Teaching and Educational Methods

FIRE Sustainability Analytics: An Innovative Approach to Engaging Undergraduate Students in Economics Research

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Abstract
In response to the growing demand for undergraduate research experiences in economics, the FIRE Sustainability Analytics program offers a compelling solution. This program provides a course-based undergraduate research experience (CURE) in empirical environmental economics for first-year students at the University of Maryland (UMD). This paper outlines the program's instructional design, highlights its role in advancing students' higher-order economic proficiencies, discusses the institutional support behind the program, describes its research projects and their outcomes, and shares insights gained from nine years of program implementation.

1 Introduction

In 2014, the University of Maryland (UMD) launched the First-Year Innovation and Research Experience (FIRE) program to provide a sequential course-based undergraduate research experience (CURE) to first-year undergraduate students. A CURE distinguishes itself from traditional research opportunities by enabling a single faculty mentor to engage an entire classroom of students in one or more research projects. Students simply enroll in a course sequence to embark on a research journey. By introducing students to research early in their college tenure, a first-year CURE can have a substantial impact on their academic trajectory.

Open to students of all disciplines, Sustainability Analytics is a research stream within FIRE affiliated with the Department of Agricultural and Resource Economics.[1] It focuses on research in empirical environmental economics with a dedicated faculty who trains and mentors cohorts of 30–40 students. Students learn the statistical software program R and develop data science skills used to organize, summarize, analyze and visualize data. They learn how to use reproducible workflows that exemplify best practices in scientific research. As their skills develop, students contribute to a new or ongoing research topic under the guidance of the Faculty Leader. FIRE Sustainability Analytics students develop strategies for communicating research results and recommendations to a variety of audiences in oral, written, visual, and digital formats. As projects are improved, they are showcased at both university-level and national conferences.

FIRE Sustainability Analytics addresses multiple obstacles that hinder both faculty and students in pursuing undergraduate research. It allows students to be involved in authentic research projects, enhances students' career readiness, underscores the value of faculty mentorship for undergraduate research, and accommodates a substantial number of students at once. This paper discusses the administration, instructional design, and institutional support for FIRE Sustainability Analytics, research projects and outcomes, and lessons learned that may help inform similar initiatives at other institutions.

[1] FIRE Sustainability Analytics is the only stream affiliated with the Department of Agricultural and Resource Economics. The Department of Cell Biology and Molecular Genetics is the only department affiliated with more than one stream.

2 Course Administration and Instructional Design

2.1 Overview

FIRE annually enrolls more than 600 students in sixteen research streams across multiple disciplines. Students accepted into UMD can join the FIRE program by enrolling in FIRE Semester 1.[2] In this General Education Scholarship in Practice course, students learn about the different research streams, including FIRE Sustainability Analytics, and develop basic research and career readiness skills. Toward the end of the fall semester, students submit their research group preferences, and thirty to forty students, who chose FIRE Sustainability Analytics, are selected to join the research group. FIRE matches students solely based on their research interests, so students can join FIRE Sustainability Analytics regardless of their academic background, performance, or selected major. This program feature helps overcome obstacles that impede students from gaining research experience through internships, research assistantships, or an honors program where selection depends on academic performance (Bangera and Brownell 2014).[3]

In the past three cohorts, FIRE Sustainability Analytics students have majored in computer science (11 percent), economics (10 percent), government and politics (9 percent), environmental science or environmental studies (8 percent), and engineering (5 percent). The remaining students (57 percent) have yet to declare a major before joining the program.

Figure 1 shows the FIRE course sequence in chronological order. Following their introduction to FIRE and being matched to FIRE Sustainability Analytics, students enroll in a two-semester course sequence that spans the spring semester of their first year and the fall semester of their second year. During the summer in between, students can choose to participate in the FIRE Research Internship, a three-credit course where students spend fifteen hours a week, for eight weeks, engaging in FIRE Sustainability Analytics accelerated research activities. After the completion of FIRE Semester 3, students can apply to become Peer Research Mentors (PRMs) who help train students in FIRE Semester 2 and lead research projects in FIRE Semester 3.

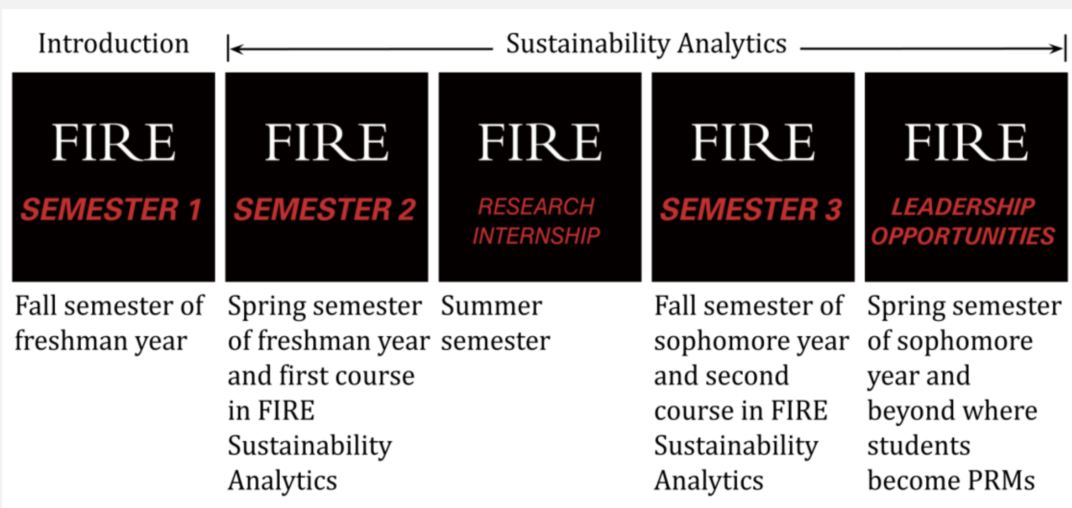

Figure 1: The FIRE Course Sequence

[2] Students not affiliated with other UMD first-year living-learning programs have two pathways to enroll. Some are invited by FIRE during the admission process. Others can submit an application to the FIRE program and join if their application is approved.

[3] FIRE was specifically designed and targeted to provide enhanced opportunities to students not admitted to UMD freshman honors programs.

In all FIRE courses, students are graded primarily on their participation and effort. There is no minimum grade that each student has to obtain to progress through the course sequence from FIRE Semester 1 to FIRE Semester 3. If a student does not pass a course sequence, a conversation is arranged to discuss the reasons behind their previous academic struggles and explore their probability of success as well as how to achieve success in the next course sequence. After FIRE Semester 3, only up to 8 students are selected to become PRMs in a year.

The rest of this section describes the curriculum for the FIRE Sustainability Analytics course sequence consisting of: FIRE Semester 2, FIRE Research Internship, and FIRE Semester 3. In addition, we summarize how course activities contribute to building Hansen's (1986, 2001) higher-order proficiencies, six learning outcomes that he argued all economic majors should achieve (Salemi and Siegfried 1999). Hansen suggested shifting the focus of economics instruction to what students can do with their learning, and he proposed that economics majors should learn how to: gain access to existing knowledge, display command of existing knowledge, interpret existing knowledge, interpret and manipulate economic data, apply existing knowledge, and create new knowledge.

2.2 FIRE Semester 2

The first course in the FIRE Sustainability Analytics sequence encompasses three primary learning outcomes. Students should:

1. Develop proficiency in R programming to clean and combine data, create tables and visualizations, and test hypotheses.
2. Gain an understanding of the environmental science problems and public policies examined in the environmental economics literature.
3. Build collaborative relationships with others who represent diverse cultures, races, ages, genders, religions, lifestyles, and viewpoints.

FIRE Semester 2 is a two-credit course that requires about six hours of a student's time per week. The course integrates three learning environments each week: a self-paced online course, a fifty-minute classroom session led by the Faculty Leader, and a lab session led by PRMs. Each week, students learn basic programming functions in R by completing assigned DataCamp[4] chapters. In each classroom session, the Faculty Leader discusses weekly plans and teaches additional programming skills to supplement the self-paced online course. Students then apply skills from the DataCamp chapters to transform publicly available data from the U.S. Environmental Protection Agency's (EPA; 2022) Clean Air Markets Program Data to replicate the data, figures, or tables created by Deschênes, Greenstone, and Shapiro (2017). This actively engages students in the process of creating a quality research paper. Together with learning how to interpret its results, students can achieve three of Hansen's higher-order proficiencies.

Supervising undergraduate students without programming skills can be time-consuming (Hoyt and McGoldrick 2017). FIRE Sustainability Analytics tackles this problem by utilizing hands-on mentoring by PRMs in the FIRE Sustainability Analytics lab. At the beginning of each semester, students are grouped with other students and a PRM with the same schedule. Students are required to go to the FIRE Sustainability Analytics lab each week to complete their paper replication assignments with their team members and a PRM. This cooperative mode of learning allows students to effectively learn the materials and simultaneously build collaborative skills (Yamarik 2007).

Students are also taught how to document their programming scripts to create a reproducible research workflow. Utilizing GitHub, students clone assignment templates mirroring specific sections of

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[4] DataCamp is a commercial online learning platform for data science that provides free, unlimited access to DataCamp for Classrooms for instructors and their students.

Deschênes, Greenstone, and Shapiro (2017). Once assignments are complete, students push their work to GitHub, where updated repositories are evaluated.

At the same time, students have to learn what questions have been addressed in the field of environmental economics so that they can eventually ask and answer new questions. To learn about the forefront of environmental economics research, students take turns reviewing working papers at the beginning of each week's classroom session. At the beginning of the semester, the Faculty Leader compiles a repository of working papers from the National Bureau of Economic Research and researchers' websites. Each student chooses a paper they would like to discuss during a week of class. By summarizing their selected paper in class, students can display their understanding of existing findings. As an introduction to causal inference, students must identify the treatment, outcome, and control variables in each paper. This activity allows students to display their command of and to interpret existing knowledge as Hansen's higher-order proficiencies.

During the last three weeks of class, students combine their interest and understanding of research in environmental economics to propose new research questions. Students compile annotated bibliographies to justify their questions' novelty and identify data that indicates the questions' feasibility. These activities allow students to access and display their command of existing knowledge. Next, they begin applying and creating new knowledge via writing a research proposal, achieving five of Hansen's higher-order proficiencies. After the semester, the Faculty Leader chooses two to three research questions that will be worked on in FIRE Semester 3.

Table 1 identifies which course activities allow each student to achieve each of Hansen's proficiencies. The sequencing of course activities in Table 1 illustrates how learning is scaffolded in this course. Table 2 lists which course activities enable each student to achieve the course's learning outcomes. A list of FIRE Semester 2 assignments in 2023 can be found in the 2023 FIRE198 Syllabus provided in the Supplementary Materials.

2.3 Summer Research Internship

Since its inception, FIRE has placed a high value on providing an accelerated research experience and enhancing career readiness through an optional summer program. The nature of the summer program offered by FIRE has evolved over the years. From 2015 to 2021, FIRE Sustainability Analytics selected Summer Fellows from among FIRE Semester 2 students through a competitive application process. Once selected, these fellows worked alongside the Faculty Leader for twenty hours per week over eight weeks and received a modest stipend.

In the summers of 2020 and 2021, FIRE Sustainability Analytics collaborated with the U.S. Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS). USDA APHIS suggested research questions that could inform their agency, provided information from their staff, and funded the Summer Fellows program.

During the COVID-19 pandemic in 2020 and 2021, FIRE introduced a noncompetitive Summer Scholars program. This program aimed to advance knowledge and offer a sense of community to all FIRE Semester 2 students who were interested. FIRE Sustainability Analytics Summer Scholars dedicated four hours a week for four weeks to learning how to critique causal conclusions in empirical health research. Because the program focused on community building and the required time commitment was low, Summer Scholars did not receive a stipend nor course credit.

Post-COVID-19, FIRE strives to establish a financially sustainable summer program that does not rely on university funding or external institutions to provide student stipends. Building on the positive experiences students had while working with USDA APHIS, FIRE created a Summer Research Internship program that emulates an industry or institution-based internship experience. Unlike the past Summer Fellows program, where students competitively applied and received a stipend, FIRE Semester 2 students can enroll in a three-credit course to become FIRE Summer Interns. The students spend fifteen

Table 1: FIRE Sustainability Analytics Activities that Achieve Hansen's Proficiencies

Course	Proficiency Activity	Access existing knowledge	Display command of existing knowledge	Interpret existing knowledge	Interpret and manipulate economic data	Apply existing knowledge	Create new knowledge
FIRE Semester 2	Replicating a published paper		x	x	x		
	Working paper presentation		x	x			
	Proposal writing	x	x	x		x	x
FIRE Summer Research Internship	Querying, cleaning, and combining numeric and spatial data	x			x		
	Presenting the research project		x			x	x
FIRE Semester 3	Literature review writing	x	x	x			
	Data collecting	x					
	Data cleaning and combining				x		x
	Creating tables and plots				x	x	x
	Testing hypotheses				x	x	x
	Forming conclusions					x	x

hours a week for eight weeks collaborating with the Faculty Leader and addressing faculty-led research questions.

FIRE Summer Research Interns, both FIRE Semester 2 students and other undergraduates not previously affiliated with FIRE, gain valuable experience by querying, cleaning, and combining new data sets to address research questions directed by the Faculty Leader. They also acquire spatial analysis skills, which they apply to their projects. At the conclusion of the program, students present their research background and findings in slide presentations to students from other research streams. Preparing for these presentations allows students to showcase their command of economic knowledge,

Table 2: FIRE Sustainability Analytics Activities that Fulfill Course Learning Outcomes							
Course	**Learning Outcomes Activity**	**Develop proficiency in R**	**Understand enviro. problems and policies**	**Build collaborative relationships**	**Differentiate between prediction and inference models**	**Develop resilience to revise projects**	**Present research outcomes**
FIRE Semester 2	Replicating a published paper	x		x			
	Working paper presentation		x	x			
	Proposal writing		x	x			
FIRE Semester 3	Literature review writing		x	x			
	Data collecting, cleaning, and combining	x		x			
	Visualizing data	x		x			
	Testing hypotheses	x		x	x	x	
	Forming conclusions		x	x	x	x	
	Presenting the research project		x				x

apply existing knowledge, and generate new insights as Hansen's advanced proficiencies. Summer Research Interns become extremely proficient FIRE Semester 3 students and team leaders, who are able to help train their peers and accelerate team progress when students return in the fall.

Table 1 in section 2.4 identifies which course activities allow each student to achieve each of Hansen's (1986, 2001) proficiencies. For a list of FIRE Summer Research Internship assignments in 2023, please refer to the Supplementary Materials provided in the 2023 FIRE199 Syllabus.

2.4 FIRE Semester 3

FIRE Sustainability Analytics Semester 3 has six learning outcomes. The first three continue the learning outcomes from FIRE Semester 2:

1. Develop proficiency in R programming to clean and combine data, create tables and visualizations, and test hypotheses.
2. Gain an understanding of the environmental science problems and public policies examined in the environmental economics literature.

3. Build collaborative relationships with others who represent diverse cultures, races, ages, genders, religions, lifestyles, and viewpoints.

The three new learning outcomes introduced in this course are that students will be able to:

4. Develop the ability to differentiate between prediction and inference models used in applied economics.
5. Develop the resilience to revise and refine research projects by incorporating peer and instructor feedback.
6. Present research outcomes to audiences with varying technical backgrounds using various modes of communication.

Approximately 80 percent of students typically continue through the third semester. At the beginning of the fall semester of their second year, these students form teams of three to five students with similar schedules that meet weekly in the FIRE Sustainability Analytics lab. Each team selects an ongoing research project initiated in past years or a new one proposed by their cohort in the spring semester and chosen by the Faculty Leader as described in section 2.2. Each research project must fulfill the four criteria of "new knowledge" as defined by Henderson (2018):

1. Be of interest beyond the classroom.
2. Be addressed by a scientific method.
3. Be questions that do not have a definitive answer in the literature.
4. Produce findings that are disseminated.

The course utilizes two learning environments weekly: a classroom session where the Faculty Leader teaches additional research skills for fifty minutes and mentoring or collaborative work in the FIRE Sustainability Analytics lab for one to four hours. Students take ownership of their chosen research question and engage in an authentic research experience from start to finish in the FIRE Sustainability Analytics lab under close supervision of the Faculty Leader and PRMs. Their research workflow includes writing a literature review, collecting data, creating a summative data set, interpreting the data in the form of plots and maps, testing hypotheses, and forming conclusions, which fulfills all of Hansen's higher-order economic proficiencies as shown in Table 1. The process of collecting, cleaning, analyzing, and interpreting data guides students through an authentic data experience as recommended by guidelines of the American Statistical Association (2014) and as described by Grimshaw (2015). In addition, students develop resilience by submitting a draft of an output or a revised version each week.

Toward the end of the semester, students present their ongoing work at the annual FIRE Summit. At this scientific poster session, students develop their presentation skills and communicate their findings to FIRE Semester 1 students who have not joined a research group. At the end of the semester, students create a scientific research poster and present their findings to Faculty Collaborators who can provide technical feedback on the projects. Students who completed both FIRE Semester 2 and FIRE Semester 3 receive a FIRE Researcher micro-credential that can be displayed on places like LinkedIn and Portfolium. Course credits from FIRE Semester 1 and Semester 3 also count toward UMD's Scholarship in Practice general education credit requirement.

Table 2 lists which course activities enable each student to achieve the course's learning outcomes. A list of FIRE Semester 3 assignments in 2023 can be found in Supplementary Materials in the 2023 FIRE298 Syllabus.

2.5 Peer Research Mentorship

Toward the end of FIRE Semester 3, interested students can apply to become a PRM, and up to eight students are selected each year. The primary roles of PRMs are to mentor new students and continue contributing to ongoing research projects. Like all FIRE Sustainability Analytics students, they receive credit by enrolling in a course. However, PRMs have the flexibility to adjust their commitment levels based on their chosen credit load. One-credit PRMs spend at least five hours in the FIRE Sustainability Analytics lab each week while two-credit PRMs spend at least eight hours in the lab each week.

PRMs play an essential role in the training process as they are more approachable to their fellow students, making it easier for students to ask for help. Since they have gone through the course sequence, they can address common difficulties. Moreover, they receive basic training to foster inclusivity,[5] teamwork, and camaraderie within the research group. Additionally, they serve as role models, illustrating how research experiences can be leveraged to secure fellowships and internships.

PRMs also continue to work on projects they contributed to when they were in FIRE Semester 3. If other current FIRE Semester 3 students are interested in working on the same project, the PRMs will become the team leader. Every spring semester, PRMs are responsible for creating posters for these projects and presenting them at UMD's Undergraduate Research Day. This event welcomes any undergraduate student with a supporting faculty member to present their research projects. PRMs are also encouraged to create research products that can be submitted and presented at other university-level and national conferences throughout the year, such as UMD's College of Agriculture and Natural Resources (AGNR) Cornerstone Event, the Annual American Fisheries Society Conference, the American Geophysical Union's Annual Meeting, Posters on the Hill, or the EPA Social Justice Data Challenge.

By continually contributing to research projects and disseminating them to different audiences, PRMs strengthen all of their higher-order economic proficiencies. The Faculty Leader provides regular ongoing feedback on each PRM's interaction with new students, which develops and improves their leadership skills. Due to their close relationship with the Faculty Leader, PRMs receive personalized letters of recommendation that allow them to secure competitive post-FIRE opportunities.

3 Institutional Support

Four factors contribute to making FIRE Sustainability Analytics an authentic undergraduate experience that enhances career readiness: a Faculty Leader, Faculty Collaborators, FIRE Administrators, and a collaborative learning space. This section describes the institutional support that FIRE Sustainability Analytics receives.

3.1 A Faculty Leader

The demand for faculty time is one of the main obstacles to engaging undergraduate students in research (Hoyt and McGoldrick 2017). To overcome this problem, the FIRE program appoints a dedicated Faculty Leader for each research stream. The Faculty Leader for FIRE Sustainability Analytics[6] teaches one section of FIRE Semester 1, FIRE Semester 2, and FIRE Semester 3 a year and is present in the FIRE Sustainability Analytics lab for at least sixteen hours a week throughout the semesters. Besides ensuring research, educational, and mentorship excellence within FIRE Sustainability Analytics, the Faculty Leader serves in two administrative committees within the FIRE program. The Faculty Leader is not in a tenure-track position, so Dr. Ruangmas does not have to prioritize publications over mentoring undergraduate students. However, the Faculty Leader can advance in UMD's Clinical Professor Track, which emphasizes teaching ability, scholarly, and administrative accomplishments.

The Faculty Leader determines which research questions are pursued, allowing students to work on novel research questions in environmental economics, but she does not have to supervise student-led

[5] Each semester, PRMs must read at least two assigned articles and write their reflections. In the Fall 2023 semester, they read articles by Kennedy, Fry, and Funk (2021) and Vera (2021).

[6] The Faculty Leader for Sustainability Analytics is appointed by the FIRE program. However, the Faculty Leader's office and the FIRE Sustainability Analytics lab are provided by the Department of Agricultural and Resource Economics.

research projects that extend beyond her expertise as can happen in other economics capstone courses (Klein 2013).

3.2 Faculty Collaborators

The key to a Faculty Leader's success depends on research excellence, educational excellence, and mentorship excellence (Light, Fegley, and Stamp 2019). Tenured Faculty Collaborators in the Department of Agricultural and Resource Economics support the Faculty Leader's research excellence. Each year, the Faculty Collaborators review research questions that will be undertaken and provide feedback to research progress presentations at the end of the semester. Current Faculty Collaborators are Dr. Lars Olson and Dr. Jorge Holzer. Dr. Olson is the founding faculty. Prior Faculty Collaborators are Dr. Anna Alberini and Dr. Sebastien Houde. With the backing of the Department of Agricultural and Resource Economics, the Faculty Leader consistently seeks advice from other professors and guest speakers within the department.

3.3 FIRE Administrators

The FIRE Administration team consists of a Director, two Assistant Directors who are also Faculty Leaders, and two staff Assistant Program Directors. They oversee recruitment and program-wide administration to support all 16 FIRE research groups and play a crucial role in providing the foundation for FIRE Sustainability Analytics educational and mentoring excellence. FIRE trains students in a CURE where active collaboration, iteration, and problem-solving without a solutions manual are essential. This process differs greatly from teaching a traditional course (Stamp 2017). At the start of each semester, the FIRE Administration assists Faculty Leaders in "backward designing" the curriculum, where learning outcomes are prioritized and course activities are later designed to meet the intended outcomes (Bean 2011, ch. 12). Throughout the semester, the FIRE Administration facilitates community of practice discussions on various topics, including tracking students' progress, enhancing their professional skills, and supporting their career goals—similar to the program described in Light, Fegley, and Stamp (2019). Furthermore, the FIRE Administration aids in building a community among Faculty Leaders across diverse research groups, fostering interdisciplinary research collaborations. The FIRE Administration organizes the annual FIRE Summit, providing all FIRE students the opportunity to showcase their ongoing research projects.

3.4 A Collaborative Learning Space

A learning environment such as a collaborative workspace facilitates student learning through interaction with the environment (Dewey 1986). The FIRE Sustainability Analytics lab, referred to as "the lab," was created from a shared office space that was remodeled and equipped as a modern collaborative learning center incorporating design practices of the SCALE-UP initiative (Beichner 2006) and the Learning Spaces Collaboratory (Narum 2013). The Faculty Leader's office is adjacent to the lab with a connecting door between. The lab itself comprises three large-screen monitors, three desktop computers, meeting tables, a small library, code cheat sheets, and research posters produced by the group. Images of the lab are featured in Figure 2. The Faculty Leader is available in the lab for a minimum of sixteen hours each week, while students are required to spend at least four hours per week working in the lab as part of the FIRE Sustainability Analytics course sequence. At the beginning of each semester, students indicate their availability in a survey form, and the Faculty Leader then groups students with similar schedules together. Students within the same group are required to come into the lab during the same time. Since research is an ongoing endeavor, mandatory lab hours assist students in establishing routines and effectively managing their time.

The large-screen monitors in the lab enable students to share their laptop screens with others. This functionality encourages collaborative work on programming scripts and research outputs.

Figure 2: The FIRE Sustainability Analytics Lab

Students can also seek guidance and feedback from PRMs. Being in a collaborative environment allows students to enrich their learning process through discussions with their peers (Yamarik 2017), and it develops professional skills such as teamwork, effective communication, and time management. Prior research has shown that these skills are both highly valued by employers and associated with success in life (National Research Council 2012; Heckman and Kautz 2012).

Once a collaborative learning space has been set up and the Faculty Leader has been appointed, the annual costs of running FIRE Sustainability Analytics are modest. Operational costs include a Posit Cloud subscription to ensure students have equal access to computing resources and poster printing to showcase students' work at various events. Other costs are institution-specific. At Maryland, the FIRE program provides Faculty Collaborators a small overload stipend to compensate for their commitment, which is in addition to their normal teaching load.

4 Research Projects and Outcomes

Since its inception in 2015, FIRE Sustainability Analytics has continued to produce and disseminate high-quality research projects. Table 3 shows a timeline of the eleven research projects that the group has worked on and presented at university and national conferences. The rest of this section briefly summarizes each research project.

Table 3: Research Project Timeline

	2015	2016	2017	2018	2019	2020	2021	2022	2023
1. Household Energy Use		a, b							
2. Fisheries Mgmt and Conservation Status	a	a	c						
3. Groundwater Use				d					
4. El Niño and Fisheries					a	e			
5. Grey Markets						f			
6. NBP and Social Justice									
7. Citrus Canker							a, e		
8. Forest Protection and Leakage							a		
9. Air Pollution and Crime							a, e		
10. COVID-19 and Water Pollution							a, g		
11. Light Rails and Air Pollution								e	a

Legend

Project has ended

Still in development

Note: The following letters designate where each research project was presented:

a: Poster presented at UMD's Undergraduate Research Day
b: Poster presented at Posters on the Hill
c. Presentation at 2017 Annual American Fisheries Society Conference, Tampa, FL
d: Multiple posters presented at American Geophysical Union's Annual Meeting
e: Poster presented at UMD AGNR Cornerstone Event
f: Results presented to USDA APHIS
g: Video created for EPA Social Justice Data Challenge

4.1. Project Summaries

1. Household Energy Use
   Faculty Leader: Ian Page
   Faculty Collaborators: Anna Alberini and Sebastien Houde
   Project Description: Three projects concerning household energy use were conducted. One project examined how presentation of energy efficiency information online influences consumer purchase decisions. Another project analyzed the impact of fuel efficiency on household driving patterns in Italy and the United Kingdom. The third project studied households' energy audit choices and their differences in energy consumption patterns using data from greeNEWit, a local energy auditing company.
   Project Outcome: The third project was chosen to represent the state of Maryland at the 2016 Posters of the Hill conference.

2. Fisheries Management and Conservation Status
   Faculty Leader: Ian Page
   Faculty Collaborator: Lars Olson
   Project Description: To study how trade and species characteristics impact conservation status, students combined data from the Food and Agriculture Organization (FAO) with data from the International Union for Conservation of Nature and Natural Resources (IUCN). Project Outcome: This project resulted in a presentation "Synthesizing Trade Data and Fishery Conservation Status" in a session of the 147th Annual Meeting of the American Fisheries Society.

3. Groundwater Use
   Faculty Leader: Ian Page
   Faculty Collaborator: Lars Olson
   Project Description: The project analyzed which factors influence the farmers' decisions with respect to irrigation technology, crop choice, and groundwater extraction rates in the High Plains aquifer.
   Project Outcome: Two posters titled "Predicting Groundwater Usage with Machine Learning Methods and Traditional Statistical Techniques: An Application to the Ogallala Aquifer" and "Modeling the Determinants of Agricultural Groundwater Extraction in the Ogallala Aquifer" were presented at the American Geophysical Union's 2018 Annual Meeting.

4. El Nino and Fisheries
   Faculty Leader: Thanicha Ruangmas
   Faculty Collaborators: Lars Olson and Jorge Holzer
   Project Description: To study what fisheries have been affected by the 2015 El Niño, thirteen groups of students chose specific species to study and created data sets summarizing daily sea surface temperature and average latitude and longitude of each fishing vessel targeting those species.
   Project Outcome: Students presented a research poster at two of UMD's research events. The project did not continue due to inadequate data about each fishing trip.

5. Grey Markets
   Faculty Leader: Thanicha Ruangmas
   Faculty Collaborator: Lars Olson
   Project Description: With funding from the USDA APHIS, the project identified farms selling live poultry and eggs in Delaware, Maryland, and Virginia using publicly available online data from federal and state registries, online directories, and Google Places. Results from the project can provide information to support USDA APHIS's mission to safeguard U.S. agriculture and to enhance their capability to disseminate information during a poultry disease outbreak.
   Project Outcome: The Summer Fellows gave a presentation to 125 professionals from USDA APHIS and submitted a final report and programming codes used in the project to USDA APHIS.

6. NBP and Social Justice
   Faculty Leader: Thanicha Ruangmas
   Faculty Collaborator: Lars Olson and Jorge Holzer
   Project Description: Deschênes, Greenstone, and Shapiro (2017) found that the NOx Budget Program (NBP) decreased summertime NOx emissions from regulated counties by 330 to 440 tons but did not conclude if it evenly benefits all demographic groups. Eight groups of students re-examined the NBP's effect on reducing NOx from power plants in different North American Electric Reliability Corporation Regions. Each group then used an air pollution dispersion model to identify impacted communities and found different results.
   Project Outcome: The students were unable to clearly identify the winners and losers from the regulation due to a weak counterfactual. Code developed from the project is now being used as training materials for current students.

7. Citrus Canker
   Faculty Leader: Thanicha Ruangmas
   Faculty Collaborator: Lars Olson
   Project Description: With funding from USDA APHIS, the research project examines a stylized model of the optimal management of citrus canker. Optimal intertemporal policies for citrus canker control are being examined in two cases; first, in a single homogenous landscape and second, in a multiple heterogeneous landscape where the infestation can disperse from one orchard to another.
   Project Outcome: A manuscript which involves a theoretical analysis and a numerical case study in a homogenous landscape setting is being developed.

8. Forest Protection and Leakage
   Faculty Leader: Thanicha Ruangmas
   Faculty Collaborator: Lars Olson and Jorge Holzer
   Project Description: Sierra Leone and Liberia had high deforestation rates before establishing national parks to protect the Gola rainforest region on either side of the border. The project examined the change in deforestation rates after specific areas were protected.
   Project Outcome: The project found that protected areas reduced deforestation rates inside them. However, deforestation rates significantly increased in the 10 km buffer areas outside the park in Sierra Leone. The project did not continue as there were limited qualitative data sources and people willing to give interviews.

9. Air Pollution and Crime
   Faculty Leader: Thanicha Ruangmas
   Faculty Collaborators: Lars Olson and Jorge Holzer
   Project Description: According to Herrnstadt et al. (2021), air pollution can alter people's cognition and lead to higher violent crime rates. As Baltimore City has one of the highest crime rates in the United States, the project examines whether the same conclusion can be established.
   Project Outcome: Results showing correlations between pollution and crime were selected to represent the state of Maryland at the 2022 Posters on the Hill event. Since then, the relationship between crime rates and air pollution is being examined at the city and neighborhood level.

10. COVID-19 and Water Pollution
    Faculty Leader: Thanicha Ruangmas
    Faculty Collaborators: Lars Olson and Jorge Holzer
    Project Description: The impact of COVID-19 lockdowns on water quality changes in different areas of the Chesapeake Bay is being analyzed. Improved water quality has been identified in some areas.
    Project Outcome: Three students identified vulnerable communities with high pollution increases and made a video highlighting this result. The team of students received an "Honorable Mentions" award for the EPA's Environmental Justice Video Challenge for Students. The project is still in progress.

11. Light Rails and Air Pollution
    Faculty Leader: Thanicha Ruangmas
    Faculty Collaborators: Lars Olson and Jorge Holzer
    Project Description: Numerous studies have looked at the pollution reduction effect of subway openings, most notably Gendron-Carrier et al. (2022), but few have looked at light rails. This project is examining the impact of light rail openings on air pollution.
    Project Outcome: The project found that the only city that improved air quality after light rail opening is Charlotte, North Carolina. A credible counterfactual is being developed to establish whether the opening of light rails causes this.

5 Lessons Learned

5.1 FIRE Sustainability Analytics can fulfill a call for an equitable research opportunity for undergraduate students.

It is widely accepted that research skills are integral to achieving career readiness, whether in the job market or for graduate school (Hoyt and McGoldrick 2017). A high-impact practice that greatly contributes to this preparedness involves immersing students in research experiences (Kuh 2008). An equitable undergraduate research experience can increase participation from underrepresented minorities making scientific research more inclusive (Bangera and Brownell 2014). Despite the demand for undergraduate research experiences, the economics curriculum is still falling behind (Henderson 2018). FIRE Sustainability Analytics provides a solution to this conundrum by engaging large numbers of undergraduate students in research, regardless of their background or academic performance. From 2017 to 2021, the fraction of first-generation students in FIRE exceeds that of Carillon Communities[7] by 68 percent, surpasses College Park Scholars[8] by 36 percent, and more than doubles that of the Honors College.[9] FIRE and the UMD Office of Institutional Research Planning and Assessment used propensity score matching between FIRE students and demographically and academically matched students who did not participate in FIRE or any other living-learning program to examine the impact of FIRE

[7] Carillon Communities is a one-year living-learning program where first-year students work with faculty to ask *big questions* that matter to our world and learn to use teamwork and creative problem-solving approaches ("About," University of Maryland Carillon Communities, 2024).

[8] College Park Scholars is a two-year living-learning program for academically talented students ("About," University of Maryland College Park Scholars, 2024).

[9] The Honors College is a highly acclaimed living-learning program for students with exceptional academic talents. It creates a close-knit community faculty and undergraduates committed to acquiring a broad and balanced education ("About Us," University of Maryland Honors College, 2024).

participation on three-year retention rates. In every cohort from 2014 to 2019, FIRE participation increased three-year retention with an average increase in three-year retention rates of 5.6 percent.

5.2 FIRE Sustainability Analytics can introduce students to environmental economics research and foster an appreciation of data analytics.

In every cohort, only a few students are familiar with environmental economics before joining FIRE Sustainability Analytics. Our observation indicates that exposure to the field's research during FIRE Semester 2 often sparks increased interest and appreciation for environmental economics among many students. In a class survey conducted at the end of FIRE Semester 2 in 2023, we inquired about the extent to which class activities enhanced their appreciation of research in FIRE Sustainability Analytics. Students were given the options of responding with "To a great extent," "Somewhat," "Very little," or "Not at all." The survey results, illustrated in Figure 3, clearly demonstrate that active involvement in preparing a literature review presentation, which involves delving into cutting-edge research papers, and participating in PRM sessions, where they discuss the data analysis methods employed in published research papers, contributed significantly to increasing their appreciation. In contrast, more passive activities such as listening to podcasts or lectures did not generate as much interest.

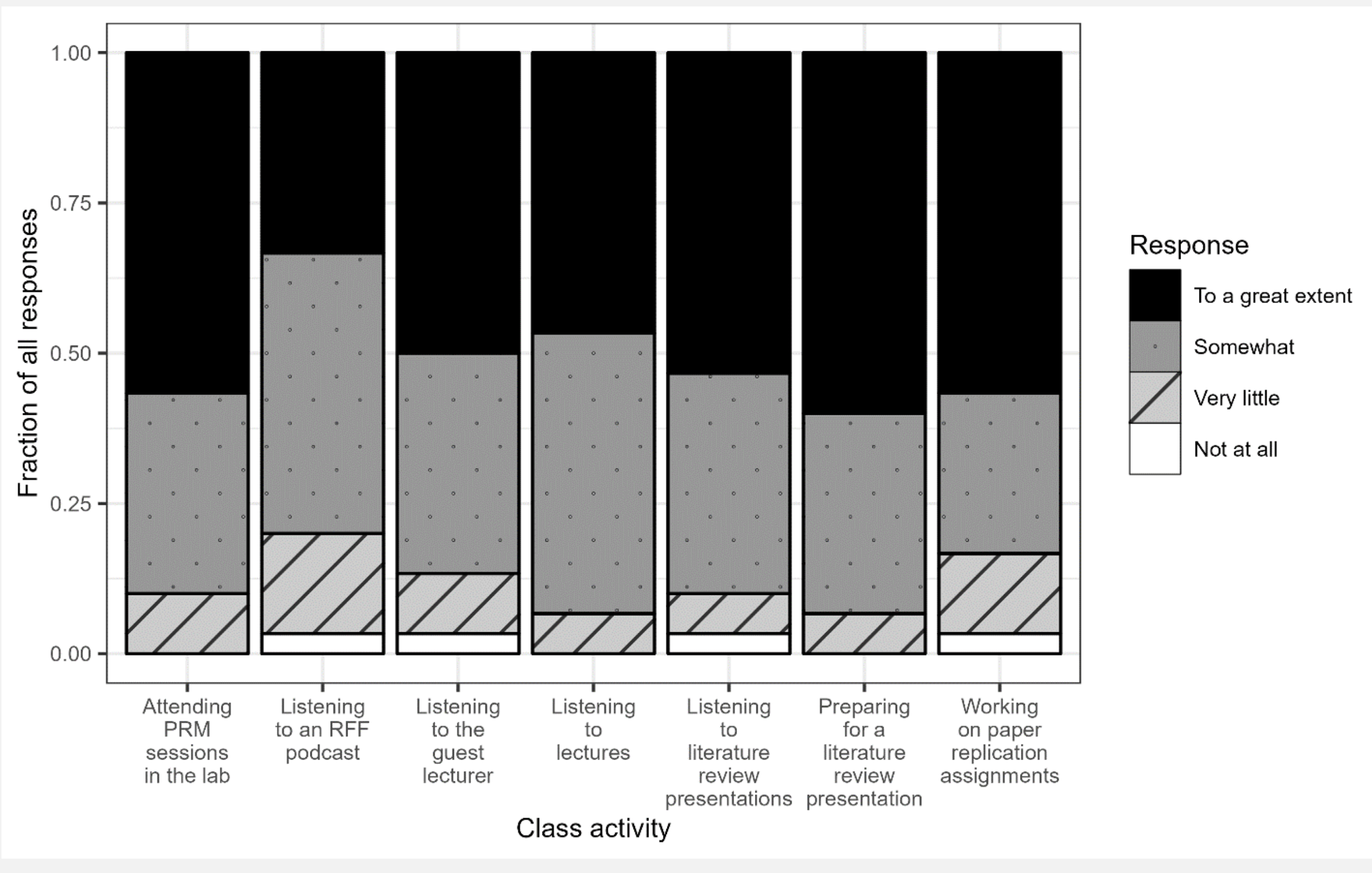

Figure 3: Class Activities That Increased Their Appreciation of FIRE Sustainability Analytics

Our experience aligns with the findings of Russell, Hancock, and McCullough (2007), indicating that an undergraduate research experience can result in increased interest in STEM careers. Over the years, several students initially majoring in environmental studies have opted to include a minor in geographical information systems. Economics students have developed an interest in applied microeconomic topics. Other students have shifted their focus from a Bachelor of Arts to a Bachelor of Science to specialize in data analytics.

5.3 An undergraduate experience can help develop Hansen's higher-order proficiencies in economics.

We affirm Henderson's (2018) findings that a well-designed undergraduate research experience can facilitate the development of Hansen's higher-order proficiencies. In addition to the previously presented Table 1 in section 2.4, which establishes the connection between class activities and Hansen's higher-order proficiencies, we further provide insight into students' perceptions of their proficiencies and learning outcomes through a class survey at the conclusion of FIRE Semester 3 in 2023, as depicted in Figure 4. This figure comprises four panels, each representing one of Hansen's higher-order proficiencies. Each bar in the figure illustrates the fraction of students' responses to the question "In your opinion, what learning outcomes have you achieved in the two semesters of FIRE Sustainability Analytics?" for specific learning outcomes of the courses. Students could choose "To a great extent," "Somewhat," "Very little," or "Not at all" for each learning outcome. We then link the learning outcomes to four of Hansen's six higher-order proficiencies as shown in four panels of the figure, where each panel represents one of Hansen's higher-order proficiencies. Two proficiencies are not represented because the survey was initially designed to improve the course in the future.

Figure 4 reveals that the majority of students perceive they can demonstrate a command of existing knowledge and interpret and manipulate economic data. Not surprisingly, as proficiencies become more advanced, the proportion of students who self-assess as proficient declines. Only about half of the students feel that they can interpret existing knowledge and apply it to a great extent. In part, these perceptions may stem from the addition of basic machine learning or modeling for prediction to the course content in 2023 and a resulting compression of material during the last part of the course. Assessing these learning outcomes is a useful part of the ongoing process to improve the program.

Furthermore, Figure 4 highlights that the benefits derived from the experience are not distributed equally, with students who invest more effort into their projects reporting greater benefits. Top-performing students have indicated that their work in FIRE Sustainability Analytics played a significant role in securing prestigious opportunities, such as the Ernest F. Hollings Undergraduate Scholarships, becoming Merrill Presidential Scholars, securing internships at the Federal Reserve, and working for esteemed organizations like the consulting firm Guidehouse and the International Monetary Fund.

5.4 Faculty-led projects can alleviate expertise and time constraints.

While one third of economic programs already offer research experience through student-led projects (Hoyt and McGoldrick 2017), there are challenges associated with establishing a successful undergraduate research program. First, faculty members are tasked with supervising research projects across diverse fields in economics, often extending beyond their expertise (Klein 2013). Second, the research projects stop after the semester ends and do not get disseminated. Third, both faculty and undergraduate students face difficulty navigating time constraints as developing a rigorous research project that contributes novel insights requires several years of work (Fenn et al. 2010).

FIRE Sustainability Analytics provides a potential solution to these challenges by involving undergraduate students in faculty-led research projects. The FIRE Sustainability Analytics's approach to project management has evolved over time in response to faculty and student experiences. When FIRE Sustainability Analytics was launched, the stream's research agenda was largely determined by a few tenure-track Faculty Collaborators in the Department of Agricultural and Resource Economics. The FIRE program recruited a Faculty Leader to direct the program's day-to-day activities, oversee student mentoring, and coordinate multiple projects with the faculty collaborators. Students were matched with

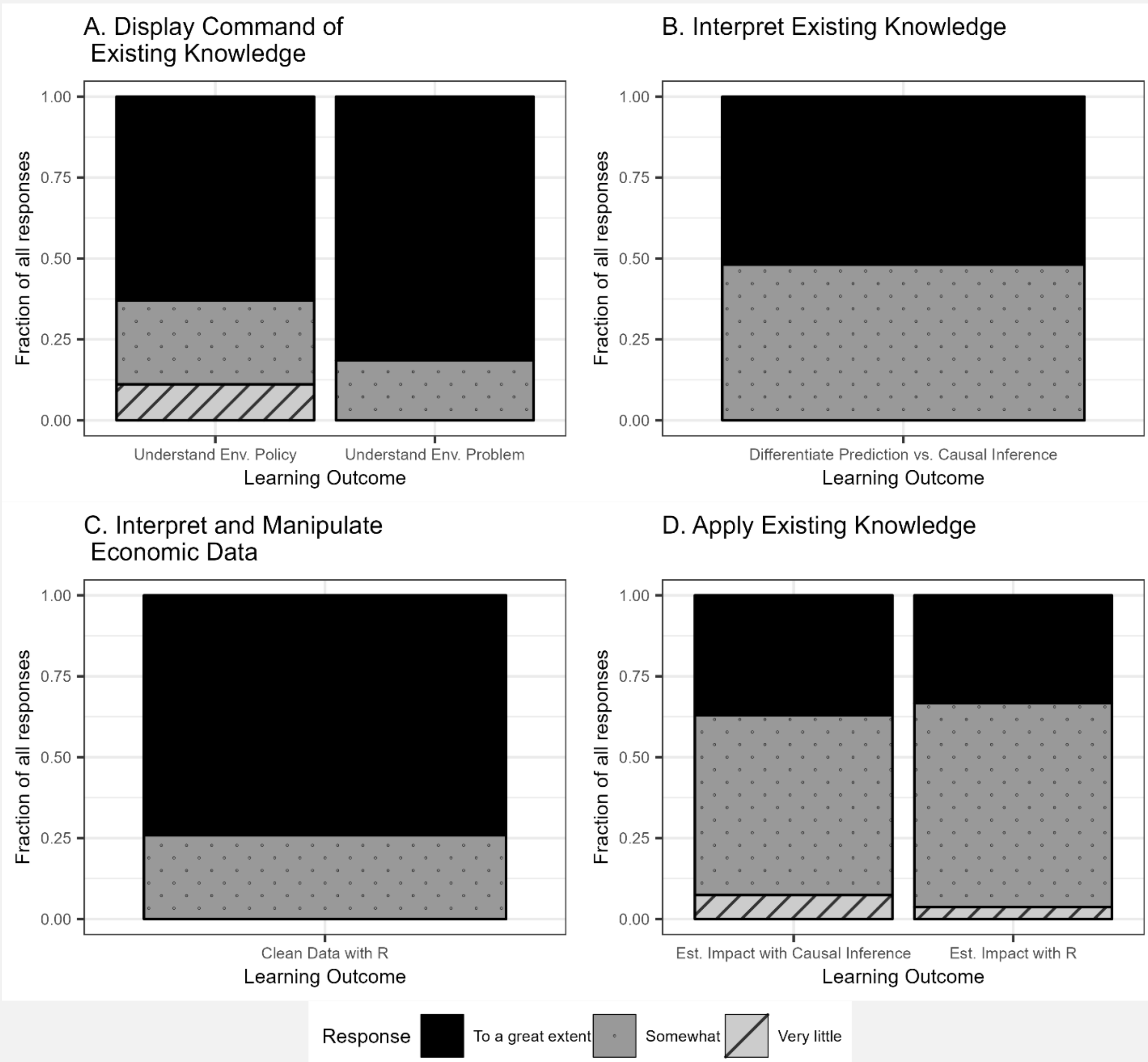

Figure 4: Student's Perceptions of Their Learning Outcomes and Proficiencies

projects and trained in research techniques appropriate for their project. The challenges of managing up to four research projects, not all within the expertise of the Faculty Leader, while simultaneously training students, made this mode of operation difficult to sustain.

In 2019, the initial Faculty Leader advanced professionally, and FIRE Sustainability Analytics welcomed a new Faculty Leader, Dr. Ruangmas, who led her own research project with the support of Faculty Collaborators. During her first two years, it was decided to streamline project management and the entire class worked on answering one faculty-led research question, with the class divided into groups focused on answering the same question in different geographic areas. However, this approach resulted in reduced student engagement and lower student retention. Through conversations with students, Dr. Ruangmas learned that some students, especially those majoring in environmental science or environmental studies, were extremely well-versed in highly interesting research topics. As a result, Dr. Ruangmas allowed students to brainstorm research questions at the end of FIRE Semester 2, and she chose specific topics for the class to work on in FIRE Semester 3.

Pursuing faculty-led projects that are selected from a pool of student ideas allows the Faculty Leader to supervise projects aligned with her specialization. Faculty-led research by student teams also addresses the challenge of time constraints, as each student within a team contributes to a specific aspect of a larger project (Gitter 2021). Faculty oversight and the overlap between new cohorts and peer mentors enables projects to span multiple years, so a deeper understanding of research questions can be developed, and findings can be presented at various venues. PRMs who have already worked on the topics can quickly onboard new students. This approach not only overcomes time limitations but also offers students authentic research experience and professional development within a collaborative setting. While we have generated new knowledge in undergraduate projects, as defined by Henderson (2018), our aspiration is to publish our findings in the future.

6 Conclusion

A well-designed undergraduate research program, such as FIRE Sustainability Analytics, can offer significant benefits to students provided it receives the necessary institutional support and faculty commitment. Still, we believe that a smaller program implemented at the department-level can achieve the same benefits. Instead of a three-course sequence, a similar research program in applied economics can be condensed to two courses: a research methods and data analytics course, followed by a research-intensive course experience. These could be offered as a two-course sequence where the first benefits all students, with the second engaging interested students in an in-depth, authentic research experience.

In conclusion, we hope that this paper provides an outline for implementation of a course-based undergraduate research experience and an overview of the student success outcomes it can achieve.

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References

American Statistical Association. 2014. "Curriculum Guidelines for Undergraduate Programs in Statistical Science." Retrieved from https://www.amstat.org/docs/default-source/amstat-documents/edu-guidelines2014-11-15.pdf

Bangera, G., and S.E. Brownell. 2014. "Course-Based Undergraduate Research Experiences Can Make Scientific Research More Inclusive." *CBE—Life Sciences Education* 13(4):602–606.

Bean, J.C. 2011. *Engaging Ideas: The Professor's Guide to Integrating Writing, Critical Thinking, and Active Learning in the Classroom.* Hoboken NJ: Wiley.

Beichner, R. 2006. "Chapter 29. North Carolina State University: SCALE-UP." In *Learning Spaces,* EDUCAUSE.

Deschênes, O., M. Greenstone, and J.S. Shapiro. 2017. "Defensive Investments and the Demand for Air Quality: Evidence from the NOx Budget Program." *American Economic Review* 107(10):2958–2989.

Dewey, J. 1986. "Experience and Education." *The Educational Forum* 50(3):241–252.

Fenn, A.J., D.K. Johnson, M.G. Smith, and J.L. Stimpert. 2010. "Doing Publishable Research with Undergraduate Students." *The Journal of Economic Education* 41(3):259–274.

Gendron-Carrier, N., M. Gonzalez-Navarro, S. Polloni, and M.A. Turner. 2022. "Subways and Urban Air Pollution." *American Economic Journal: Applied Economics* 14(1):164–196.

Gitter, S. 2021. "A Guide for Student-Led Undergraduate Research in Empirical Micro-Economics." *Journal of Economics Teaching* 5(3):83–115.

Grimshaw, S.D. 2015. "A Framework for Infusing Authentic Data Experiences within Statistics Courses." *The American Statistician* 69(4):307–314.

Hansen, W.L. 1986. "What Knowledge Is Most Worth Knowing for Economics Majors?" *American Economic Review* 76(2):149–153.

Hansen, W.L. 2001. "Expected Proficiencies for Undergraduate Economics Majors." *The Journal of Economic Education* 32(3):231–242.

Heckman, J.J., and T. Kautz. 2012. "Hard Evidence on Soft Skills." *Labour Economics* 19(4):451–464.

Henderson, A. 2018. "Leveraging the Power of Experiential Learning to Achieve Higher-Order Proficiencies." *The Journal of Economic Education* 49(1):59–71.

Herrnstadt, E., A. Heyes, E. Muehlegger, and S. Saberian. 2021. "Air Pollution and Criminal Activity: Microgeographic Evidence from Chicago." *American Economic Journal: Applied Economics* 13(4):70–100.

Hoyt, G.M., and K. McGoldrick. 2017. "Promoting Undergraduate Research in Economics." *American Economic Review* 107(5):655–659.

Kennedy, B., R. Fry, and C. Funk. 2021. "6 Facts about America's STEM Workforce and Those Training for It." Retrieved from https://www.pewresearch.org/short-reads/2021/04/14/6-facts-about-americas-stem-workforce-and-those-training-for-it/

Klein, C.C. 2013. "Econometrics as a Capstone Course in Economics." *The Journal of Economic Education* 44(3):268–276.

Kuh, G.D. 2008. "High-Impact Educational Practices." *Peer Review* 10(4):30–31.

Light, C., M. Fegley, and N. Stamp. 2019. "Training Program for Research Educators of Sequential Course-Based Undergraduate Research Experiences." *FEMS Microbiology Letters* 366(13).

Narum, J.L. 2013. *A Guide: Planning for Assessing 21st Century Spaces for 21st Century Learners.* Derwood MD: Learning Spaces Collaboratory.

National Research Council. 2012. *Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century.* Washington, DC: The National Academies Press.

Russell, S.H., M.P. Hancock, and J. McCullough. 2007. "Benefits of Undergraduate Research Experiences." *Science* 316(5824):548–549.

Salemi, M.K., and J.J. Siegfried. 1999. "The State of Economic Education." *American Economic Review* 89(2):355–361.

Stamp, N. 2017. "Opinion: The Sweet Spot on the Teaching-Research Continuum." *The Scientist,* September 2. https://www.the-scientist.com/opinion/opinion-the-sweet-spot-on-the-teaching-research-continuum-30976.

U.S. Environmental Protection Agency. 2022. "Clean Air Markets Program Data" [Data set]. Retrieved from https://campd.epa.gov/

"About," University of Maryland Carillon Communities. Accessed March 12, 2024, https://carillon.umd.edu/about

"About," University of Maryland College Park Scholars. Accessed March 12, 2024, https://scholars.umd.edu/about

"About Us," University of Maryland Honors College. Accessed March 12, 2024, https://honors.umd.edu/about-us/

Vera, O. 2021. "You've Got Snail Mail: How Letters from STEM Professionals Are Changing Young Lives." Retrieved from https://www.simonsfoundation.org/2021/12/15/youve-got-snail-mail-how-letters-from-stem-professionals-are-changing-young-lives/

Yamarik, S. 2007. "Does Cooperative Learning Improve Student Learning Outcomes?" *The Journal of Economic Education* 38(3):259–277.