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Foreword: Stepping into the Unknown with Research

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ABSTRACT:
Deep and broad work is being done by undergraduates, with a significant increase in the last three decades. The growth in undergraduate research opportunities has important effects in the STEM community. In particular, course-based research is a means toward attaining more inclusivity in the research community. This article provides some practical advice and resources for getting started, and describes the author's own efforts to integrate sports analytics work, service-based learning and social justice research into his undergraduates' research experiences.

Keywords: course-based undergraduate research experience, business, industry and government, sports analytics, service-based learning, social justice research

Introduction

Mathematics teaches problem-solving, which inherently involves getting stuck and learning to get unstuck. As a professor, this process from stuck to unstuck almost becomes second nature. You work on a research question and simply get stuck – really stuck. You work on writing a homework or test question and get stuck – really stuck. You sit down to write an article that was tentatively outlined in your mind and stare at a blank screen for what seems like uncountable minutes that could be hours. In academia, "not knowing" leads to discovery. Stepping into the unknown is what leads to the breathtaking view of a new intellectual landscape. Research, in particular, is often a process of pursuing many unsuccessful ideas before finally realizing success.

One need only to attend an undergraduate student research poster session to see examples of the deep and broad work being done by undergraduates. Such work has seen a significant increase in the last three decades. While there are many metrics of success and levels of activity, let's look at the size of the undergraduate student poster session at the Joint Mathematics Meetings (JMM). The session began in 1991 with no judges, no prizes and 12 posters involving fewer than 20 students [DG]. In 2020, just before the pandemic, there were approximately 360 posters and nearly 600 student presenters [Mat].

The growth in undergraduate research opportunities (UROs) has important effects in the STEM community. A 2007 study [RHM] found that "many types of undergraduate research experience fuel interest in STEM careers and higher degrees. No formulaic combination of activities optimizes the URO, nor should providers structure their programs differently for unique racial/ethnic minorities or women. Rather, it seems that the inculcation of enthusiasm is the key element—and the earlier the better. Thus, greater attention should be given to fostering STEM interests of elementary and high school students and providing UROs for college freshmen and sophomores."

Undergraduate research can be in-class or out-of-class. Regarding course-connected research, in their 2017 paper, "Course-Based Undergraduate Research Experiences Can Make Scientific Research More Inclusive," Bangera, Brownell, and Hatfull note that the diversity of the U.S. is not reflected in the country's scientific research community. Hispanics, African Americans, and Native Americans made up 31% of the general population in 2010 with only 18% of this population attaining a STEM bachelor's degree and 7% attaining a doctorate. The authors note how undergraduate research experiences "are becoming more or less a prerequisite for admission into graduate school and eventually a career in academia..." They also note that "the limited number of undergraduate research opportunities available and the structure of how students are selected for these independent research lab positions exclude many students and can perpetuate inequities in the research community." The essay encourages course-based research as a means to mitigate this issue and attain more inclusivity in the research community.

It's important to note that course-based undergraduate research experiences in mathematics do not have a long history. During the late 1990s to early 2000s, national calls for undergraduate STEM education reform led to a common theme that students should participate in a research experience. While other STEM fields grew in their course-based research experiences, even as of 2022, such experiences in mathematics (especially pure mathematics) are virtually non-existent in the literature as noted in [DSW]. Even so, we'll see through the pages of this special issue that course-based undergraduate research experiences in mathematics are and have been active. Through your reading, you can be ready to engage your students in course-based undergraduate research.

1 Where to begin?

A natural question in mentoring undergraduate research is where to begin. You may feel interested but unprepared to mentor such work. Note, this is a similar position to many students as they begin their research. The 2007 study by Russell, Hancock and McCullough [RHM] stated that the most frequent request by undergraduate researchers was increased or more effective faculty guidance. You may feel the same regarding beginning to mentor undergraduate research – in or out of the classroom. You are willing and interested, but want guidance. You have three mentors, Michael Dorff, Allison Henrrich and Lara Pudwell, offering advice and insight in their book "A Mathematician's Practical Guide to Mentoring Undergraduate Research (Classroom Resource Materials)" on creating an undergraduate research program (URP) [DHP]. On MAA Reviews, the book is noted as "a complete 'how to' guide to create a URP from scratch, including the benefits and challenges of doing so...." [Gab] The book details best practices in establishing an undergraduate research program and also dispels various misconceptions such as assuming one needs advanced students for research when the goal is enthusastic and hard-working students, and not necessarily advanced students, and the fact that undergraduate research may not require additional time in your schedule but simply a readjustment in how your time on mentorship and scholarship is spent.

Course-based research can connect with the community. Service-based learning enables students to learn and/or implement classroom material while volunteering with an agency (usually a non-profit or social service group); students engage in reflection activities to deepen their understanding on the material and its impact. To jumpstart such work, we can again turn to trusted resources like "Service-Learning Essentials" by Barbara Jacoby [Jac]. The book offers insight on such topics as what service-learning opportunities your institution should offer, advice on how to engage students in critical reflection, and the ever-important best practices for developing and sustaining service-learning partnerships that mutually benefits the campus and community.

Course content can also connect with business, industry and government (BIG). The Preparation for Industrial Careers in Mathematical Science (PIC Math) program of the Mathematical Association of America funded by the National Science Foundation and National Security Agency prepares faculty to make industrial connections for course-based research. In such a course, the faculty member doesn't lecture but facilitates students as they work in small groups to solve data analytics problems from business, industry and government. The National Academy of Sciences' 2012 report [Nat] presented 10 vital breakthrough actions for US prosperity and security. Among these was business, industry and government's involvement with college and universities with internships, students projects, advice on curriculum design and real-time information on employment opportunities in business. The PIC Math program is such an action. A 2019 report shared that more than 1,300 undergraduates at more than 100 US universities and colleges participated in PIC Math courses [DW]. Making BIG connections can be difficult for faculty who haven't spent time in industry. The PIC Math program contains such training. Another option is to explore the myriad of resources and activities of the BIG Math Network [Big]. Students at all levels may be interested in the Big Math Industry-Student Connection Series [Big] which serves as an interactive "office hours" focused on connecting students directly with industry members who can answer student-generated questions.

Rather than reaching out to BIG or nonprofits in your community, you can also lead students to questions to spark their interest. The key can be finding resources that pose such questions. For example, to work in social justice with mathematics, you can read "Mathematics for Social Justice" by Gizem Karaali and Lily S. Khadjavi [KK]. The book covers topics such as sea level change, fairness in electoral redistricting, and school choice. Each chapter discusses the relevant mathematics, how an instructor prepares for the class, open-ended questions for reflection, and extensions. Such books can springboard a professor and students to areas of inquiry – beginning the research journey.

2 Example Projects

We've discussed resources to help get you started with research in and out of class, with BIG, nonprofits, or in areas such as social justice. Let's see examples. Research often also requires a new, customized approach to solution. As such, students use their skills in the course to expand into new areas of learning. For this and other reasons, research teaches skills beyond the classroom and beyond mathematics. This section presents examples from the author's work and gives larger context to elements gained by the students.

College-based research: A trove of research ideas may exist in your academic community. The author specializes in sports analytics. His expertise developed and was established working with college coaches in men's basketball [Ber]. A key in such a connection is establishing trust. The group worked on a large variety of analytics questions – collecting shot data for every game, supplying scouting reports from online statistical databases, and giving the statistics attained by every five-player lineup combination. This work led to research questions from the coaches and the possibility to integrate questions into classes. The sports analytics group began in 2013 with three students. The work also expanded to women's basketball, men's and women's soccer, football, baseball, lacrosse, and volleyball. The group roughly doubled in size for multiple years, reaching almost 100 students in the fall of 2019, just before the global pandemic.

Working with the coaches led to broader connections with college athletics. The author teaches a discrete mathematical modeling course teaching topics like Monte Carlo simulation, Markov Chains, optimization, and sports ranking to largely math and computer science majors. In a final group project for the course, a group was tasked with creating automated game previews of men's basketball games from online statistics of the team. Such automated narratives would aid college athletics and the content they share with fans. Here is an excerpt of a game preview, created entirely by computer code, for the January 8, 2021 game between Davidson College and the University of Dayton:

> Davidson has a 3-2 record on their home court and is 6-4 overall this season. Davidson is averaging 71.3 PPG, which ranks 209th in the nation. Opponents are scoring a low 64.6 points on the Davidson defense. They are 45.7% and 35.9% from the field and the three point line, respectively. Davidson makes 9.4 threes per game. From the free throw line, they are shooting 70.2%. In wins, Davidson scores 14.5 more points than their opponent. However, when they lose, they get beaten by an average of 5.0 points. Hyunjung Lee spearheads Davidson's scoring, collecting 16.9 points per game while shooting 55.4% from the field. Along with Lee, Kellan Grady helps offensively, scoring 16.3 PPG on 42.3% shooting.

One important aspect in service-learning, BIG or college-based research are the deliverables. What is being delivered to the partner? In the automated game previews, a code with an intuitive and easy-to-use interface for someone who hasn't taken coding is necessary. Creating automated game previews is the underlying mathematical problem but having it usable by the partner is of fundamental importance to the problem's success.

BIG research: The success of the sports analytics group led to connections with professional sports organizations and work outside the classroom. The group was posed an open problem, involving the analysis of the data produced by STATS LLC and their SportVU cameras for National Basketball Association (NBA) games. Specifically, for each game, the NBA teams received an XML file containing raw coordinate data for each player along with the UNIX time code and game clock information. Coordinate data was also supplied for the ball—with this being 3 dimensional data. This data was captured for each 1/25 of a second producing a 40–45 MB file for each game. The research involved analyzing specific types of moments in the games. Note, this is intentionally vague since the work fell under a confidentiality agreement.

The first step was, quite literally, where to begin given the size of the dataset. The students explored related work which repeatedly involved creating a database. The students began such a task. In time, the author noticed their progress was much, much slower than anticipated. Such a miscalculation regarding the time needed for research isn't uncommon. Yet, the difference between expectation and the actual solution time made the author pause. What led to the original expected timeline? Through reflection, the author realized the research group needed only portions of the SportVU data. As such, the group could quickly preprocess and extract the relevant data. Then, the work would focus solely on that smaller dataset.

The author's research group inadvertently began working on methods that were ideal solutions to other questions, not theirs. Undergraduate research often requires such customized steps. This is a strength of the work. The students make their choices and chart their journey to solution. Yet, one can also suddenly change one's trajectory in undesired ways. As such, checkpoints can be important to help maintain focus. Your group can define deliverables to be produced at scheduled times or schedule moments to literally stop and reflect on the project and its progress. Rarely are benchmarks or periodic reflection on one's progress needed for textbook problem-solving. Yet, it is vital in research and a skill that is beneficial far beyond classroom work.

Service-based learning: The author has worked with his college's Center for Civic Engagement to create service-based learning opportunities in his classes. Communication of data is an important research tool and to facilitate learning in this area, the author has students create infographics. In a general education course (Finite Mathematics), the author springboards from a section in the text on visual representations of data to a data visualization group project. The students work with community and college partners to visualize data of interest. With such projects, students benefit the very town in which they are educated. Further, the students help their community and world before they receive their diploma. Such experiences emphasize how their education can serve and impact the world. Figure

1 contains sample infographics. Two are from the general education class. The one on the left was created for the local Habitat for Humanity office. The one in the middle was for the Davidson College Sustainability Office. The one on the right was developed in an independent study and produced via the request of the Davidson College men's basketball team.

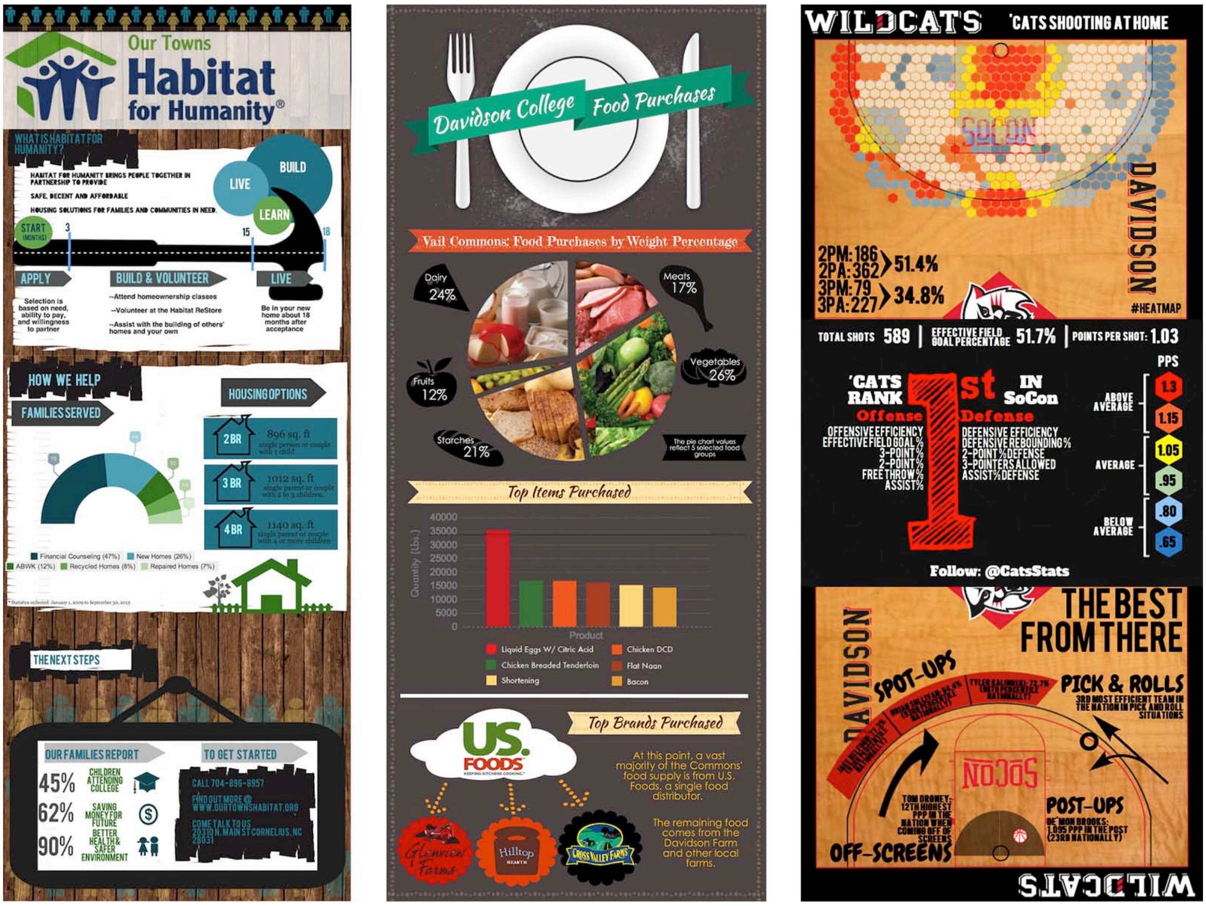

Figure 1: Examples of infographics from service-based learning courses at Davidson College.

In the aforementioned mathematical modeling course, the author has worked with a local food pantry that was undergoing renovation; his students gave recommendations on the eventual layout via insights gleaned from their Monte Carlo simulations. Also using simulation, groups have offered recommendations to local schools on their carpool processes. It should be noted that all of these classes have 3-6 class periods set aside to work solely on the research project. The benefits of investing signifcant instructional time was also seen in a broad study, across multiple institutions, related to a bioinformatics course-based research experience[Sha]. As such, course-based research experiences need adequate instructional time to acheive its full benefits to the students. Much can be gained but some course content will likely need to be omitted to create such space in the term.

Social Justice research: To aid course-based research on topics in social justice, the author collaborated with Dr. Joseph Ewoodzie, a sociology professor at Davidson College. For decades, banks in the U.S. denied mortgages to people, mostly people of color, in urban areas, preventing them from buying a home in certain neighborhoods or getting a loan to renovate their house. The practice — once backed by the U.S. government — started in the 1930s and took place across the country. Redlining, as it is called, is among many of the legally-sanctioned policies used to enforce racial segregation across the United States. In the mathematical modeling class, a group gathered data in redlined areas of Charlotte, NC. They analyzed how closely clustering the data overlays with the redlining of the past. Said another way, they investigated if and how the redlined boundaries are still seen when the areas are clustered by housing prices, health inequalities and other statistics especially associated with systemic racism. The students created an interactive dashboard. The dashboard enabled Dr. Ewoodzie and his researchers to explore the data.

Working with outside partners from one's college community, BIG, or the nonprofit sector requires students to understand what's needed and what needs to be delivered. At times, the partner's understanding of their own needs evolves as a project unfolds. As such, checkpoints with the partner are necessary to ensure a project aligns with the partner's needs. Else, projects can be created that are academically interesting but limited in their usefulness with a partner. It is very important to determine the minimum amount of communication a group will have with a partner. A full understanding of this helps identify suitable partners and also helps the students guage the level and frequency of acceptable contact with the partner.

3 Conclusion and Remark

Ready to dive into this special issue with its plethora of ideas on course-based research? Keep track of your ideas as you read the articles. These initial ideas can be the springboard into course-based research. Such work can serve as momentum into future ideas. And, before long, you will be a resource to others.

When posed with a research question, the first step is to take a step into that unknown. For those experienced in course-based research, there was that first step – into the unknown. When the author first created the sports analytics group, three students walked into his office and asked to create analytics for the men's basketball team, which was and is a highly successful program. The author responded regarding his willingness if the students understood their work might not produce usable results for the team. The students understood. And so, they took their first step and began studying, creating, and sharing their work with assistant coaches. In the end, their work became integrated into game preparation. Yet, fundamental to this success was the willingness to take that first step – into the unknown. With this issue, you have a host of mentors supplying insight and resources. Enjoy the journey with your students as you get stuck and unstuck in exploration and discovery. The next steps is yours.

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