Board 293: First Cohort Experiences During an International Research Experiences for Undergraduates Program Focused on Fractional-Order Circuits and Systems

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Introduction

"Circuits and systems" refers to the fields encompassing all topics relating to the design, analysis, and implementation of electrical circuits. Electrical circuits are the foundation upon which smart devices, wireless communications, automotive systems, power systems, and healthcare devices are built. To continue advancing each of these fields requires highly qualified engineers who can design circuits and systems but also creatively import concepts from new fields to overcome challenges we cannot yet even imagine. One emerging area incorporating concepts from outside the traditional circuits domain is fractional-order circuits and systems. This area brings concepts from fractional calculus [1], the branch of mathematics concerning differentiation and integration to non-integer orders, into the design, analysis, and implementation of electrical circuits and systems. While fractional calculus has traditionally been a domain of mathematicians, recent progress has shown that many systems encountered in electronics, signal processing, control theory, and biological modelling are well described by fractional-order models [2, 3, 4]. Applications of fractional-order systems range from the control of industrial machines with lower control effort and lower energy costs [5] to modelling the electrical impedance of skeletal muscle to track changes in tissue properties to monitor for injury and disorder [6]. However, advances in the design and practical implementation of fractional-order circuits and systems requires engineers trained on these topics and exploring research in these areas.

In support of this mission our project team is coordinating an International Research Experiences for Students (IRES) site to provide summer research experiences for University of Alabama (UA) students at the Brno University of Technology (BUT) in the Czech Republic. The collaboration between UA and BUT leverages the unique concentration of faculty at BUT with active fractional-order circuits and systems research [7, 8 9] and collaboration history between the program coordinator (Freeborn) and BUT faculty [10, 11, 12].

In this work an overview of the first iteration of the logistics, cultural/social activities, and research activities of the IRES program are detailed. The feedback from participants regarding their experiences, perceived learning gains, and perceived value of the program collected from the evaluation activities are presented. The evaluation of this first iteration informs which aspects of the program were most successful (technical training) and which would benefit from additional focus in future cohorts (team building).

Summary of IRES Program Activities

For the first iteration of this IRES site, five undergraduate students (4 men, 1 woman) enrolled in electrical and computer engineering at UA were recruited for participation. Students were recruited from the population of students who had completed (or were in the process of completing) junior level courses related to electrical circuits. After recruitment, participating

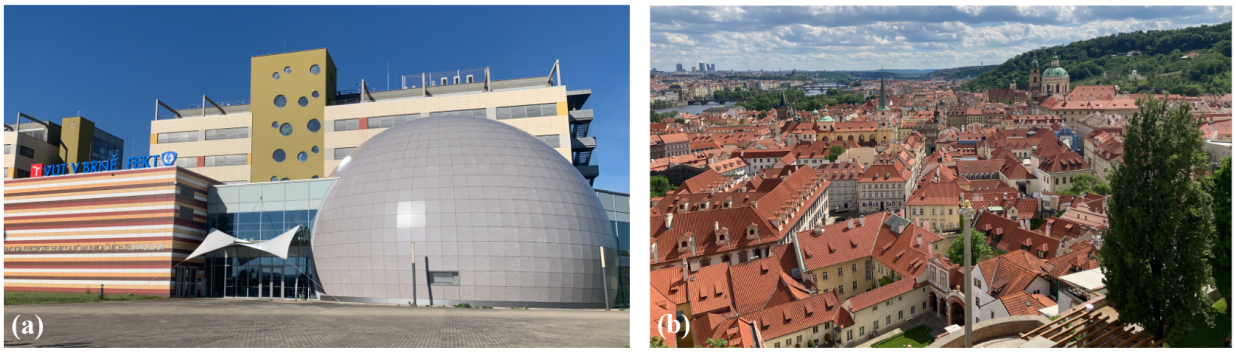

Figure 1: (a) Brno University of Technology and (b) overview of Prague from Prague Castle visited by IRES participants.

students completed a one-semester prep-course at UA in the spring semester immediately before their summer research at BUT.

In the prep-course, participants met weekly with the program coordinator (Freeborn) for 2-hours over 15 weeks. These classes were to prepare them for their summer research by introducing fractional calculus, fractional circuits, design methodologies, approximation techniques, and design tools (MATLAB, LTSpice). Additionally, this course provided activities and discussions to support students in their international travel (e.g., passport & medical requirements, currency, food culture, inter-city and inter-country buses/trains) and collaboration with international faculty (e.g., communication strategies, project requirements, documentation requirements). Students were required to maintain a digital notebook that captured their class activities, design/simulation work, and notes on important course readings. This notebook was reviewed at four timepoints during the semester with feedback provided to improve documentation practices. This was to prime students to use a digital notebook to capture all of their research activities throughout their summer research.

After the prep-class, students travelled with the program coordinator to Brno in the Czech Republic to begin their 12-week international research experiences. On arrival in Brno, participants were housed on campus at BUT in the student dormitories. Dormitories were shared accommodations with each IRES participant sharing a living space with a current BUT student. This shared-accommodation was intentional to facilitate interactions with students beyond the IRES cohort. Once on campus, the BUT coordinator provided an orientation to the students to introduce them to campus, research labs, research mentors, and activities for them to pursue in Brno. After the orientation, students met with the BUT mentors to establish expectations for the summer and the launch of their projects. The BUT mentors were all professors from the Faculty of Electrical Engineering and Communication at BUT (in either the Department of Radio Electronics or Department of Telecommunications). Faculty were selected based on their active research related to fractional-order circuits and systems and their interest in mentoring undergraduate students. Students were provided access to an electronics laboratory on campus as their shared research space. For research activities, participants were expected to spend 40 hours per week towards their specific research. The BUT campus building where students worked through the summer is shown in Fig. 1(a).

The specific research activities of this cohort included characterizing integrated circuits to emulate fractional-order characteristics, evaluating approximations of fractional-order capacitors

for future designs, designing fractional-order analog filter circuits, and determining the fractional-order impedance of materials. While each participant had their own unique research project guided by a BUT mentor, all had overlap in terms of the design/simulation tools, hardware, and measurement instruments.

The program coordinator remained in Brno for three weeks to transition students into their projects and establish the relationships with their BUT mentors. During this period the cohort and coordinator participated in two social/cultural activities on weekends in the Czech Republic. The first weekend had the group tour Brno to visit cultural/historical sites including Spilberk Castle, Brno City Museum, 10-Z Bunker (World War II nuclear fallout shelter), and St. James and the Brno Ossuary. The second weekend included a tour of Prague to visit Old Town Square and astronomical clock, Prague Castle (with sample in Fig. 1(b)), the Museum of Communism, and time for students to explore on their own. These trips aimed to increase students' knowledge about Czech culture/history and help them learn to navigate in Brno (using city transit) and in the Czech Republic (using regional bus systems). Prior to this experience, 4 of the 5 students had never used public transportation (substantiating the need for this type of training to support students).

After the departure of the program coordinator, participants continued their research under the mentorship of the faculty in Brno for the remainder of the 12-weeks. In addition to the direct mentoring from the BUT faculty, each week participants had a virtual check-in (using the Zoom platform) with the coordinator. During check-ins students would outline accomplishments, challenges, and plans for the following week with an opportunity to get technical suggestions or insight on navigating relationships with their mentors. During the last week of the program, participants delivered 20-minute formal presentations to the participating BUT faculty group summarizing their summer research. This served as the final culminating experience to close-out their time in Brno prior to their travel back to the United States. After returning to UA, students had the opportunity to continue their research with their BUT mentors with aims of translating their research efforts into conference submissions.

Student Satisfaction with IRES Experience

To evaluate student satisfaction and perceptions of the IRES program, participants were invited by the evaluation team at the Institute for Social Science Research (ISSR) to complete two online surveys. These surveys were completed before and after participants' summer research experience in Brno (referred to as pre/post surveys). The pre-summer survey provided information about expectations and a baseline for many of the post-summer questions. The end-of-summer survey was a comprehensive assessment of the students' experiences that included both close-ended and open-ended questions. All five participants from the first cohort completed the student surveys.

After their summer participation, students rated the IRES Site program overall on a scale from 1=Poor to 5=Excellent, with the distribution of values provided in Table 1. There was significant variation in individual ratings of the program, ranging from 2=Fair to 5=Excellent, with a mean

of 3.40. While this finding does support that the overall rating is positive, the fair/good ratings of some participants highlight room for improvement.

Table 1: Rate the IRES Site program overall (n=5)	**1-Poor**	**2-Fair**	**3-Good**	**4-Very Good**	**5-Excellent**	**Mean**
Overall	0	1	2	1	1	3.40

To further evaluate participants' level of satisfaction with the IRES experience, they were asked to rate various aspects of the program using a five-point scale, where 1=Extremely dissatisfied and 5 = Extremely satisfied. These ratings are detailed in Table 2.

Table 2: How satisfied are you with the following aspects of your IRES experience? (n=5)	**1-Extremely dissatisfied**	**2-Somewhat dissatisfied**	**3-Neutral**	**4-Somewhat satisfied**	**5-Extremely satisfied**	**Mean**
Research mentoring	0	1	0	0	4	4.40
Physical conditions in the lab/project environment	0	0	1	1	3	4.40
Research experience overall	0	0	1	2	2	4.20
International travel	0	0	1	2	2	4.20
Development of technical skills	1	0	0	1	3	4.20
IRES Site program overall	0	1	1	0	3	4.00
Research project topic	0	1	0	2	2	4.00
Relevance to career	0	0	1	3	1	4.00
Networking opportunities	0	1	0	3	1	3.80
Opportunities for social activities	0	0	4	1	0	3.20
Organized group activities/ field trips	0	2	1	2	0	3.00
Bi-weekly seminars	1	0	2	2	0	3.00
Group dynamics in the lab/project environment	1	1	3	1	0	2.40

These specific measures indicate that, on average, students were somewhat satisfied or better for 9 of the 13 items with mean ratings from 3.80 to 4.40. Like the overall program rankings there is significant variation across individual measures with no items for which all students gave ratings of either "Somewhat" or "Extremely" satisfied. Four of the five student (80%) were extremely satisfied with their research mentoring, although one student was somewhat dissatisfied. Four of the five students were either extremely satisfied or somewhat satisfied with the physical conditions in the lab, their research experience overall, international travel, development of their technical skills, their research project topic, relevance to their career, and networking opportunities.

The item with the lowest score (2.40) was the group dynamics in the lab/project environment, which may have had a significant influence on the participants' perspectives of the overall program. Students co-worked in a shared lab space on the campus at BUT for the entire 12-

weeks of the program. As a result, interpersonal friction or conflict between participants may have strongly influenced their overall feelings regarding the program and motivated low scores for other items related to group dynamics (opportunities for social activities, organized group activities/field trips). This is supported by feedback from one participant to an open-ended question asking what they would change about the program. This participant noted:

- *"I wished there were more organized team building activities. It was honestly pathetic how easily we got mad at each other for different views or beliefs and then let that divide the group."*

Based on this feedback, future iterations of the program should focus on developing the cohort experience prior to the international travel. While students did spend more than 20 hours together during the prep-course prior to travel, it did not translate into activities that created a positive cohort experience.

The focus on intentionally developing a positive cohort experience may be especially important for a small, international research cohort which has different pressures than undergraduate research experiences in the U.S. The smaller number of students (compared to U.S. based research experience for undergraduates sites which have 8-12 students), the limited access to their support networks, and stressors of navigating daily living tasks in a foreign country likely increase the friction between participants and impact the group dynamics. The stressors of living in a foreign country were likely significant for this cohort of students as only 2 of the 5 participants had previous travel experience outside of North America. Future iterations of the program could include workshops offered by the University of Alabama's Crossroads program from the Division of Community Affairs to help improve group dynamics. Workshops from Crossroads focus on creating spaces for dialogue on campus and the wider community. These workshops could help students learn and practice discourse and listening skills to navigate communicating with each other through disagreements or stressful situations.

Student Assessments of Knowledge Before and After IRES

On the post-IRES survey, students were asked to report their current knowledge on a range of topics (focused on research activities and electrical circuits) and to *reassess* their prior knowledge at the beginning of the summer, using values of 1-Nothing to 5-Substantial amount. (They had previously assessed their knowledge on these items in the pre-summer survey.) This approach aimed to provide a better estimate of what they had learned. Some studies have shown that novice learners tend to over-estimate their understanding of topics and having them reassess their prior understanding after a program gives a better estimate of how much they have learned [13, 14]. Table 3 presents the means for (1) the students' initial pre-IRES assessment of their knowledge, (2) their reassessment at the end of the summer of their pre-IRES knowledge, and (3) their assessment of their current knowledge after the IRES program.

Table 3: Participants' self-assessment of how much they knew about the following (n=5):	**Pre-IRES**	**Pre-IRES (Reassessed)**	**Post-IRES**	**Mean Difference**
Research process	3.0	2.2	3.8	**1.6**
Developing research questions	2.8	2.2	3.8	**1.6**
Designing a research study	2.6	2.0	3.4	**1.4**
Finding research articles	4.0	2.6	4.4	**1.8**
Preparing a research presentation	2.4	2.2	3.4	**1.2**

Interpreting research findings	3.4	2.2	4.2	**2.0**
Presenting research findings	2.8	2.6	4.2	**1.6**
Applying to graduate school	2.6	2.6	3.4	0.8
Ethics in science	2.8	2.4	3.6	**1.0**
Technical and scientific writing	2.8	2.6	3.4	**1.0**
Project management	2.4	2.4	2.8	0.4
Evaluating a research study	3.4	2.0	3.4	**1.4**
Fractional-order circuits and systems	3.4	1.8	3.8	**2.0**
Understanding how international collaborations work	2.6	1.4	3.4	**2.0**
Using MATLAB for visualizing data	4.0	2.6	4.4	**1.8**
Using MATLAB for solving circuits and systems equations	3.8	2.2	4.0	**1.8**
Using LTSpice for simulating electric circuits	3.6	3.2	4.2	**1.0**
Equipment to measure and test electric circuits	4.0	2.8	4.6	**1.8**
Czech Republic	2.6	1.4	3.6	**2.2**

As noted in Table 3, the reassessment means are lower than the pre-IRES means with the exception of two items (applying to graduate school and project management) which have equal means on the pre-IRES and reassessment measures. This supports that participants over-estimated their understanding of topics on their first survey (which aligns with previous studies of novice leaners and supports the use of the reassessment approach here). The largest differences between the original and reassessment scores were observed for finding research articles, using MATLAB, and using equipment to measure/test electric circuits. This suggests that participation in this research (which required extensive focus on each of these tasks) altered students' estimation of these abilities. This is not surprising, as their summer research required extensive review of recent literature related to their topics, advanced use of MATLAB for simulations and data visualization, and use of precision instruments including an impedance analyzer and frequency response analyzer (both of which require careful configuration and calibration prior to measurement).

Reviewing the post-IRES scores, students felt they knew more about all items after the IRES experience. Comparing their reassessment of their pre-IRES knowledge with their post-IRES knowledge, they rated their knowledge increases between 0.4 and 2.2 points higher after their summer experience. Mean differences (comparing reassessment and post-IRES scores) that are statistically significantly different ($p < 0.05$) based on a paired-samples *t*-test are bolded in Table 3. Of the mean differences, only two (applying to graduate school and project management) did not have statistically significant increases. This may be attributed to the fact that these two topics were not the focus of any specific training or workshops in either the prep course or summer research.

The highest ratings for post-IRES knowledge were for equipment to measure and test electric circuits (4.6), using MATLAB for visualizing data (4.4), and finding research articles (4.4). The largest gains, however, were in their knowledge of the Czech Republic (mean difference of 2.2 points), understanding how international collaborations work (2.0 points), fractional-order circuits and systems (2.0 points), and interpreting research findings (2.0 points). This supports the intention that the combination of the prep-course, international research experiences, and cultural/historical activities were increasing students' perceptions of their knowledge in these domains.

For further insight into their experiences, the post-IRES survey prompted participants to: Describe your positive feelings about the value/benefits of the program overall and to your career. The complete set of responses from the participants' to this prompt are below:

- *"This program showed what I needed to develop in order to have clear communication with my superiors. This includes knowing and explaining my own limitations. I also know that presentations and public speaking are skills I need to spend more time developing. I also gained valuable experience with organizing data that can be better visually interpreted."*
- *"This was a great experience overall. Throughout the summer, I learned various new technical skills that helped me understand theoretical concepts. My mentor was great, and we met regularly to discuss obstacles and progress. Plus I was able to travel."*
- *"I believe that this program opened me up to a lot of new experiences, in and out of the lab. I got to work with many new instruments and expand on my career specific skills. I think this is beneficial to my career as it is a great talking point on my resume. Not many people get to have an opportunity as such."*
- *"This program was the first time I've worked full time and in a technical setting. Working in a foreign country allows for a good discussion topic and learning experience."*
- *"I learned a lot about how to structure and organize experiments on my own. Furthermore, this program was the deciding factor for me to continue my education and eventually work in R&D. On another note, I had several enjoyable traveling experiences outside the lab."*

Participants were also prompted to describe what they had learned about themselves during this experience. Samples of participants' answers to this prompt included:

- *"I learned that I have a lot more perseverance than I initially believed. This is because I faced many stressful situations during this project and still managed to finish with some meaningful results in the end."*
- *"I learned that I often overthink things and stress myself out about it. I was worried that I would struggle in this research, but it was far easier than expected and the resources for help were abundant."*
- *"I learned to adapt to living in a foreign environment surrounded by people speaking a different language than myself."*

The students' own words support that they gained confidence in their technical abilities, their ability to contribute to research, and how to navigate working/living in a foreign country. These gains all align with goals of our program and support that the current activities are helping students to grow in those areas. The level of students' reported confidence in a highly complex technical topic (fractional-order circuits) supports the use of research experiences by other groups to introduce undergraduate students to these topics. But further investigation is needed to evaluate if these experiences are translating into research advances and the recruitment of students to continue exploring these topics in future graduate studies.

Summary

Student satisfaction ratings for the IRES experience overall were highly varied. However, most students were quite satisfied with their research mentoring, their experiences in their assigned lab environment, the skills gained, and the products produced during their time in Brno. The opportunity to travel and participate in research internationally was universally noted as a plus. They appreciated the opportunity to develop and refine their knowledge and skills as researchers in their fields. Group dynamics (or lack thereof) was a noted issue with all students. According to student feedback, more interaction and collaboration across projects, if possible, could help address lack of group cohesion. Future iterations of this program will focus on this aspect of the program to improve the student experience.

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