcategory (i.e., 9 out of 29 total PD programs or 31%). This finding is consistent with those in the research literature (Garet et al., 2001; Sunal et al., 2001). Although workshops are one of the most common types of PD programs, other research suggests they have minimal impact on instructor behaviour and student learning (Cho & Rathbun, 2013; Dede et al., 2009). This is especially true for one-off workshops (i.e., single-meeting single-topic workshops) (Cleland et al., 2009; Lim & Wang, 2017).

In contrast, *mentorship* and *discuss-and-reflect* PD program types are associated with beneficial PD experiences. Such experiences include, for example, sharing experiences and techniques (Czerniawski et al., 2017; Harrison & McKeon, 2008; Rodgers & Skelton, 2014), feeling supported in their teacher role (Hurst, 2010; Nevgi & Löfström, 2015), forming a community of practice instead of feeling isolated within their departments (Nixon, 1996), and developing teacher identities (Kwan & Lopez-Real, 2010; Nevgi & Löfström, 2015). Furthermore, research indicates faculty prefer *mentorship* and *discuss-and-reflect* PD program types (Czerniawski et al., 2017).

Although *mentorship* and *discuss-and-reflect* PD program types are associated with more desirable and preferred experiences by PD program participants (compared to the single-meeting single-topic *workshops*), our results reveal *mentorship* and *discuss-and-reflect* PD program types were the least frequently offered at all three IHEs. The limited offerings or absence of these types of PD programs reveals an opportunity to better support instructors who teach undergraduate STEM courses by offering more of such programs.

4.1.2 PD Participants

The results of this study show PD programs at the three IHEs were available to their part- and full-time faculty, regardless of academic discipline. Although this reflects a high level of inclusion in PD program participation, the broader research literature suggests there may be benefits to offering STEM-oriented or STEM-discipline-specific PD programs (Hunter, 2019; McLean et al., 2008; Tobias, 1990). Because existing research on the state of STEM in the US reveals traditional teaching methods fall short of achieving the desired student learning outcomes (Hunter, 2019; Schussler et al., 2021; Tobias, 1990), a potential line of future research is to examine the impact that PD programs comprising mixed-discipline participant cohorts (i.e., from both STEM and non-STEM disciplines) versus STEM-only participant cohorts have on undergraduate STEM education transformation.

4.1.3 PD Program Facilitators

Research suggests effective PD program facilitators are those whom PD program participants perceive to be colleagues (Rogers et al., 2007), care about PD program participants' growth and teaching (Rogers et al., 2007), have facilitation skills (Heppner & Johnston, 1994; Kaslow et al., 2004a), are from the same or similar discipline as participants (Rogers et al., 2007), and those who make time to build community (Czerniawski et al., 2017; Harrison & McKeon, 2008; Nevgi & Löfström, 2015). Thus, the peer-to-peer relationships that are possible when PD program facilitators are also faculty members suggests faculty members provide additional value as PD program facilitators.

Our results show all PD programs offered at the community college and emerging-research institution were facilitated by faculty members, whereas most PD programs offered at the research-intensive university were facilitated by staff. Although it was beyond the scope of the present study to investigate PD program participants' perceptions of the PD program facilitators, future research could investigate (1) whether PD program participants' perceptions vary depending on whether program facilitators are staff or faculty members and (2) whether one type of facilitator over the other leads to better PD program participants' learning outcomes and more improved teaching practices.

4.1.4 PD Program Context

PD program context includes the IHE type and environment (inc. physical and socio-cultural) in which a PD program is implemented. The PD programs examined in this study took place in the context of public US IHEs. The socio-cultural environment included institutional and departmental teaching-related norms and practices. This includes, for example, the priority each IHE placed on teaching. Generally, research-intensive institutions prioritize research over teaching (Skelton, 2013), emerging research institutions focus on increasing research efforts while maintaining teaching efforts (Birx et al., 2013), and community colleges prioritize teaching over research (Brown & Bickerstaff, 2021). These generalizations apply to the three IHEs in the present study.

How an IHE prioritizes research and teaching heavily influences how its instructors decide to approach their teaching. For example, faculty at research-intensive universities feel that teaching and attending PD programs are undervalued by their departments because their IHE prioritizes research (Skelton, 2013). However, when faculty at research-intensive universities are encouraged to develop their pedagogical knowledge and skills, they are more likely to attend PD programs and implement what they learn into their teaching methods (Lieff et al., 2012; Nevgi & Löfström, 2015; Skelton, 2013).

Prioritizing teaching and placing value on faculty participation in PD programs is considered a linchpin in transforming antiquated approaches to undergraduate STEM education (van Lankveld et al., 2017). The community college and emerging research institution in the present study have institutional norms that prioritize education and instructors' PD. In contrast, the research-intensive university neither expects nor requires faculty to attend teaching-focused PD programs.

4.2 PD Program Impact on Higher Education Transformation

To answer RQ2, this section discusses the extent to which each suite of PD programs offered at each IHE is likely to transform undergraduate STEM education. To do so, the discussion draws upon and is organized using the factors in Futrell's model of PD as a transformer of education. This study's results and how they are connected to the broader research literature are discussed.

4.2.1 Local Focus

The PD programs examined in this study were developed to meet the local needs of the instructors at the three IHEs. The extent to which those needs were met is challenged by the existing research literature. In all three cases, PD programs were designed to meet general teaching needs among faculty with a wide range of disciplinary backgrounds.

Previous research suggests faculty have positive experiences in mixed-discipline PD program cohorts (Kaslow et al., 2004b; Nixon, 1996). Other research, however, suggests benefits from (1) STEM-oriented or discipline-specific PD programs (Hunter, 2019; Neumann, 2001; Tobias, 1990), and (2) PD programs tailored to participants' needs and preferences (McLean et al., 2008; Rogers et al., 2007). Benefits include collegiality among faculty in the same/similar discipline (Quinlan, 1998), "enhancing pedagogical practice" (McLean et al., 2008, p. 576), and retaining students in STEM courses (Hunter, 2019; Tobias, 1990). Thus, the general absence of STEM-oriented or discipline-specific PD programs at the three IHEs suggests that offering more of such programs could further aid the transformation of undergraduate STEM education at these IHEs.

4.2.2 Funding

Futrell and others view funding for PD programs as a necessity (Futrell et al., 1995; McKee et al., 2013; Nixon, 1996; Sunal et al., 2001). A study that surveyed 700 higher education instructors concluded one of the greatest barriers to PD for instructors was lack of funding to participate (Dilshad et al., 2019) because off-campus PD programs often incur a cost (i.e., travel, registration). Also, on-campus PD programs are not sustainable without sufficient and continuous funding (Eckel & Kezar, 2003a, 2003b).

This study's results highlight the essential link between program funding and program sustainability. For example, the research-intensive university offered many PD programs between 2014 and 2019, but 73% of those programs were discontinued by 2019. When external sources of funding for these programs were depleted, there was no internal funding to continue them. To further highlight the importance of institutional financial investment in instructors' PD, all PD programs that were internally funded in 2014 were sustained by the end of 2019 at all three IHEs.

4.2.3 Local Leadership

Local leadership here focuses on PD facilitators and department chairs because they are leaders who are most directly connected to faculty participating in PD programs. According to a study by Rogers et al. (2007), benefits to having local leaders or faculty members be PD program facilitators include they are easily accessible in times of need and can promote collegiality among themselves and PD program participants. At the community college and emerging research institution, all PD programs were facilitated by faculty members, which provides the benefits of peer-to-peer relationships between facilitators and participants. Therefore, the community college's and emerging research institution's suites of PD programs had an advantage that increased its capacity to provide participants with beneficial PD experiences compared to the research-intensive university.

At the same time, other research emphasizes the importance of department chairs' leadership and encouragement of instructors' PD. Their support is associated with positive faculty attitudes towards teaching and research on teaching (Lieff et al., 2012; Nevgi & Löfström, 2015). Although outside the scope of this study, future research could examine the qualities of department chairs that contribute to the transformation of undergraduate STEM education at the department level.

4.2.4 Long-Range Planning

Long-range PD planning is key to effective transformation initiatives in education (Futrell et al., 1995; McKay & Cutting, 1974). Planning involves "defining an organization's goals, establishing an overall strategy for achieving those goals, and developing a comprehensive suite of plans to integrate and coordinate activities" (Robbins et al., 2007, p. 5). Long-range planning for undergraduate STEM education transformation must consider (1) providing STEM faculty with teaching-focused PD programs, (2) allocating time for STEM faculty to participate in such PD programs, and (3) developing recognition and reward structures for implementing active-learning teaching methods.

STEM education transformation is more likely to take place at IHEs that prioritize learning and effective instructor PD. For example, among our cases, only the community college expected faculty to engage in PD. In contrast, at research-intensive universities, teaching is often viewed as a "low-status activity" (Skelton, 2013, p. 916). So, PD programs at research-intensive universities are likely to have less impact on transforming STEM unless there are shifts in the ways these types of IHEs prioritize, value, recognize, and reward instructors for using effective teaching methods.

4.2.5 Teachers and PD

Education transformation efforts are more likely to be effective when teachers and their PD are valued (Futrell et al., 1995). When college and university faculty participate in PD programs, there is greater potential for STEM transformation (Derting et al., 2016; Guskey & Sparks, 2004; Rutz et al., 2012). Research suggests long-term engagement in PD programs "encourage[s] a perspective on teaching as a lifelong endeavour and necessitate[s] continuous learning by faculty" (Brancato, 2003, pp. 61). It also helps instructors become more comfortable implementing changes in the classroom and improves student learning outcomes (Brown, 2004).

Furthermore, instructors are more likely to adopt active-learning teaching methods when they participate in PD programs for at least one semester (Supovitz & Turner, 2000; Henderson et al., 2011). Almost 67% the of the PD programs at the research-intensive university were semester-long or year-long programs, compared to about one-third at the community colleges' and the emerging research institution's suites of PD programs. This suggests that the research-intensive university has a potential advantage over the other two IHEs in using faculty PD as a vehicle for STEM education transformation. For this potential to be fully realized, a critical mass of instructors must successfully participate in such PD programs and apply what they learn in those programs to their teaching.

4.2.6 Collegiality Among Peers

Collegiality among peers is needed for education transformation (Futrell et al., 1995). *Discuss-and-reflect* and *mentorship* PD *program types* promote such collegiality among peers (Czerniawski et al., 2017; Harrison & McKeon, 2008; Hurst, 2010; Kwan & Lopez-Real, 2010; Nevgi & Löfström, 2015; Nixon, 1996). They are associated with the additional incentive and outcome of building supportive professional networks (Watkins, 1999). Poyas and Smith (2007) found that interacting with peers in a PD program and developing a supportive teaching network with them were among the most valuable experiences faculty had while participating in a PD program. The studies cited here highlight the value that faculty place on peer-to-peer interactions and supportive networks made possible through their participation in PD programs. They also reinforce the already discussed value that faculty place on *mentoring* and *discuss-and-reflect* PD *program types*.

4.2.7 Time to Participate in PD

It is just as necessary for faculty to have access to PD programs as it is for them to have time to participate in these programs (Futrell et al., 1995). Having time to participate in PD programs, however, is often a challenge for faculty at IHEs (Skelton, 2013). One study, for example, documented 68% of faculty PD program participants reported the lack of time as a notable barrier to participating in PD programs (Dilshad et al., 2019). Furthermore, studies about research-intensive universities reported faculty members often feel there is little time in their schedules to participate in PD programs because they must prioritize research over teaching (Austin et al., 1997; Skelton, 2013). Other faculty at research-intensive universities who teach courses but do not have a permanent position are especially unable to spend time on their PD (Korhonen & Törmä, 2016).

Although it was beyond the scope of this study to collect data about individual instructors' time spent on PD, data about whether IHEs build in time for their faculty to participate in PD programs was collected. Of the three IHEs, only the community college expected its faculty members to complete PD programs as part of their employment and promotion. At the emerging research institution and the research-intensive university, faculty engaged in PD programs on a voluntary and ad hoc basis. If faculty at these two IHEs had built-in time for participating in PD programs, faculty participation in PD programs would likely increase and so would the potential for PD programs to transform undergraduate STEM education. Built-in time could be implemented in different ways. Possible ways include, but are not limited to, offering (1) a required year-long PD program for all new and incoming faculty members; (2) a semester-long teaching release to engage in PD; and (3) rewards in the merit, promotion, and tenure review processes for completing PD programs.

4.3 Implications

The above discussion of our results in the context of this study's theoretical framework (i.e., Borko's and Futrell's models) and the extant research literature suggest some IHEs' suites of PD programs are better poised to transform undergraduate STEM education than others. Among our cases, all three suites of PD programs had the components of a PD system as outlined by Borko. However, as the extant literature reveals, it is necessary but not sufficient to simply have these components in place because the ways in which these components are structured or implemented can have greater or lesser impact (e.g., *mentorship* PD program types are associated with more benefits than *workshop* PD program types). Similarly, all three suites of PD programs address the Futrell factors needed for PD to transform education, but the three IHEs satisfy these requirements to different degrees. Thus, their respective suites of PD programs have varying potential to transform undergraduate STEM education. Synthesizing the discussion of our results and the extant literature, we find the suite of PD programs at the community college has the greatest potential to transform undergraduate STEM education, followed by the emerging research institution, and then the research-intensive institution.

The reader might assume that this is the natural order of how things should shake out; however, Nobel Prize winner Carl Wieman challenges this assumption. He believes, “A necessary condition for changing college education is changing the teaching of science at the major research universities, because they set the norms that pervade the education system regarding how science is taught and what it means to ‘learn’ science” (Wieman, 2007, p.15). Whether a research-intensive institution or not, IHEs can learn from each other about what works at other institutions and how they might increase the potential to transform undergraduate STEM education at their own institutions. (To increase this potential at the three IHEs in this case study, IHE-specific recommendations are discussed in Appendix A). Such efforts would benefit from being informed by and grounded in theory about how PD programs can transform undergraduate STEM education at IHEs.

4.4 Framework for PD Programs to Transform Undergraduate STEM Education

To the best of the authors’ knowledge, there does not exist a theoretical framework for PD programs to transform undergraduate STEM education at IHEs. Thus, this study helps to fill this gap by proposing a new framework. The proposed framework (1) combines the slightly modified versions of Borko’s and Futrell’s models used in this study and (2) uses the discussion of this study’s results as validation for the framework (Figure 1, see next page).

The new framework possesses two dimensions across which PD programs can be understood with the goal of transforming undergraduate STEM education in mind. The first dimension is the components of a PD system (from Borko’s model), and the second dimension is the factors of PD programs that facilitate STEM transformation (from Futrell’s model). These two dimensions intersect to yield characteristics of and/or recommendations for PD programs that can facilitate undergraduate STEM education transformation at IHEs. In Figure 1, the column headings are the components of a PD system, and the row headings are the factors in the relationship between PD and STEM education transformation. Each characteristic and/or recommendation in the figure was developed at the intersection of a row heading and column heading. These recommendations can be used to design, implement, and evaluate PD programs at IHEs. Thus, this framework is a useful tool for staff, faculty, and administrators charged with overseeing PD programs at their institutions.

Factors in Relationship between PD and Undergraduate STEM Education Transformation	Components in PD System for STEM Instructors at an IHE			
	PD Program Type	**Faculty PD Participants**	**PD Designers and Facilitators**	**PD Context**
Local Focus	The program type meets instructors' needs at the IHE.	The PD participants are STEM instructors at the IHE.	The PD designers and facilitators have experience teaching STEM at the IHE.	The local PD context informs the PD programs offered.
Funding	Funding needed for desired PD program types is allocated.	Funding for participant compensation is allocated, esp. when participation is not expected/required.	Funding to compensate PD designers and facilitators is allocated.	Funding for PD programs at the IHE is allocated.
Local Leadership	Leaders at the IHE have input on the types of PD programs that aim to transform undergraduate STEM education.	PD participants have leadership roles to transform undergraduate STEM education.	PD designers and facilitators have leadership roles to transform undergraduate STEM education.	Leaders at the IHE create contexts conducive to instructors' PD and undergraduate STEM education and transformation.
Long-range PD Planning	PD programs are longer-term in duration (i.e., at least one semester) and provide participants with practice and feedback.	PD participants develop long-term PD goals for themselves as instructors and engage in ongoing PD.	PD designers and facilitators offer PD programs that cultivate instructors' long-term PD goals and transform undergraduate STEM education.	The PD context has long-range plans to transform undergraduate STEM education through instructors' PD.
Instructors Engagement	Instructors have input on the types of PD programs that are offered.	Instructors are expected to participate in PD programs.	Instructors serve as PD program designers and facilitators.	Instructors have the means and agency to create contexts conducive to offering PD programs.
Collegiality	PD programs provide opportunities to develop collegiality among peers.	PD participants develop collegial relationships with colleagues in their PD program cohort.	PD designers and facilitators cultivate collegiality with and among participants.	The PD context values collegiality among instructors in support of transforming undergraduate STEM education.
Time to Participate	PD programs are designed to optimize instructors' time participating in the program.	PD participants commit time to participate in PD programs.	PD designers and facilitators manage time to optimize participants' learning, growth, and development as instructors.	The PD context builds in time for instructors to participate in PD programs.

Figure 1. A framework for PD Programs to Transform Undergraduate STEM Education at IHEs, which combines Borko's and Futrell's models

4.5 Limitations

This study characterizes three suites of PD programs offered over a 5-year period (2014-2019), each at a different type of public US IHE: a community college, an emerging research institution, and a research-intensive university. Examination of each IHE's suite of PD programs permits interinstitutional comparisons and provides insights into a range of PD programs offered at public US IHEs. Nevertheless, the results are not necessarily generalizable to all institutions of each institution type. Furthermore, the results may not be generalizable to private US IHEs and non-US IHEs because they may have different institutional norms, practices, and funding structures.

4.6 Conclusion

This multiple case study characterized three suites of PD programs offered from 2014—2019 at three types of public US IHEs: a community college, an emerging research institution, and a research-intensive university. The results suggest the community college's suite of PD programs (1) is better structured and implemented to provide STEM instructors with beneficial PD experiences and (2) has greater potential to transform undergraduate STEM education compared to the other two IHEs. The results suggest that all three institutions can increase their potential to transform undergraduate STEM education in specific ways to further broaden participation in STEM education, workforce development, and career pathways. To the authors' knowledge, this is first study that systematically compares multiple PD programs at multiple types of institutions. Although the institution-specific results and recommendations (Appendix A) are not necessarily generalizable to other like institutions, the results do highlight the range of PD programs at public US IHEs and their potential to transform undergraduate STEM education and the recommendations are likely applicable in varying degrees to other IHEs. Lastly, the innovative framework of PD programs at IHEs (Figure 1) offers utility as a tool for designing, implementing, and evaluating PD programs aimed at transforming undergraduate STEM education at public US IHEs and possibly other contexts.

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Authors contributions

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Appendix

Appendix A

IHE Specific Recommendations

1. Recommendations for PD Program Structure and Implementation

The discussion of this study's results in the context of Borko's model of a PD system and what the existing literature says about the components in that model inform the following recommendations for how each IHE in the study can enhance the structure and implementation of its suite of PD programs.

The community college had institutional norms that value faculty participation in PD programs, it offered both *mentorship* and *discussion-and-reflection* type PD programs, and all its PD programs were facilitated by faculty. Although the community college had PD programs more likely to provide participants with beneficial experiences compared to the other two IHEs, recommendations to further enhance their suite of PD programs include: (1) invest in more *mentorship* and *discussion-and-reflection* type PD programs, (2) offer STEM-oriented or discipline-specific PD programs for STEM faculty, and (3) require PD program facilitators who facilitate discipline-specific PD programs to have similar academic backgrounds as PD program participants.

Like the community college, the emerging research institution had institutional norms that value faculty participation in PD programs and all PD programs were facilitated by faculty. Of note, it offered approximately the same percentage of *discuss-and-reflect* type PD programs as it offered *workshops*. The emerging research institution can improve its suite of PD programs by (1) following the same recommendations for the community college and (2) offering *mentorship* type PD programs to faculty members.

The research-intensive university can improve its suite of PD programs by (1) following the recommendations made for the community college and emerging research institution and (2) prioritizing STEM education by creating a PD system that recognizes and rewards STEM instructors for high quality teaching.

2. IHE-Specific Recommendations for PD Impact on STEM Higher Education Transformation

The discussion of this study's results in the context of Futrell's model and what the existing literature says about the factors in that model inform the following recommendations about how each IHE in this study can enhance the potential of their suites of PD programs to transform undergraduate STEM education.

The community college's suite of PD programs outshined those of the research-intensive university in terms of its potential to transform undergraduate STEM education. Specifically, the community college (1) maintained a local focus by offering all PD programs locally, (2) internally funded all PD programs, (3) supported local leadership for PD programs, (4) valued and prioritized instructors' PD, (5) provided PD experiences that promote collegiality among faculty, and (6) provided built-in time for faculty to participate in PD programs.

Thus, recommendations to enhance the community college's suite of PD programs' potential to transform undergraduate STEM education include (1) prioritize long-term planning for PD programs and (2) increase the number of PD programs that promote collegiality among faculty, such as *mentoring* and d*iscuss-and-reflect* type PD programs.

Although the emerging research institution also maintains a local focus by offering all PD programs locally, internally funding all PD programs, supporting local leadership for PD programs, and valuing and prioritizing instructors' PD, it can enhance its PD program suite's potential to transform undergraduate STEM education by (1) also following the recommendations for the community college above and (2) providing built-in time for faculty to participate in PD programs.

Although the research-intensive university maintained a local focus for instructors' PD by having on-campus PD programs and supported local leadership PD by hiring staff to facilitate PD programs, there is room for improvement. The results of this study suggest the research-intensive university's suite of PD programs has low potential to transform undergraduate STEM education. It can increase this potential by (1) following the recommendations made above for the community college and emerging research institution; (2) allocating a budget to internally fund high quality teaching-focused PD programs; (3) encouraging department chairs to support faculty participation in PD programs; and (4) offering faculty members opportunities to facilitate PD programs and, as such, serve as local leaders.

A final recommendation that applies to all three IHEs is to deliberately pursue the goal of transforming undergraduate STEM education and to engage in long-range planning that purposefully incorporates the PD of their instructors. A framework for transforming undergraduate STEM education through PD programs is laid out in Section 4.4 of this article.