Designing Innovations Research Stream – A Design Research Program for First-Year Students

Dr. Mohammad Fazelpour, University of Maryland College Park
Benjamin Treadwell Landon, University of Maryland College Park
Prof. Jeffrey W. Herrmann, University of Maryland, College Park
Dr. Patrick Killion, University of Maryland College Park

Designing Innovations Research Stream – A Design Research Program for First-Year Students

Mohammad Fazelpour
- Department of Mechanical Engineering
- University of Maryland
- College Park, MD, 20742
- mfazelp@umd.edu

Benjamin Landon
- University of Maryland
- College Park, MD, 20742
- blandon1@terpmail.umd.edu

Jeffrey W. Herrmann
- Department of Mechanical Engineering and Institute for Systems Research
- University of Maryland
- College Park, MD, 20742
- jwh2@umd.edu

Patrick J. Killion
- Director of First-Year Research Programs
- University of Maryland
- College Park, MD, 20742
- pkillion@umd.edu

Abstract

Understanding how teams solve design problems can influence students' perspectives on designing innovative products and systems. Furthermore, education needs to be tailored to engage first-year students in undergraduate research opportunities which increases student retention and graduation rate among STEM majors. A new initiative at the University of Maryland, the First-Year Innovation & Research Experience Program (FIRE), provides authentic research experience to first-year students. This paper introduces a new program, the Designing Innovations Research Stream, that engages first-year students in design research. The goal is that students will learn about design by investigating how teams solve complex design problems and then apply this knowledge to a real-world situation. The Designing Innovations Research Stream consisted of two semesters and a 10-week summer research fellowship. In the first semester of Designing Innovations, students learned about the design process and the standard design tools used to solve design problems. In the second semester, they designed an experiment to observe and analyze design team activities. The success of the program is evaluated by (i) surveying the students who completed the program, and (ii) the published papers from students who work in the program. The survey assesses students' understanding after completing the program via four major categories: design process, research, communication, as well as teamwork. The results of 51 students over three years show that 84% of responses either strongly agree or agree that their comprehension of the four categories has improved. The results also indicate that the most important subject learned, according to the students, was research methods, design research, teamwork, and communication. Finally, three peer-reviewed papers primarily written by students presented at international conferences demonstrate the program was successful in producing publishable results.

Keywords design education, design research, undergraduate research

1. Design Education for Undergraduate Students

Engineers increasingly work in new interdisciplinary fields of endeavor that address organizational challenges and societal issues related to public policy, sustainability, and economic development [1]. Although the challenges will change over time, engineers who can apply essential design skills can help people solve problems even as new technologies replace the old ones. Engineers will not only design products and technical systems but also help design processes that involve people in addition to technology.

To devise diverse solutions for a wide variety of problems and people, engineers must be able to use a variety of design processes. No single design process will be sufficient for every situation because the quality of existing knowledge, the performance of existing solutions, the uncertainty about the future, the nature of the risks, the consensus of the stakeholders, the abilities of the users, and many other factors will vary. In some novel problem situations, there may be no obvious appropriate design process, and engineers will have to design the process by dividing the problem into appropriate subproblems and deciding how to approach each one.

This topic is especially important because many engineers work on design teams, and the members of a team need to work together to carry out the design process. An ad hoc approach to planning the design process will create confusion and increase the risks of project failure (e.g., poor product or system performance as well as cost and schedule overruns).

Despite the growing need for design process planning skills, existing engineering education programs fail to provide opportunities for engineering students to learn these meta-reasoning skills. Many engineering students learn only standard product and systems development processes [2, 3]. In a typical engineering design course, the students follow the assigned process mechanically because their project deliverables follow the steps in the process.

Engineering students need to study design. In other disciplines, students begin by observing the phenomena to be studied, but engineering students are plunged into a design process (especially in cornerstone design courses) before they have ever seen anyone design. Indeed, engineering students learn about design in cornerstone design courses, but they learn only one process, which is a limited perspective, and they have little opportunity to reflect upon the process and consider alternatives. By observing more experienced students and professional engineers, new engineering students gain a richer understanding of design. Moreover, this type of activity will allow students to reflect on the many ways that design can be done. Engineering design researchers often study student design teams to learn about design; engineering students should do the same as they begin to become reflective practitioners.

To address this issue, the Designing Innovations (DI) Research Stream in the First-Year Innovation & Research Experience (FIRE) program at the University of Maryland (UMD) provides authentic research experience and extensive mentorship to first-year students [4]. Designing Innovations students study how designers solve system design problems. In particular, they

(a) identify appropriate system design problems,

(b) develop designs that solve these problems,

(c) plan and conduct experiments in which they observe subjects designing systems,

(d) identify the strategies that the designers use, and

(e) build and use simulation models to evaluate design strategies.

These studies cover a variety of design domains but focus on how a designer or team decomposes the design problem into subproblems. The students discover the similarities and differences of design strategies across different problems in multiple design domains and how the design strategies influence the quality of designs that are generated. This type of research requires a variety of qualitative and quantitative research methods. All students have opportunities to design systems of different types, plan research studies, collect, and analyze data. This paper introduces the DI Research Stream and describes the success of the research stream by analyzing the results of a survey among students and presenting three conference publications from the results of research conducted by students.

2. Background of Undergraduate Research

The President's Council of Advisors on Science and Technology (PCAST) reported that the United States needs approximately one million more graduates in STEM, which is science, technology, engineering, and mathematics majors, to meet economic projections [5]. The report recommended developing discovery-based research courses in the first two years of college to excite interest among college students in STEM majors [5]. Moreover, engagement of first-year college students in discovery and authentic research experience increases students' retention, promotes interests among students in STEM majors, and exposes them to open-ended problems [6, 7, 17, 18].

Although the advantages of undergraduate research experience are notable, there are obstacles that can prevent students from participating in undergraduate research. There are limited opportunities for conventional one-on-one advising structure between undergraduate researchers and faculty members, post-doctoral fellows, or even graduate students. Faculty members prefer to choose juniors and seniors for undergraduate research opportunities, while first- and second-year students have difficulties finding research experiences on campus. Therefore, a small fraction of first- and second-year students can explore undergraduate research opportunities.

To address these challenges, first-year research and project-based learning programs have been established at colleges and universities [6, 8–11]. The University of Texas (UT) at Austin developed the Freshman Research Initiative (FRI), a novel approach to engaging first-year students in authentic research and discovery [7, 11]. FRI is a 9 credit-hour program that provides the opportunity for students to conduct research in their first three semesters in the College of Natural Sciences under the supervision of a research educator and a faculty leader. The FRI program currently has 30 research streams across different disciplines (biology, chemistry, astronomy, computer science, and mathematics) [12]. Students who completed the FRI program have significantly higher chances of graduating with a STEM degree and graduating in 6 years [7]. Similar to FRI, a sequence of two courses in the field of phage discovery and genomics for first-year students was developed [6]. The course has been widely implemented at 73 colleges and universities, and more than 4,700 students have taken it in five years. More recently, the Freshman Introduction to Research in Engineering program in the Department of Mechanical Engineering at UT-Austin was established to provide authentic research and discovery opportunities for first-semester students [10]. In comparison to the FRI program, which has approximately 30 research streams and a three-semester sequence, the Freshman Introduction to Research in Engineering is limited to first-semester students in the Department of Mechanical Engineering [10].

3. The First-year Innovation and Research Experience

The First-Year Innovation & Research Experience (FIRE) at the University of Maryland College Park engages first-year students in discovery and authentic research [4]. The FIRE program focuses on education through research and promotes advantages in persistence, retention, degree completion, professional, and academic accomplishments among first-year students. The FIRE program, established in 2014, consists of a wide range of STEM majors including the natural, applied sciences and engineering as well as other non-STEM majors including arts and humanities, social sciences and public health (see fire.umd.edu/clusters for a complete list). The components of the FIRE program and students' experiences are discussed in the following section.

FIRE Programmatic Components

The FIRE program currently consists of 16 innovation and research streams that involve the synergistic efforts of at least one faculty leader, one dedicated research educator, a group of trained peer mentors, and the students served, as shown in Figure 1.

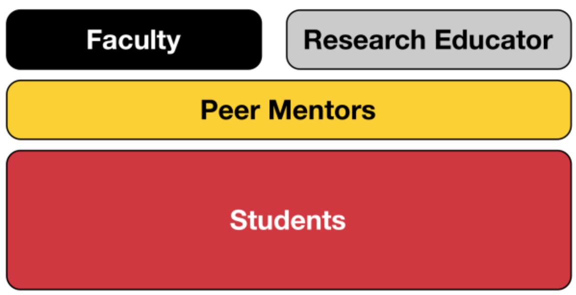

FIGURE 1 FIRE Innovation and Research Streams [4]

Stream Faculty Leader

The faculty provides leadership concerning the overall research agenda of the stream. They collaborate with the research educator on research agenda development and grant writing. Faculty leaders often benefit from the data and research produced by the undergraduate researchers and peer mentors working on the research agenda.

Research Educators

Research educators are responsible for overall operation of research streams including curriculum development, instruction, evaluation, students' training, research progress, and peer mentors on a daily basis. These subject matter experts, who also have experience in instruction and mentoring undergraduate students in a research setting, are appointed as professional-track faculty (Assistant Clinical Professor). The research educator has an essential role in FIRE students' success and stream outcome. While the students appreciate the commitments and availability of access to a dedicated faculty, the research educators establish a long-lasting relationship with students through research, academic, and personal mentorship.

Peer Mentors

Undergraduate peer mentors are recruited and trained for each FIRE stream. Peer mentors are selected primarily among the students who have completed their three-semester FIRE stream experience. They achieve research accomplishments within their stream while expanding leadership experience through mentoring a new cohort of students.

This programmatic structure or a structure similar could be adopted and adapted by other engineering educators as it not only offers constant support and guidance to the students but also allows for more educational retention, personal development, and provides lasting relationships.

Fire Programmatic Processes

This section presents students recruitment and experience in the FIRE program.

Student Recruitment and Demographic

FIRE students are recruited among first-year undergraduate students who have not been admitted in their preferred academic department. FIRE students are recruited through (i) sending invitations (with admission letters) to students who have just been admitted to the university and (ii) introducing the FIRE program to admitted students at open house events and inviting them to apply. In the 2016-2017 school year, FIRE enrolled approximately 500 students (50% female and 50% male).

Student Experience

The FIRE program experience includes one semester of research preparation, two semesters of research stream involvement, and a final semester for transitioning to the next-step opportunities that are shown in Figure 2 and Table 1 [4]. As a result of completing the three-semester FIRE experience, students earn nine General Education credits which count towards graduation. It is worth noting that, because the FIRE curriculum is aligned with the university's General Education requirements, participating in FIRE helps these students' progress toward their degree no matter what their major is or might be in the future.

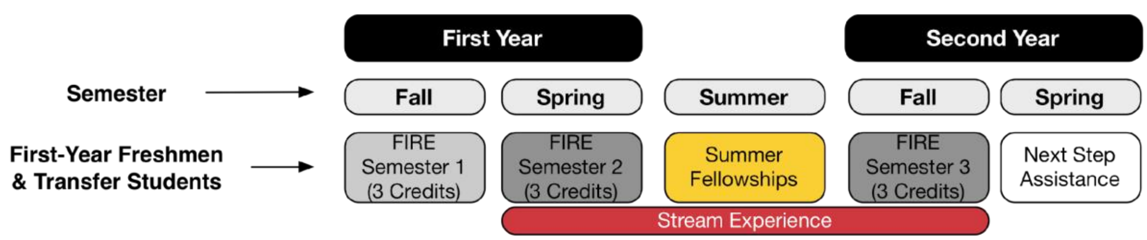

FIGURE 2 FIRE Courses and Process [4]

FIRE Semester 1. The FIRE experience begins with a course designed to prepare a broad population of students for research. Learning outcomes include mastery of primary literature analysis, data analysis and visualization, team collaboration and scholarly communication.

Students study the research agendas of FIRE streams, meet affiliated faculty members and then select the one that best matches their interests.

FIRE Semester 2. The second-semester stream experience focuses on community development, discipline-specific safety and methods training, and defining the scope and objectives of research projects. Students build confidence, self-efficacy, and relationships with their peers and the research educator.

FIRE Semester 3. The third-semester stream experience is defined by applying research skills and enabling students to develop leadership and communication skills.

In addition to this three-semester sequence, in the spring of the first year (semester 2) students can apply for the FIRE Summer Fellows Program. The Summer Fellows Program is a 10-week research experience for FIRE students to work in their chosen streams under the supervision of their research educators. In the summer of 2017, the FIRE program hosted 87 summer fellows.

TABLE 1 FIRE General Education Courses [4]

Course	Credits	Degree Impact	Description
FIRE Semester 1	3	General Education	**Research-readiness:** Primary literature analysis, data analysis and visualization skills, team collaboration and scholarly communication.
FIRE Semester 2	3	General Education	**Research-capacity:** Methods training, discipline background, research engagement.
FIRE Semester 3	3	General Education	**Research-independence:** Methods refinement, discipline application, research accomplishment.

4. Designing Innovations Research Stream

The Designing Innovations Research Stream began in January 2017. The objective of this research stream was to engage first-year students in design research, specifically, answering this consider the following research question: *How do designers tackle system design problems?*

In particular, students in the Designing Innovations stream learned how to do the following: (a) identify appropriate system design problems, (b) develop designs that solve these problems, (c) plan and conduct experiments in which they observe subjects designing systems, and (d) identify the strategies that the designers use. These experiments covered a variety of design domains but focused on how a designer or design team decomposes the design problem or design process. The students discovered the similarities and differences of design strategies across different design problems in multiple design domains and how the design strategies influence the quality of designs that are generated. This type of research required a variety of qualitative and quantitative research methods. All students had opportunities to design systems of different types, plan research studies, and collect and analyze data.

The students in the Designing Innovations stream began their study of design problems by learning about the design process and attempting design problems themselves. This design experience was meant to provide them with valuable experience about doing design and the insights needed to plan their study of designers.

The activities in this stream were designed to provide opportunities for students to learn the following skills:

General skills:

- Design of experiments
- Statistical analysis of results
- Technical writing
- Presentations

Design skills:

- Understanding a design problem (including requirements and objectives)
- Decomposing a complex problem into sub-problems
- Generating feasible design alternatives
- Modeling and prototyping to test and evaluate alternatives
- Selecting alternatives (decision making)

Qualitative techniques:

- Observing and recording subjects
- Coding activities
- Qualitative data analysis
- Software to capture and evaluate designs
- Simulation models of design processes

A cohort of students participated in the Designing Innovations both spring and fall semesters; however, a small group of students received the summer fellowships where they had an immersive research experience under the supervision of the research educator.

The courses had both class and lab meetings. The class sessions, which were 50 minutes per week, focused on the lectures, class activities, design reviews, and regular evaluations of individual and team research progress. The research lab meetings focused on training on specific related topics and skills that students should acquire. Furthermore, during the research lab meetings, team members worked in a collaborative environment to make progress towards their projects and group assignments. The course required that each student spend eight hours (excluding class time) of independent and collaborative research per week. These eight hours included approximately (at least) two hours of collaborative lab activities.

Program and Courses' Contents

Spring Semester

The objective of the Designing Innovations Research Stream was to advise the first-year students to do design research and study how teams solve design problems. However, typical first-year students have not taken any design courses and are not familiar with the engineering design process. Therefore, the course for the spring semester was developed to train students to collect and analyze design team activities.

The course consisted of two projects. The first project was to identify and solve an appropriate system design problem which can be found among online design challenges such as Design Challenges and Competitions sponsored by NASA. Students solved the selected design challenge through following the engineering design process, which took the first eight weeks of the semester. Students presented their design solutions during weeks 9 and 10.

The second project was to perform a pilot study where students experience how to collect and analyze design team activities. The students were tasked to study a relevant research paper on protocol studies and reproduce its results. To do this project, they recorded themselves as subjects while solving a design problem, analyzed protocols, wrote a report, and presented their results. For the second project, students received a lecture on human subjects research and completed the Collaborative Institutional Training Initiative needed modules.

There were 25 students in the Designing Innovations course in spring 2017. For both projects, the students worked in groups of five. The students' performance was evaluated through nine group assignments, nine individual assignments, ten online reading assessments, two group presentations, and two project reports.

Summer

Six students were selected as FIRE Summer Fellows in the Designing Innovations Research Stream. They worked for 10 weeks (20 hours per week) on

- reviewing the literature to identify coding schemes have been used to analyze design activities,
- analyzing a protocol using different coding schemes, and
- preparing the application materials to obtain IRB approval for human subject experiments.

Fall Semester

In the fall semester, the returning students focused on research accomplishments using the training that they received in the spring. The project for the fall semester was to design and conduct a new experiment. To do that, students (in groups of four) were tasked to review the literature to identify research gaps. The objective was to help students frame experiments' objective(s) to address identified research gaps. The students identified potential design problems, participants, required data analysis, and coding methods for the experiments. The students were responsible for recruiting and bringing the participants to a design studio. In the design studio, the students could observe and record how participants solve the design problem. Then the students analyzed the data and communicated their results through writing a research paper and presenting the results in class. The research educator and faculty leader provided the students with feedback on their project and presentation.

The students' performance was evaluated through eight group assignments, six individual assignments, nine online reading assessments, two group presentations, and one research paper.

In 2017, 12 students (out of 25) returned to complete their experience with the Designing Innovations, while the retention rate of FIRE program across all streams was approximately 70%. Students failed to return for multiple reasons. Because the FIRE courses are not mandatory, some students chose to focus on their required courses to avoid delaying graduation. Some students lost interest in the research agenda of the stream, and others transferred to another university.

Demographic and Students Majors

The number of students who attended DI stream from 2017 to 2019 is summarized in Table 2. The first cohort (2017) included five female students and 20 male students; the second cohort (2018) included five female students and 21 male students and the last cohort (2019) included 4 female and 12 male students. Many of the students have majors in engineering and computer science, where female students are underrepresented. Table 3 describes the majors of the students in the Designing Innovations stream.

Table 2 The number of students who attended the DI stream 2017-2019

Year	Number who attended the first semester	Number who attended the second semester
2017	25	12
2018	26	26
2019	16	15

5. Evaluation of Designing Innovations Research Stream

Surveys

A survey was conducted among students who completed the program in Fall of 2017, 2018, and 2019 to evaluate how participation in the Designing Innovations improved students' knowledge of engineering design process and design research. Fifty-one students (out of 53) have completed the survey. The survey was created based on the course learning objectives and asked for responses to 18 assertions in four categories: (1) design process, (2) design research, (3) design communication, and (4) teamwork [13]. The whole survey is available in the Appendix section of this paper.

The results of the survey are presented in Table 4 and Table 5. The item number on the left hand side of the survey corresponds to reflective statements where the student responded with a strength of agreement, which varied between items (see appendix of the paper). For example, for item 10 (learning about different coding schemes to describe design activities), the median response was "strongly agree." For items 1 (identifying design problems), 14 (improving technical writing skills), and 15 (in-class presentations) the median response was "agree." For 13 of the 18 items, 40 or more students answered with a response of "agree" or "strongly agree." For the remaining five of these 18 items, fewer than 40 students answered with a response of "agree" or "strongly agree": item 5 (design for customer needs), item 12 (drawing conclusions from data), item 13 (effective documentation and presentation), item 14 (technical writing skills), and item 15 (oral presentation skills).

Table 3 Students' Major Distribution 2017-2019

Major	Number of students
Undecided	27
Computer Science	21
Engineering	13
Business	2
Architecture	1
Psychology	2

Information Science	1

These responses indicate that students who completed the Designing Innovations stream believe that they have learned the key skills for design research, skills about the general design process, and teamwork skills. In particular, the students most strongly agreed that they are better prepared for future design projects, for human subject research, coding design, and working in a team environment.

At the end of the survey the students were asked to describe (as a short essay) the most important thing(s) they have learned from enrolling and completing the DI stream; the responses of the students were summarized into six categories: (1) research methods/design research, (2) teamwork/collaboration, (3) communication, (4) time management, (5) resilience, and (6) leadership. The results for students' written responses are summarized in Table 5. The results show that the majority of students, 36 out of 51 responses, indicated that Research Methods and Design Research are the most important things that they learned in the DI stream. In addition, 22 students indicated that participation in the DI stream has honed their teamwork skills. Communication, time management, resilience, and leadership were among other important things they have learned.

Sample Projects and publish papers

The DI stream students worked on a variety of different research topics in engineering design and design research. They reviewed the literature, found research gaps, and designed and conducted experiments to address those gaps. The following are some of the important projects that these students completed:

- the effect of team size on problem decomposition and solution quality,
- how non-technical vs. technical teams use the engineering design process,
- the effect of fixation on design outcome and decomposition.
- graphical interface to record and analyze design activities,
- design for additive manufacturing.

The results of these projects were published as three peer-reviewed conference papers [14-16]. In the first project [16], teams of 1, 3, and 5 designers solved the following design problem: *design a machine to separate different materials that are recycled at a recycling plant*. The designers were recorded (talking with each other or thinking aloud) while solving the problem. The protocols were coded using micro- and macro- strategies to represent problem decomposition and design process for each team. A rubric was developed to evaluate the quality of design solutions with criteria on meeting constraints, manufacturability, feasibility, and cost. It was found that the larger team size analyzes design solutions more and proposes solutions less than smaller teams. The teams of three scored the best on final designs. These teams of three used a fair amount of both proposing solutions and analyzing solutions when solving the complex design problem contributing to their overall better design.

The second project used a user graphical interface to record and analyze design activities [15]. This project analyzes design development through an experiment in which designers are to create an ideal hypothetical factory layout in which the designer's actions were recorded using a software developed through Tkinter and the designer solves a problem using a graphical user interface. Tkinter is the standard Python Interface to graphical user interface. The data collected by the software indicates that designers decompose problems into subproblems which were focused on independently.

Table 4 Summary of survey responses (*n* = 51)								
	Number of responses							
Item Number(s)	**Strongly Agree**	**Agree**	**Somewhat Agree**	**Neither Agree Nor Disagree**	**Strongly Disagree**	**Disagree**	**Somewhat Disagree**	**Not Applicable**
(A) Design Process								
1	23	17	9	1	0	0	0	1
2	19	23	6	2	0	0	0	1
3	22	18	7	2	1	0	0	1
4	18	23	7	1	1	0	0	1
5	16	20	8	5	1	0	0	1
6	25	18	5	2	0	0	0	1
(B) Design Research								
7	22	20	7	0	1	1	0	0
8	25	19	7	0	0	0	0	0
9	20	23	7	1	0	0	0	0
10	28	19	3	0	0	0	0	1
11	23	21	5	0	1	0	0	1
12	20	19	9	1	0	1	0	1
(C) Design Communication								
13	21	18	10	1	0	1	0	0
14	18	18	11	4	0	0	0	0
15	17	20	7	5	1	1	0	0
(D) Teamwork								
16	25	19	4	3	0	0	0	0
17	23	18	9	1	0	0	0	0
18	24	20	6	1	0	0	0	0

Table 5: Survey Writing Responses

Topic	**Number of Students**
Research Methods/Design Research	36
Teamwork/Collaboration	22
Communication	9
Time Management	6
Resilience	2

Leadership	1

Finally, the third project [14], designing for additive manufacturing, investigates additive manufacturing techniques of unit cell design using 62 senior mechanical engineering students who experimented with two initial unit cells, honeycomb and rhombus, while following four unit cell guidelines which consisted of desired flexibility of the unit cell in the direction of shear loading [14]: (1) disconnect unit cells from side joints, (2) remove the transverse connection, (3) replace straight edges with curved ones, and (4) remove top and bottom legs connected to the boundary. These guidelines enhance shear flexibility. The mechanical engineering students produced 143 unit cell combinations which were tested on novelty and variety. Data on cluster size, shear flexure, thickness, shear and flexure improvement were also collected. The results of this project revealed that guidelines 2 and 3 yield novel and variety unit cells.

The results of the survey and published papers demonstrate that there is a significantly positive impact of the Design Research Innovations Stream on students' confidence and knowledge of engineering design principles such as design process, design research, teamwork, and communication. These concepts are evident in the peer-reviewed student published papers shown at international conferences which further demonstrates the successful application of the program.

6. Conclusion

This paper described a research stream called Designing Innovations, which is part of the University of Maryland's First-Year Innovation & Research Experience Program. The Designing Innovations stream is at the intersection of design education, design research, and design process (Figure 3). This design education program engaged first-year students in design research. Students in this stream learned the engineering design process and how to design and conduct human subject research and analyze design activities. A survey of students who completed the Designing Innovations stream shows that the students agree that they learned about design processes, design research, design communication, and teamwork.

This program is an innovative approach to design education in which students learn by studying design activities and doing design research. Although expanding the program to include all first-year engineering students may be impractical, modules in which first-year engineering students observe and evaluate design activities can be added to cornerstone design courses.

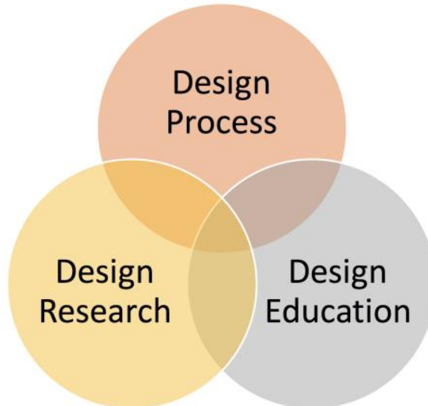

Figure 3 Designing Innovations

7. References

[1] Engineering N. A. of, 2005, *The Engineer of 2020: Visions of Engineering in the New Century*, National Academies Press, Washington, D.C.

[2] Dym C. L., Little P., and Orwin E. J., 2013, *Engineering Design: A Project-Based Introduction*, Wiley.

[3] Dieter G., and Schmidt L., 2012, *Engineering Design*, McGraw-Hill Education, New York.

[4] "The First-Year Innovation & Research Experience - https://fire.umd.edu/," p. Date Accessed 02/27/2018.

[5] President's Council on Science and Technology, 2012, *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics*, Washington, D.C.

[6] Jordan, T. C. et al., 2014, "A Broadly Implementable Research Course in Phage Discovery and Genomics for First-Year Undergraduate Students," *MBio*, **5**(1), pp. e01051-13.

[7] Rodenbusch S. E., Hernandez P. R., Simmons S. L., and Dolan E. L., 2016, "Early Engagement in Course-Based Research Increases Graduation Rates and Completion of Science, Engineering, and Mathematics Degrees," *CBE-Life Sci. Educ.*, **15**(2), pp. 1–10.

[8] Bailey R., Szabo Z., and Sabers D., 2004, "Assessing Student Learning about Engineering Design in Project-Based Courses," *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, Salt Lake City, Utah, p. 9.227.1-9.227.14.

[9] Dym C. L., Agogino A. M., Eris O., Frey D. D., and Leifer L. J., 2005, "Engineering Design Thinking, Teaching, and Learning," *J. Engineering Educ.*, **94**(1), pp. 103–120.

[10] Pang M. A., Seepersad C. C., and Landsberger S., 2017, "The Development of a Freshman Engineering Research Program," *ASEE Annual Conference & Exposition*, Columbus, Ohio, p. Paper ID #20513.

[11] Beckham J.T., Simmons S. L., Stovall G. M., and Farre J., 2015, "The Freshman Research Initiative as a Model for Addressing Shortages and Disparities in STEM Engagement," *Directions for Mathematics Research Experience for Undergraduates*, pp. 181–212.

[12] "FRI Research Streams - https://cns.utexas.edu/component/cobalt/items/5-research-

streams?Itemid=1971," p. Date Accessed 02/27/2018.

[13] Moazzen I., Miller M., Wild P., Jackson L., and Hadwin A., 2014, "Engineering Design Survey," *Proc. Canadian Engineering Education Association (CEEA14) Conf.*, p. Paper 54.

[14] Boyd, I., Fazelpour, M., "Design for Additive Manufacturing: Effectiveness of Unit Cell Design Guidelines as Ideation tools," ASME 2019 International Mechanical Engineering Congress and Exposition (IMECE), Salt Lake City, UT.

[15] Taha, F.M., Taha, R.M., West, K., Fazelpour, M., Herrmann, J.W., Polvinale, M.A., "An Automated Approach to Recording and Analyzing Design Activities Using A Graphical User Interface," ASME 2019 International Design Engineering Technical Conferences and Computers and Information in Engineering (IDETC/CIE)Conference, Anaheim, CA.

[16] Jacobs, S.H., Pfarr, M.C., Fazelpour, M., Koroma, A.K., Mesfin, T.A., "Effect of Team Size on Problem-solving and Solution Quality: An Empirical Study," ASME 2019 International Design Engineering Technical Conferences and Computers and Information in Engineering (IDETC/CIE) Conference, Anaheim, CA.

[17] Sabatini, David A."Teaching and Research Synergism: The Undergraduate Research Experience." *Journal of Professional Issues in Engineering Education and Practice*, vol.123, no. 3, 1997, pp. 98–102.,

https://doi.org/10.1061/(asce)1052-3928(1997)123:3(98).

[18] Tomovic, M. M. (1994). "Undergraduate research-prerequisite for life- long learning." Proc., 1994 ASEE Annual. ConI, June 26-29, 1994, Edmonton, Alberta, Canada, Am. Soc. for Engrg. Educators, Washington, D.C., 1469-1471.

APPENDIX

Designing Innovation Research Stream Survey

The objective of this survey is to evaluate the knowledge of students enrolled in the Designing Innovation Research Stream at First-Year and Innovation & Research Experience Program (FIRE) at University of Maryland. By completing this survey, you will help the research educator to assess the program outcome and adjust the curriculum to improve students' learning experience. Your participation would be invaluable to the research educator and the faculty leader. This survey is conducted among students who completed the Designing Innovations to evaluate students' self-reported knowledge and skills for four following categories: (a) design process, (b) design research, (c) design communication, (d) teamwork.

(A) Design process

Name and briefly explain the design project you completed in the Designing Innovations

Think about the project you just explained. To what extent do you agree or disagree with the following assertions:

1- Membership in FIRE Designing Innovations has helped me to identify appropriate system design problems.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e

7	6	5	4	3	2	1	0

2- Membership in FIRE Designing Innovations has helped me to elicit requirements from problem statements and/or clients.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

3- Membership in FIRE Designing Innovations has helped me to generate feasible design solutions using ideation tools.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

4- Membership in FIRE Designing Innovations has helped me to use decision-making metrics and select alternatives.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

5- Membership in FIRE Designing Innovations has helped me to refine the selected design concept to meet customers' needs.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

6- The skills I learned from membership in FIRE Designing Innovations will be helpful in future design projects.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat Disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

(B) Design research

Name and briefly explain the protocol study experiment your group designed and conducted in the FIRE Designing Innovations.

Think about the project you just explained. To what extent do you agree or disagree with the following assertions:

7- Membership in FIRE Designing Innovations has helped me to identify design research gaps and opportunities.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat Disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

8- Membership in FIRE Designing Innovations has helped me to learn how to design and conduct human subject research and protocol studies.

Strongly Agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

9- Membership in FIRE Designing Innovations has helped me to identify appropriate design problems for my experiment.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

10- Membership in FIRE Designing Innovations has helped me to learn about different coding schemes to describe design activities.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

11- Membership in FIRE Designing Innovations has helped me to analyze design activities using the coding scheme for my experiment.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

12- Membership in FIRE Designing Innovations has helped me to draw conclusions from the data analysis to address my experiment research objective(s)/question(s).

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e

7	6	5	4	3	2	1	0

(C) Design communication

For three following statements, please consider all papers and reports you completed in the FIRE Designing Innovations

13- Writing assignments (papers and reports) of FIRE Designing Innovations have helped me to effectively document and present the design.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

14- Writing assignments (papers and reports) of FIRE Designing Innovations have helped me to improve my technical writing skills.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

15- In-class presentations of FIRE Designing Innovations have helped me to improve my oral presentation skills and effectively present the project findings.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

(D) Teamwork

Think about your teamwork and team dynamics during the Designing Innovations

16- Membership in FIRE Designing Innovations helped me deal with team members' various working styles.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

17- For group projects and assignments of FIRE Designing Innovations, I have known my roles and responsibilities in the team.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

18- Membership in FIRE Designing Innovations helped me to work productively in my team.

Strongly agree	Agree	Somewh at agree	Neither agree nor disagree	Somewhat disagree	Disagree	Strongly Disagre e	Not Applicabl e
7	6	5	4	3	2	1	0

Describe the most important thing you have learned from your experience in the Designing Innovations