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Guest editorial: Reflections on Course-Based Undergraduate Research

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Introduction

The primary goal of this special issue is to provide an open-access resource to university faculty teaching mathematics courses. This editorial serves as a reader's guide to this issue. Some faculty may wish to include Course-Based Undergraduate Research Experiences (CUREs) in the mathematics classes that they are teaching, and other faculty members may already be teaching CUREs but are seeking additional ideas and advice. The 13 articles in this issue are collectively written by 24 university faculty members who have taught CUREs at 10 different institutions of higher education. These authors illustrate several models for CUREs, demonstrating their pros and cons, and have reflected on how they would improve upon their teaching. It is our hope that other faculty members will be encouraged to adapt and implement similar CURE courses within their own institutions.

A secondary goal of this issue is to show undergraduate students examples of what they might expect when deciding whether to register for CUREs in mathematics. This goal is important to us because we, as undergraduate students at the Massachusetts Institute of Technology over 20 years ago, had the opportunity to participate in undergraduate research, both through coursework and paid summer internships. We found that the level of initiative required for beginning in research through coursework was lower. For example, we both enrolled in MIT's first-year advising seminars led by faculty who ran these as CUREs to introduce students to research in the faculty member's area of expertise. Through participating in these CUREs, we learned mathematics that was new to us at the time and solidified our

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desire to pursue mathematics as an undergraduate major. We also found that if we wanted to pursue additional research in greater depth, then it would be sensible to later seek out paid opportunities. We feel that we have personally reaped the benefits of these experiences, as they have significantly shaped our outlook on research; and in turn, these undergraduate experiences have positively shaped our educational trajectories and career paths.

The inclusion of research experiences within university mathematics classes has seen rapid growth over the past decade and its benefits have been well studied [3]. Its benefits have included increased participation by under-represented populations in mathematics (see [5, 8, 10]) and increased student interest in mathematical science careers (see [5, 7, 8]). However, there are unique challenges to faculty who choose to run a CURE, as teaching students to perform research is sometimes daunting. Technical hurdles to learning research-level mathematics have prompted some schools to develop a sequence of CURE courses (see [5, 8]), although this is not always necessary. One way to foster originality in the research is through having a sponsoring organization which provides suggestions for research questions to be investigated by the undergraduate students (see [5, 9, 10]).

Many of the authors for this special issue have sought additional funding, either through internal sources [6, 10], external sources, or both [5]. Some of the external funding sources are the following: National Science Foundation (NSF): Research Experience for Undergraduate Faculty [4], United Health Foundation [5], Improving Undergraduate STEM Education [7], Division of Undergraduate Education [13]; U.S. Department of Education's Hispanic Serving Institution grant [8]; Howard Hughes Medical Institute's Inclusive Excellence grant [3, 12, 13].

In what follows, we summarize the articles in this special issue with respect to course structures, types of learning contexts, and types of institutions represented. We hope that this synopsis will help direct readers' attention to articles that may be of interest to them due to similarities in some of the features described. We also hope to show readers that the benefits of running a CURE are likely to outweigh any difficulties that need to be overcome.

Classifications of course structures represented in this special issue

In Table 1, we identify the kind of research that students pursued during the CURE. While six of the articles [5, 6, 7, 9, 10, 11] discuss aspects of data analytics / probability / statistics used in CURE courses, this special issue also provides examples of other mathematical topics including graph theory [4], algebra and combinatorics [8], optimization [12], and education [13].

Table 1. Structure of courses described in this special issue.

Article #	Research described in article	Required course for major?	Part of a course sequence?	Majors	Freshman or Honors Seminar
4	Graph Theory	no	no	Math, Computer Science (CS), Biology (Bio), Engineering (Eng)	no
5	Data Analytics: COVID	no	yes	Math, CS, Bio, Eng, Management, Other	no
6	Data Analytics: Soccer	no	no	Math, Exercise Science, Other	yes
7	Passion-Driven Statistics	yes	no	Psychology, Sociology, Nursing, Neuroscience	no
8	Lie theory & representation theory	yes	yes	Math & CS	yes
9	Data Analytics: Call Center	no	no	Math	yes
10	Data Analytics: Amusement Park	no	no	Math, bio, business, chem, CS, economics, health sciences, music, neuroscience, physics, politics & int'l affairs, Spanish	no
11	Probability & Statistics	yes	no	Math, CS, STEM	no
12	Machine Learning	no	no	Math	no
13	Education Action Research	yes	no	Middle school math education, special education	no

Classifications of learning contexts represented in this special issue

The courses described in this issue displayed a variety of learning contexts, as shown in Table 2. We asked all authors to refer to the five dimensions of learning contexts mentioned by Auchincloss et. al. (2014) in their course descriptions: 1) use of scientific practices during research – whether the student or the instructor designed the study and the methods used in the research; 2) discovery – whether the outcome of the research is novel to the student and / or novel to the world; 3) broader relevance or importance – whether people outside of the course might benefit from knowing the research results; 4) collaboration between and among students and faculty; and 5) whether iteration was built into the course.

Table 2. Classifications of learning contexts represented, based on Auchincloss et. al. (2014).

			Types of learning contexts			
			Traditional	**Inquiry**	**CURE**	**Internship**
Dimensions of learning contexts	**Use of scientific practices**	Study design and methods driven by:	Instructor	Student	Student or instructor	Student or instructor
		Article #s		6,7, 10,13	4,5,8,9,11,12	4,5,8,9,12
	Discovery	Purpose of the investigation defined by	Instructor	Student	Student or instructor	Student or instructor
		Outcome and findings are	Previously established	Varied / may be novel	Unknown / novel	Unknown/novel
		Article #s		6,7,8,11	4,5,9,10,12,13	4,5,9,10,12
	Broader relevance or importance	Relevance of research extends beyond the course?	No	No	Yes	Yes
		Article #s	8,11	8	4,5,6,7,9,10, 12,13	4,5,6,7,9,10,12
	Collaboration	Collaboration occurs among:	Students only	Students only	Students, teaching assistants, instructor	Students & mentors
		Instructor's role is:	Instruction	Facilitation	Guidance / Mentorship	Guidance / Mentorship
		Article #s	8,11	8	4,6,9,10	5,7,12,13
	Iteration	Risk of generated "messy" data are…	Minimized	Significant	Inherent	Inherent
		Iteration is built into the process	Not typically	Occasionally	Often	Often
		Article #s	4,8,13	13	5,6,7,9, 10,11,12	5,6,7,9,10,12

Classifications of institutions represented in this special issue

The CUREs discussed in this issue have been implemented at a wide array of institutions of higher education across the United States. We describe the institutions represented in this issue, with the intention of helping readers quickly identify similarities with their own institutions. In Tables 3 and 4, we summarize some characteristics of these institutions, based on Carnegie Classification (2021) data taken from Fall 2020 enrollments and degree completion information from the academic year 2019-2020.

Table 3. Undergraduate instructional program classifications represented in this special issue

		Graduate Coexistence		
		No graduate coexistence	**Some graduate coexistence**	**High graduate coexistence**
Undergraduate Instructional Program Classification	**Arts & Sciences Focus**	Davidson College, NC **	Wesleyan University, CT ^	
	Arts & Sciences plus Professions	Central College, IA **	Furman University, SC *	University of Rochester, NY ^
	Balanced Arts & Sciences / Professions		California State Univ - Monterey Bay, CA **	
			CUNY Lehman College, NY *	
			Towson University, MD ^	
	Professions plus Arts & Sciences		Bethel University, MN **	Rensselaer Polytechnic Institute, NY *
			Lewis University, IL *	
	*Undergraduate Profile Classifications: ^ Inclusive, * Selective, ** More Selective*			

Table 1 describes the Undergraduate Instructional Program classifications of the institutions represented in this special issue. The “Graduate Coexistence” classifications refer to the extent to which these institutions offered graduate degrees, as reported by Carnegie (2021). We also hope readers will gain an appreciation that a CURE can be offered successfully at schools with no graduate coexistence [1, 6]. On the other end of the spectrum, [5] is authored by faculty members who teach at institutions with high graduate coexistence. However, the vast majority of the articles were written by faculty teaching at institutions with “Some graduate coexistence,” that is, graduate degrees were observed in up to half of the fields corresponding to undergraduate majors. In Table 1, the “Balanced Arts & Sciences / Professions” undergraduate degrees category refers to having between 41-59% of bachelors degrees awarded being balanced between arts and sciences and professional fields. Having an “Arts & Sciences Focus” indicates at least 80% of the bachelors degrees awarded in the arts and sciences; having an “Arts & Sciences plus Professions” focus indicates that 60-79% of the bachelors degrees were in the arts and sciences; and having a “Professions plus Arts & Sciences” focus indicates that 60-79% of the bachelors degrees in professional fields.

The selectiveness of the schools was categorized by Carnegie (2021) based on entrance exam (SAT or ACT) score data for first-year students. The “Inclusive” category indicates that the institutions either did not report test score data or had a low level of selectivity. The “Selective” category indicates that the institutions were in the 40th to 80th percentile of selectivity among all baccalaureate institutions. The “More Selective” category indicates the 80th to 100th percentile of selectivity.

Table 4. Size and setting of institutions represented in this special issue

		Residential Setting		
		Primarily Nonresidential	**Primarily Residential**	**Highly Residential**
Institution size [# of bachelors degrees conferred]	**Small**			Central College [300]
	Small			Davidson College [564]
	Small			Furman Univ. [836]
	Small			Wesleyan Univ. [1128]
	Medium		Bethel Univ. [784]	Rensselaer Polytechnic Institute [1573]
	Medium		Lewis Univ. [1146]	California State Univ.-Monterey Bay [1999]
	Large	CUNY Lehman College [2660]	Towson Univ. [4869]	
	Large	Univ. of Rochester [2099]		

The rows of Table 4 describe the Size classifications of the institutions, where “Small” refers to institutions with 1,000-2,999 degree seeking students – including both undergraduate and graduate students, Medium refers to institutions with 3,000-9,999 degree seeking students, and Large refers to institutions with over 10,000 degree seeking students. The number of bachelors degrees conferred between July 1, 2019 to June 30, 2020 are also provided. The columns of Table 4 describe the residential settings of the institutions. An institution is considered "Primarily Nonresidential" if fewer than 25% of the undergraduates live on campus and / or fewer than 50% of the undergraduates attend full time. An institution is considered "Primarily Residential" if 25-49% of the undergraduate students live on campus, and at least 50% of the undergraduate students attend full time. An institution is considered "Highly Residential" if at least half of the undergraduate students live on campus, and at least 80% of the undergraduate students attend full time.

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