Insights from a Five-Year National Science Foundation Research Traineeship at our University: Program Description, Evaluation, Outcomes, and Lessons Learned

Mirit Shamir, Kansas State University

Mirit Shamir is the Academic Services Coordinator for the Rural Resource Resiliency NSF Research Traineeship housed in the Alan Levin Department of Mechanical and Nuclear Engineering at Kansas State University.

Jonathan Aguilar, Kansas State University
Dr. Rebecca Cors, University of Wisconsin, Madison

Rebecca Cors is a social scientist and evaluator at WCER who studies how people learn about, and co-exist with, science and nature. She is fascinated with how people and organizations learn and develop in ways that enable them to thrive. Rebecca's career began in environmental education and outreach at places like the Wisconsin Department of Natural Resources and at a university in China, where her primary assignment as a Peace Corps Volunteer was environmental education. In 2009, she went on to work with the Institute of Environmental Decisions at ETH Zurich and, then, to earn her PhD at the University of Geneva, Switzerland, studying out-of-classroom science education. In 2017, she joined the Wisconsin Evaluation Collaborative, where she continues to support education programs through research and evaluation. She has published and presented research about out-of-school learning, science and nature education, and about collaborations to promote natural resources management. In addition, Rebecca is a Wisconsin Master Naturalist, and enjoys hiking, reading, connecting with others, and learning languages.

Dr. Ryan Robert Hansen, Kansas State University

Dr. Hansen is an associate professor in the Tim Taylor Department of Chemical Engineering at Kansas State University.

Nathan P. Hendricks, Kansas State University
Gaea A. Hock
Dr. Stacy L. Hutchinson, Kansas State University
Prathap Parameswaran, Kansas State University

Prathap Parameswaran is currently an Associate Professor and the Fornelli Engineering professorship holder at the Civil Engineering department, Kansas State University. Parameswaran's research interests pertain to all aspects of biological wastewater treatment and sustainable resource recovery from wastes using novel environmental biotechnology platforms. He is an international expert in the implementation and long term operation of Anaerobic Membrane Bioreactors (AnMBRs) and currently operates a pilot scale system at K-State's north agronomy farm to treat swine lagoon wastewater, with efforts currently supported by the DoE's IEDO office. His research interests also include: anaerobic digestion, pretreatment technologies for bioprocessing of wastes and biomass, microbial electrochemical cells for valuable products generation (electric power, hydrogen gas and advanced oxidation products such as hydrogen peroxide), downstream resource capture from photosynthetic microalgae through novel environmental biotechnology for a sustainable and green biorefinery. Dr. Parameswaran also has active research grants through the NSF and industry partners. Prathap Parameswaran is currently an Associate Professor and the Fornelli Engineering professorship holder at the Civil Engineering department, Kansas State University. Parameswaran's research interests pertain to all aspects of biological wastewater treatment and sustainable resource recovery from wastes using novel environmental biotechnology platforms. He is an international expert in the implementation and long term operation of Anaerobic Membrane Bioreactors (AnMBRs) and currently operates a pilot scale system at K-State's north agronomy farm to treat swine lagoon wastewater, with efforts currently supported by the DoE's IEDO office. His research interests also include: anaerobic digestion, pretreatment technologies for bioprocessing of wastes and biomass, microbial electrochemical cells for valuable products generation (electric power, hydrogen gas and advanced oxidation products

such as hydrogen peroxide), downstream resource capture from photosynthetic microalgae through novel environmental biotechnology for a sustainable and green biorefinery. Dr. Parameswaran also has active research grants through the NSF and industry partners.

Prof. Matthew R. Sanderson

Matthew R. Sanderson is the Randall C. Hill Distinguished Professor of Sociology, Anthropology, and Social Work and Professor of Geography and Geospatial Sciences at Kansas State University. Currently, he is working on several projects that examine co-evo

Dr. Melanie Derby, Kansas State University

Insights from a Five-Year National Science Foundation Research Traineeship at our University: Program Description, Evaluation, Outcomes and Lessons Learned

Abstract

The NSF Research Traineeship (NRT) program at Kansas State University is dedicated to enhancing graduate STEM education through a comprehensive traineeship model that integrates an applied curriculum, interdisciplinary research, professional skills development, and mentoring. The NRT at our university has prepared graduate students in STEM, both master's and doctoral students, to solve the grand challenges in the Food, Energy, and Water (FEW) nexus in rural communities by investigating engineering and socioeconomic innovations to conserve water, create renewable energy, and help rural communities thrive. Since 2018, the NRT at our university has trained 40 diverse, culturally competent STEM leaders to do interdisciplinary work, and understand their potential vocational pathways, including government, academia, and industry.

The NRT program at our university includes educational and experiential components. These components are field experiences, policy experiences at the state capital, applied course work, interdisciplinary research, faculty and peer mentoring, professional development, and periodic assessment of these components. The NRT organized three courses: a one-credit hour cross-listed course called Integrated FEW Systems, a two-credit hour cross-listed NRT Capstone, and a 0-credit NRT Seminar. In the Integrated FEW Systems course, students were introduced to systems thinking, with specific application to the FEW nexus in South West Kansas. The NRT Capstone is a project-based course that builds on knowledge students developed through the Integrated FEW Systems course. For their Capstone research, students worked in interdisciplinary teams to write a report, conference paper, or journal paper. The NRT Seminar consists of training sessions related to inclusion, career pathways, across campus resources, professional development, science communication, and exposure to FEW research initiatives.

This paper will detail the graduate-level NRT traineeship educational and experiential components at our university including program description, summative evaluation, outcomes, and insights gained from our four NRT cohorts. Evaluation findings show that the NRT at our university is an inclusive, supportive, applied curriculum that enabled 40 graduate students to train as interdisciplinary thinkers and produce innovative interdisciplinary research. This paper may also be a guide to current and future NRT programs to help them pursue elements of the traineeship that are most effective.

Introduction

Academic departments often work in silos, thus giving fewer opportunities for graduate students and faculty from different departments to interact and for graduate students to gain the skills needed to do interdisciplinary research. Interdisciplinary research and collaboration have several benefits such as addressing complex research questions and social problems and having a more productive team [1] [2]. The National Science Foundation (NSF) has funded interdisciplinary training at the graduate student level through its NSF Research Traineeship (NRT) program since 2013 [3]. The NRT program provides support for cohorts of graduate students by funding STEM education programs that emphasize innovative, evidence-based traineeship approaches in interdisciplinary research areas and transformative graduate STEM education strategies. The

NRT promotes training to enable trainees to bridge research areas and engage in cross-disciplinary team science. It also encourages the development and implementation of training curricula that prepare students for multiple career pathways. As part of NSF's engagement in the Food, Energy, and Water (FEW) Nexus and in recognition of the need for graduate students skilled in developing and applying new technologies, analyzing and developing complex systems, and engaging with food, energy and water stakeholders, the NSF funded in 2018, our university NSF Research Traineeship (NRT) in the FEW Nexus. The NRT at our university integrated professional development, research, outreach, and educational activities that were designed to promote the development of NRT students as interdisciplinary scholars and enhance their ability to communicate about research problems and their contexts to different audiences.

Since 2018, the NRT at our university has trained 40 graduate students, as shown in table 1. The NRT trainees have been master's and doctoral students from the College of Engineering, the College of Arts and Sciences, and the College of Agriculture. The NRT program at our university includes educational and experiential components. These components are field experiences, policy experiences at the state capital, applied course work, interdisciplinary research, faculty and peer mentoring, professional development for students, and periodic assessment of these components [4] [5] [6]. This paper examines the NRT at our university from a holistic view and gives insights into the five years of the program. This paper will describe the NRT program, discuss the summative assessment of the NRT at our university and the insights we have gained.

Table 1: NRT cohorts

NRT Cohort	# of students	Women	Members from historically excluded groups (e.g. Black, Hispanic, Native American)
2019-2020	16 (11 PhD, 5 MS)	8/16	1/16
2020-2021	7 (4 PhD, 3 MS)	4/8	4/8
2021-2022	8 (5 PhD, 3 MS)	3/7	3/7
2022-2023	9 (1 PhD, 8 MS	3/9	3/9
Total	40	22/40 (55%)	11/40 (27.5%)

Positionality of the author team

The author team is an interdisciplinary team and includes faculty, administration, and staff from the Colleges of Engineering, Agriculture, and Arts and Sciences. The author team does not include members from historically excluded groups (e.g. Black, Hispanic, Native American), who are historically underrepresented among STEM degree earners. The author team includes five people who identified as women. Two of these women are engineers, one is an educator, and two are social scientists. The author team also includes five people who identified as men. Three of these men are engineers, and two of these men are social scientists. As such, we have first-person experiences that allow us to relate to women in STEM. Moreover, four of the authors hold dual citizenship and have first-person experiences that allow us to relate to being an outsider. The author team has been involved in the development, implementation, and evaluation of the NRT program at our university. All the team members have research and education experiences in the FEW nexus. These experiences allow us to develop a comprehensive

interdisciplinary traineeship for food, energy, and water systems at the graduate level. In addition, all members of the author team work with STEM diverse students, both women and men, regularly, and amongst us we participate in several types of learning circles focused on promoting equality in US universities and society.

Description of the NRT program at our university

The NRT applied coursework included one credit hour Integrated FEW Systems course and the two credits NRT Capstone. The Integrated FEW Systems course was co-taught by faculty from the Colleges of Engineering, Agriculture, and Arts and Sciences. It had been offered every fall semester from 2019 to 2022. In this course, students were introduced to system thinking with specific application to the FEW nexus in South West Kansas through class discussion, lectures, guest speakers, readings and assignments. The systems framework was introduced in the book, The Macroscope [7], and students used LOOPY [8], a tool for thinking in systems, to build models of engineering and social aspects of the FEW systems in our state. Course material integrated engineering, economic, and social sciences, with a focus on the unique challenges for management, governance, communication, and policy in rural agricultural contexts.

The two credit hours NRT Capstone was co-taught by faculty from the colleges of Engineering, Agriculture, and Arts and Sciences and was offered in spring 2021 and spring 2023. In the NRT Capstone course, trainees built upon the systems thinking framework taught in the Integrated FEW Systems course. The NRT Capstone integrated theory and practice. Students worked in interdisciplinary teams and learned how to integrate research across disciplines. For a final product, students completed an original interdisciplinary research paper in one of the NRT three research themes: innovations for soil, water and microbial systems in the face of drought; hydrologic science and water conservation systems for efficient food production; and anaerobic bioreactors to transform animal waste into usable energy, water, and/or fertilizer.

NRT students could also work towards a graduate certificate on Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS). The INFEWS graduate certificate consists of 12 credit hours and 2 semesters of the NRT Seminar (0 credit hours). Core courses, Integrated FEW Systems and NRT Capstone, give students three (3) credit hours out of the 12 required credit hours. The other nine (9) credits are chosen from a list of elective courses in the FEW nexus from the Colleges of Engineering, Agriculture, and Arts and Sciences. Students must take at least one elective outside of their discipline and outside of their home college. In these elective courses, students consider the engineering, societal, and economic aspects of issues in the FEW nexus. The INFEWS certificate requirements inclusive of a list of the core and elective courses, and a short description of these courses can be found on our university Graduate School website [9].

For students' professional development, the NRT offered a seminar series in the fall and spring semesters, which included eight sessions (twice a month) each semester. NRT Seminar is a 0-credit hour seminar that has been offered on a Credit/No Credit basis. Students completed up to four semesters of NRT Seminar. The NRT Seminar consisted of training sessions related to inclusion, career pathways, campus resources, skill development to communicate across

disciplines and to diverse audiences, and exposure to FEW research initiatives. Internal or external guest speakers gave talks during seminar. Students completed a reflection activity after each seminar session. To receive credit for NRT Seminar, students had to complete six reflection activities out of the eight activities and the science communication activity. For the science communication activity, students presented their research to different audiences.

For the NRT field experience, NRT trainees spent time in the summer with FEW stakeholders to understand better the interdisciplinary nature of FEW resource challenges in rural communities tied to the diminishing natural resources, and to learn how to communicate effectively with FEW stakeholders. In summer 2020, NRT trainees engaged with FEW stakeholders from our state and FEW scholars via Zoom due to COVID-19. In summer 2021, NRT trainees visited a research farm and an irrigation district in our state, where they met with FEW stakeholders. In summer 2023, NRT trainees traveled to a different region of our state, where they met with FEW stakeholders and visited a livestock farm, a dairy farm, and the wastewater treatment plant that uses anaerobic to convert wastewater to biogas. The field experiences were organized in the summer to avoid conflict with trainees' course schedule and fall or spring breaks as well as conflict with producers harvesting or planting times. Transportation to the field sites and back was provided from campus.

To prepare NRT trainees to engage with policy that sustains the use of natural resources, NRT trainees were introduced to different water management plans and learned how to engage with political leadership and policy decision makers. NRT trainees and faculty visited with key legislators and policy-making groups about water governance/water policy in Kansas. In spring 2020, 2021, 2022, and 2023 NRT trainees met with legislatures and policy-making groups about water governance and policy in Kansas. NRT trainees were prepared to this activity during NRT Seminar where they had an overview of the state legislature and received tips on how to communicate with the legislators.

To explore different career pathways and to create a professional community, the NRT leadership team established a team-based faculty and peer mentoring to provide vocational counseling and career planning for NRT trainee to pursue industry, government, and academia positions and foster a sense of professional community [10]. The interdisciplinary team-based faculty mentoring included a development of Individual development plans (IDPs) with NRT trainees [11]. Each mentoring group had three faculty members from at least two disciplines. The IDP included skills assessments, short-term goals and long-term career goals. As part of their IDP, trainees and faculty identified critical skills to be developed, activities that could develop those skills, and target dates to achieve those skills. First year trainees met with their interdisciplinary faculty mentoring team in the fall semester to develop their IDPs and in the spring semester to review their updated plan and check their progress towards their career goals. Second year trainees met with their faculty mentoring team in the fall and spring semesters to review their updated IDPs and check their progress towards their career goals. In addition, trainees participated in monthly peer mentoring groups to respond to a monthly prompt about leadership skills, team building, and their professional goals.

Evaluation: Identifying and Measuring Intended Outcomes of the NRT Program
An external evaluator worked collaboratively with the NRT leadership team to support continuous program improvement. Data collection activities were designed to provide glimpses into how NRT student experiences compared with intended outcomes identified by NRT leaders when they designed the program. In this way, formative evaluation feedback helped NRT leaders shape the program so that it more effectively trained graduate students. This optimized the program for training students to; for example, work collaboratively with other graduate students from different disciplines and with FEW stakeholders to find solutions that promote the resiliency of rural resources.

An annual NRT trainee survey elicited student feedback about their experiences with the NRT program overall, as well as the Integrated FEW Systems course and the NRT Seminar. Students from all four cohorts, between 2019 and 2022, completed the survey after they completed their fall semester courses. Most students from each cohort responded to the annual NRT trainees' survey with a response rate of 69% or greater as shown in table 2. To elicit student feedback about their experiences with the NRT Capstone course, the external evaluator administered a survey to students at the end of the course when it was offered in spring 2021 and 2023.

Table 2: Administration of the Annual NRT Trainee Survey

NRT Cohort	Annual survey administration	Sample (surveys completed)	# students in the cohort	Response rate
2019-2020	February 2020	11	16	69%
2020-2021	December 2020	15	20	75%
2021-2022	December 2021	12	16	75%
2022-2023	December 2022	11	13	85%

At the closing of each survey, the evaluator downloaded response data from Qualtrics survey software to Microsoft Excel and analyzed them. Average rating scores and bar charts were created to support discussions with the NRT leadership team. These co-interpretation sessions were held to improve validity of the analysis by adding context about what was happening in the classroom and in the field [12]. Co-interpretation also supported NRT program planning and decision-making to improve student experiences. For this paper, tables for each course summarize data about skill building from each of four cohorts; t-test statistics show which ability gains are statistically significant. We also calculated a cross-cohort, or summative, significance statistic for each skill, called p(all cohorts). Bar graphs show ratings from students for the overall NRT program and for the usefulness of various course activities.

T-test statistics were generated to examine whether changes in abilities to carry out skill from before to after course interventions were significant. Because sample sizes for individual cohorts are small, between 6 and 15, there are several limitations to the t-test that should be considered. These limitations are less concerning for the summative t-test statistics, called p(all cohorts), that

are calculated using ratings from all cohorts and have a sample size near 30. The major limitation has to do with how, with small sample sizes, a t-test is less likely to detect a significant difference between means when there is one, called a 'Type II Error,' than with larger samples. Despite this, results tables in the following pages show that most skills for individual cohorts, p(cohorts), were statistically significant. Another limitation of performing statistical tests with small sample sizes is that these data are more likely to be non-normal, which makes t-test results less reliable. Finally, with a small sample size, a t-test statistic is not generalizable, so we would not want to conclude that results indicate something about, for example, students in other NRT programs.

How well did the NRT program support trainees' interdisciplinary research skills development?

We asked NRT trainees to give the NRT program a grade for supporting their development of five skills, where a grade of 'F' is 1 point, and a grade of 'A' is 5 points. These five skills are Communication with audiences from different academic disciplines and the public, Understanding FEW stakeholders, Identify potential research partnerships, Interdisciplinary teamwork, Understand potential career pathways: government, academia, industry. Then we calculated mean student rating for each skill. Figure 1 offers a summative depiction of student ratings for how well the NRT program supported development of the five skills. All cohorts rated the NRT program similarly for each skill, with a grade at or near 4.0, which is a 'B.'

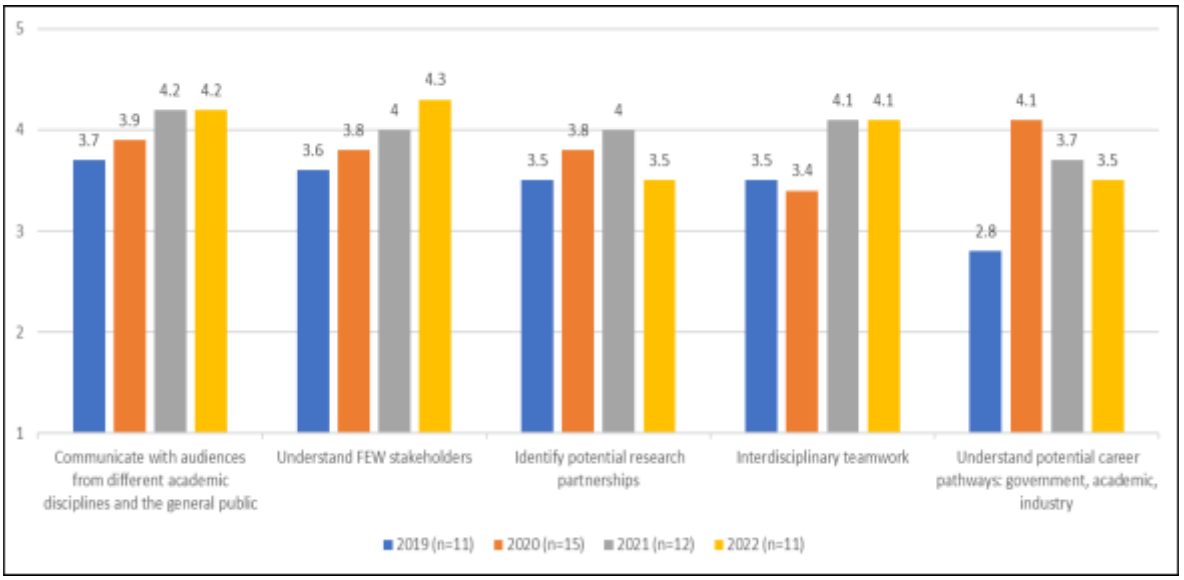

Figure 1: Students gave the NRT a grade for how well the NRT program supported trainees' development as interdisciplinary scholars

How well did the NRT Integrated FEW Systems course support trainees' skills development for interdisciplinary work?

We also wanted to gain insight into how students were building skills critical for interdisciplinary work through the NRT Integrated FEW Systems course. To this end, we asked trainees to rate their ability to perform a short list of seven key tasks before (retrospectively [13])

and after participating in the NRT Integrated FEW Systems course. These seven tasks are Collaborate on interdisciplinary teams; Communicate scientific, disciplinary knowledge to diverse audiences; Communicate across disciplinary boundaries; Be aware of diverse perspectives of FEW stakeholders; Conceptualize key FEW systems' elements, links, processes, and dynamics; Use narrative and visual tools to interpret FEW systems; and Collaborative diagnose FEW systems challenges. Survey respondents selected ratings from a five-point scale: 1=not at all able, 2=a bit able, 3=somewhat able, 4=very able, 5=extremely able.

As results in Table 3 show, for all skill areas, students indicated gains in these abilities from before to after their semester participation in the Integrated FEW Systems course. With just three exceptions, shown in gray shading, these improvements were statistically significant, p(cohort). It is worth noting that all of these non-significant exceptions occurred for the 2022 cohort, which may reflect greater variation in ratings from this cohort for these skills. That the summative statistics, p(all cohorts), show significance for each skill indicates little variation among cohort ratings about skill building.

Table 3: Students' perceived gains in seven abilities to carry out interdisciplinary systems tasks improved from before to after participating in the NRT Integrated FEW Systems course (self-report from four NRT trainee cohorts, 2019 to 2022)

Skill	Cohort	M before	M after	$p_{(cohort)}$	$p_{(all\ cohorts)}$
Collaboratively diagnose FEW system challenges	2019 (n=11)	2.6	3.6	0.00	0.00
	2020 (n=6)	2.2	3.8	0.00	
	2021 (n=7)	2.4	3.7	0.00	
	2022 (n=6)	1.8	4.0	0.00	
Communicate across disciplinary boundaries	2019 (n=11)	2.9	3.7	0.02	0.00
	2020 (n=6)	2.7	3.7	0.01	
	2021 (n=6)	3.0	4.0	0.04	
	2022 (n=6)	2.7	3.8	0.08	
Be aware of the diverse perspectives of FEW stakeholders	2019 (n=11)	2.8	3.6	0.03	0.00
	2020 (n=6)	2.0	3.5	0.02	
	2021 (n=7)	2.7	3.9	0.00	
	2022 (n=6)	2.0	3.7	0.05	
Use narrative and visual tools to interpret systems from multiple perspectives	2019 (n=11)	2.6	3.5	0.03	0.00
	2020 (n=6)	2.3	3.3	0.01	
	2021 (n=7)	2.7	3.7	0.00	
	2022 (n=6)	2.5	4.0	0.04	

Conceptualize key FEW system elements, links, processes, and dynamics	2019 (n=11)	2.7	3.6	0.00	0.00
	2020 (n=6)	2.5	3.7	0.03	
	2021 (n=7)	2.9	4.1	0.00	
	2022 (n=6)	2.3	4.0	0.00	
Communicate scientific, disciplinary knowledge to diverse audiences	2019 (n=11)	2.9	3.5	0.02	0.00
	2020 (n=6)	3.0	3.7	0.10	
	2021 (n=7)	3.0	4.1	0.03	
	2022 (n=6)	2.0	3.7	0.05	
Collaborate on interdisciplinary teams	2019 (n=11)	3.2	3.8	0.05	0.00
	2020 (n=6)	2.2	3.8	0.00	
	2021 (n=6)	2.8	3.8	0.04	
	2022 (n=6)	3.5	4.3	0.22	

How well did the NRT Seminar support trainees' skills development?

We also asked NRT trainees to rate their ability to perform a short list of six key tasks before (retrospectively [13]) and after participating in the NRT Seminar series. These tasks were Identify potential research partnerships; Communicate research in a succinct manner; Articulate how research can become interdisciplinary; Cooperate on an interdisciplinary team; Presenting research to a diverse audience, including stakeholders and other scholars; and Identify possible career paths. Survey respondents selected ratings from a five-point scale: 1=not at all able, 2=a bit able, 3=somewhat able, 4=very able, 5=extremely able. To find the gain in skills we calculated averages from before and after skill ratings and then calculated change. Standard deviations were at or less than 1.3 rating point, indicating that response variations were low.

As results in Table 4 show, for all skill areas, NRT students indicated gains in these abilities from before to after their semester participating in the NRT Seminar. With just two exceptions, shown in gray shading, these improvements were statistically significant, p(cohort). Moreovever, the summative statistics, p(all cohorts) show significance for each skill, suggesting little variation among cohorts for this skill building.

Table 4: Students' perceived gains in six abilities to carry out interdisciplinary work and science communication tasks improved from before to after participating in the NRT Seminar (self-report from four NRT trainee cohorts, 2019 to 2022)

Skill	Cohort	M before	M after	$p_{(cohort)}$	$p_{(all\ cohorts)}$
Identify potential research partnerships	2019 (n=11)	2.5	3.6	0.00	0.00
	2020 (n=15)	2.7	3.6	0.00	
	2021 (n=11)	2.5	3.4	0.00	

	2022 (n=11)	2.5	3.2	0.04	
Communicate your research in a succinct manner	2019 (n=11)	2.9	3.6	0.02	0.00
	2020 (n=15)	3.4	4.1	0.00	
	2021 (n=11)	3.2	3.9	0.00	
	2022 (n=11)	2.7	3.7	0.01	
Articulate how your research can become interdisciplinary	2019 (n=11)	3.2	3.8	0.01	0.00
	2020 (n=15)	2.6	3.7	0.00	
	2021 (n=11)	2.9	3.7	0.02	
	2022 (n=11)	2.9	3.7	0.03	
Cooperate on an interdisciplinary team	2019 (n=11)	3.0	3.7	0.04	0.00
	2020 (n=15)	3.2	3.8	0.02	
	2021 (n=11)	3.2	3.8	0.03	
	2022 (n=11)	3.4	3.7	0.31	
Presenting research to a diverse audience, including stakeholders and other scholars	2019 (n=11)	2.9	3.6	0.04	0.00
	2020 (n=15)	3.2	3.9	0.00	
	2021 (n=11)	3.2	3.9	0.00	
	2022 (n=11)	3.4	3.7	0.00	
Identify possible career paths	2019 (n=0)	NA	NA	NA	0.00
	2020 (n=15)	3.3	3.8	0.00	
	2021 (n=10)	3.8	4.0	0.34	
	2022 (n=11)	3.5	4.2	0.03	
NA=no data was collected in 2019 for this factor.					

How well did the NRT Capstone course support trainees' interdisciplinary research skills development?

Finally, we wanted to better understand how trainees' interdisciplinary research skills developed from participating in the NRT Capstone course, which the NRT program offered twice, in spring 2021 and in spring 2023. Students completed a survey in May 2021 and May 2023, respectively, after participating in the Capstone course. Response rates were 88% and 85% respectively. We asked survey respondents to rate their ability regarding three key skills before and after the Capstone course: Write a literature review; Produce research products; and Work in interdisciplinary teams. They rated their abilities using a scale of 1=not at all able, 2=a bit able, 3=somewhat able, 4=very able, 5=extremely able.

As results in Table 5 show, for all three-skill areas, NRT students indicated gains in these abilities from before to after their semester participating in the Capstone course. With two exceptions, shown in gray shading, these improvements were statistically significant, p(cohort). Moreover, the summative statistics, p(all cohorts) show significance for each skill, suggesting little variation between cohorts for this skill building.

Table 5: Students' perceived gains in three abilities to carry out interdisciplinary research tasks improved from before to after participating in the NRT Capstone course (self-report from spring 2021 and spring 2023)

Skill	Cohort	M before	M after	$p_{(cohort)}$	$p_{(all\ cohorts)}$
Write a literature review	2021 (n=14)	3.6	4.0	0.01	0.00
	2023(n=12)	3.6	4.3	0.01	
Produce research products	2021 (n=14)	3.3	3.9	0.01	0.00
	2023 (n=12)	3.4	4.0	0.05	
Work in interdisciplinary teams	2021 (n=14)	2.9	4.0	0.00	0.00
	2023 (n=12)	3.7	4.2	0.08	

Together, these results are a strong indication that the NRT program provided support for trainees' development of skills for carrying out high quality interdisciplinary research. Without exception, trainees reported improvement in their abilities from before to after their coursework and nearly all of these gains were statistically significant. This could in part relate to the relatively high usefulness ratings from students for course activities, described in the next section and illustrated in figures 2, 3, and 4.

The usefulness of NRT course activities

We wanted to learn how useful students thought the activities in the NRT program were for preparing them to carry out interdisciplinary work. We asked trainees about the usefulness of activities of the Integrated FEW Systems Thinking course, of the NRT Seminar, and of the Capstone course.

For the NRT Integrated FEW Systems course, NRT trainee survey respondents rated a list of course activities on a scale of 1=not at all useful, 2=a bit useful, 3=somewhat useful, 4=very useful, 5=extremely useful. As Figure 2 shows, according to student ratings over four years, they rated all activities as useful for developing interdisciplinary research skills. The most useful activities from the Integrated FEW Systems course had to do with the Systems map, Class discussion, Guest speakers, Faculty lectures, and Trainee presentations. More than half indicated that the Systems map, Class discussions, Guest speakers, Faculty lectures, and Trainee presentations activities were 'very' or 'extremely' useful. For example, 45% of students ranked the Systems map activity using Loopy as 'very' useful and 34% rated it as 'extremely' useful. In contrast, students' ratings for Readings and Reflection analysis were more varied. A closer look at Reflection analysis, for example, shows that just a few more that one-third of students, 40%

(33%+7%), rated this activity as ‘very’ or ‘extremely’ useful, another one-third, 37%, rated the activity as ‘somewhat’ useful, and 22% rated it as ‘a bit’ or ‘not at all’ useful. It is worth noting that not all four cohorts experienced all course activities. That is, the fourth cohort did not experience Trainee presentations, as all trainees were master’s students in their first semester, more time was allocated to class activities.

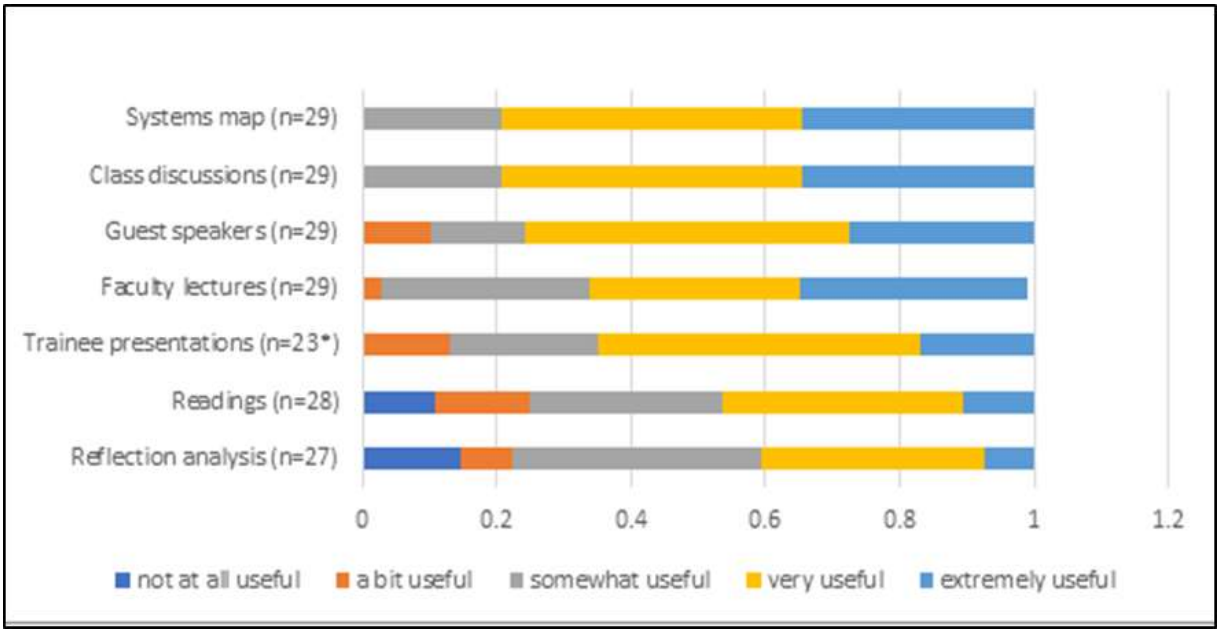

Figure 2: Students ratings of the usefulness of the NRT Integrated FEW Systems course activities. Ratings from four cohorts, 2019-2022.

For the NRT Seminar series, trainees rated a list of Seminar activities on a scale of 1=not at all useful, 2=a bit useful, 3=somewhat useful, 4=very useful, 5=extremely useful for developing interdisciplinary research skills. The stacked bar chart shown in Figure 3 allows for comparison of the usefulness of activities. Activities from the NRT Seminar that trainees found most useful had to do with presentations. More than 60% of survey respondents indicated that the Science communication presentation and practice was ‘very’ or ‘extremely’ useful. Similarly, more than fifty percent indicated that Presentations about careers and other Guest presentations were ‘very’ or ‘extremely’ useful.

It is worth noting that not all four cohorts experienced some activities. Trainees from the first cohort were involved in seminar planning by suggesting seminar topics and scheduling guest speakers. From the annual survey, we learned that NRT trainees liked to provide input about seminar topics, but did not want to take part in scheduling the guest speakers. As a result, since then, the NRT Coordinator and/or NRT faculty scheduled the guest speakers with trainee input on seminar topics. Another change was to eliminate the 3-minute thesis challenge activity from this early semester in students’ studies, because they do not yet have enough research results to talk about [14]. In addition, the fourth cohort of NRT trainees participated in podcasting training after NRT leadership learned, through seminar reflection activity, that there is an interest in podcasting.

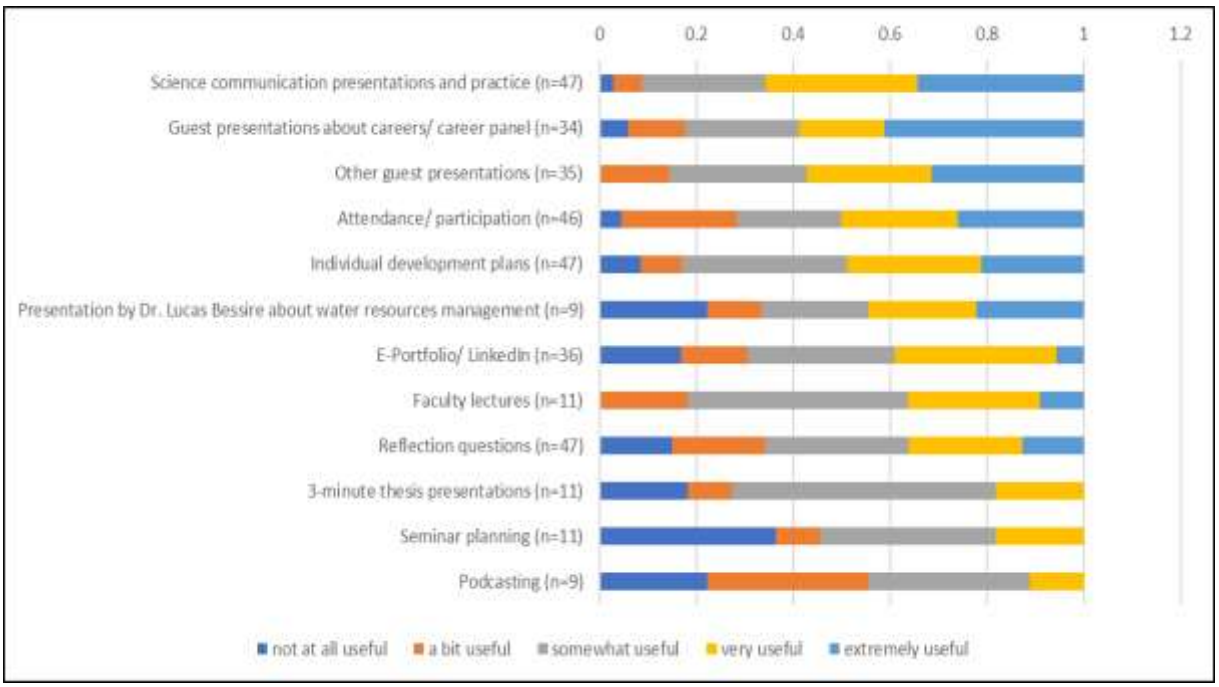

Figure 3: Student ratings of the usefulness of NRT Seminar activities Ratings from four NRT student cohorts 2019-2022

For the NRT Capstone, we asked survey respondents to rate a list of Capstone course activities on a scale of 1=not at all useful, 2=a bit useful, 3=somewhat useful, 4=very useful, 5=extremely useful. As shown in Figure 4, NRT trainees thought that most Capstone course activities were quite useful. More than 80% of survey respondents indicated that Working in interdisciplinary teams was 'very' or 'extremely' useful. At least 40% rated almost all other activities as 'very' or 'extremely' useful.

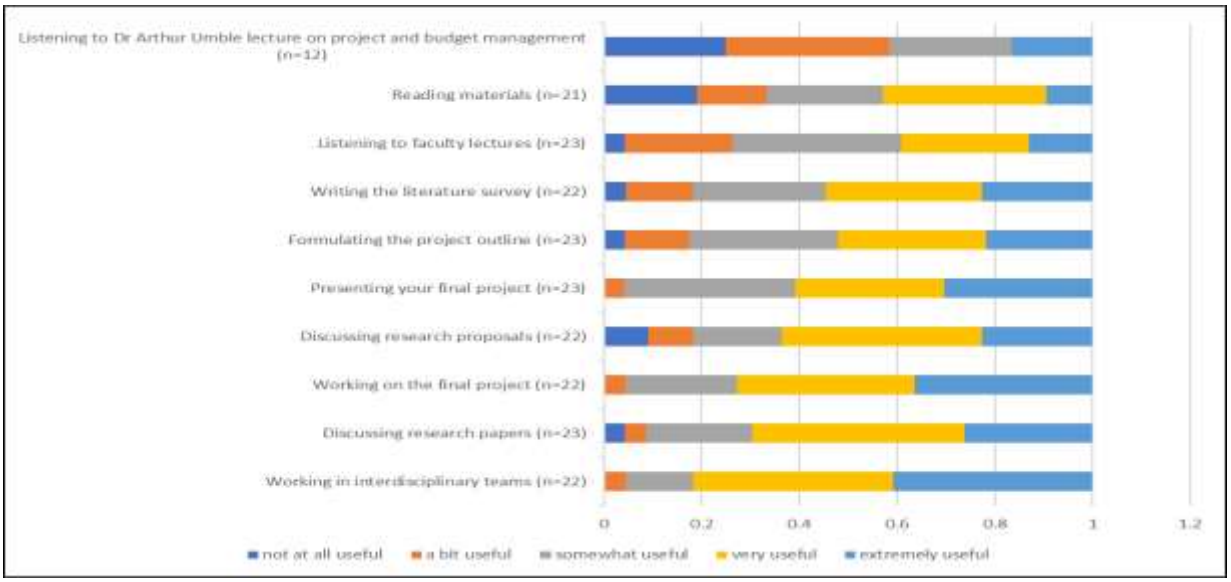

Figure 4: Students ratings of the usefulness of NRT Capstone Course activities that took place in spring 2021 and 2023

The strongest pattern seen in trainee usefulness ratings for activities in all three NRT courses is that many thought activities were useful, especially Capstone course activities. Also noticeable is that many of the activities that trainees rated as more useful had to do with communication and teamwork, presentations, class discussion, guest speakers, faculty lectures, and trainee presentations. This could reflect that the trainees came to appreciate the importance of research teamwork and of communicating with stakeholders. Evidence of this came from students' comments during informal conversations with NRT team leaders about how graduate school typically does not support students in developing teamwork and communications skills for interdisciplinary work.

Evaluation feedback drove continuous improvement actions

Throughout the five years of the NRT program, the leadership team adjusted the program based on formative feedback. Formative feedback was elicited regularly through systematic survey and interview research, and through a bi-annual meeting with the student advisory board. For example, first semester NRT trainee survey feedback (2019) indicated that trainees needed job search coaching earlier in their program than NRT leaders had originally planned. So, starting in the second year of the program, these career-planning meetings were scheduled earlier. We also learned that faculty mentoring, career panels, and guest speakers were very useful for career planning. Thus, we continued this kind of programming and worked over the semesters to enrich it, based on trainee feedback each semester. As a result, team-based faculty mentoring supported students in identifying the careers they wanted and NRT graduates have found jobs in industry, military, and academia. In addition, through conversations with NRT trainees, program leaders learned that NRT graduates are more competitive in their job searches because of their interdisciplinary experiences, which they could display to potential employers through research papers and on their resume.

Feedback was particularly important for informing the NRT leadership team about how to support trainees as they worked to develop skills to do interdisciplinary research. This was because, even though they reported gains in interdisciplinary teamwork skills, especially communications skills, NRT leadership encountered challenges in bringing together students from diverse disciplines to do interdisciplinary research in the FEW nexus as part of the NRT Capstone course. Through evaluation feedback and through interactions with students, Capstone course leaders saw that the most challenging aspects of interdisciplinary teamwork for students had to do with team logistics such as delegating and sharing project tasks, project pacing, and peer interaction. The success of interdisciplinary research requires collaborators to develop a consensus in terms of topic, methods, and outcomes at the beginning of the project [15]. The NRT leaders' response action to help students was to enhance team collaboration and communication by adding more team building activities to the NRT curricula. One of these activities was the "Listeners and Talkers" activity, which gives students practice communicating within groups. Mango Singham from Case Western Reserve University has developed the Listeners and Talkers activity to increase participation with no coercion [16]. During this activity, students were asked to self-identify as either "talkers" or "listeners". Then, all students who identified as talkers were asked to sit together in one part of the classroom, and discuss what made them become a talker, how they can develop their listening skills, and how they can help

listeners talk more. All students who identified as listeners were also asked to sit together in another part of the classroom and discuss what made them become listeners, how they can develop their talking skills, and how they can help talkers to listen more. After 20 minutes of group discussion, the two groups reported to the class. Another challenge trainees had was identifying meeting times that worked for all group members to meet. To overcome scheduling conflicts, the NRT incorporated workdays into the course schedule, so student teams could work on the Capstone research project during some class periods. Although these workdays were helpful, successful teams needed to meet outside of the course time and find common meeting times.

We also learned, through formative evaluation feedback, and through informal conversations among students and faculty, that disseminating interdisciplinary research poses challenges for students and faculty. A major reason for this was that many conferences and journals are discipline specific, finding the right audience (e.g., journal or conference) for interdisciplinary research was challenging. Finding time to publish research was also a factor. Students were motivated by the opportunity to publish an interdisciplinary journal paper and add it to their curriculum vitae, but were not able to finish it within one semester. To support students and faculty, the NRT leadership team encouraged NRT trainees to publish either a conference paper or a journal paper. Another challenging aspect of organizing interdisciplinary Capstone course was forming the teams so that research topics aligned with all students' academic backgrounds. The NRT leadership team explored how to make interdisciplinary research more central to graduate work and found out that it varies among departments and disciplines at our university.

In addition, we learned through the formative evaluation feedback that it is useful to use a visualization tool, such as Loopy, to teach systems thinking. The tool allowed students to simulate how FEW systems behaved. Because of the mixed survey ratings from the second cohort about the Integrated FEW Systems textbook readings, the NRT leadership team kept the textbook but adjusted the amount of readings for the one-credit course. NRT leaders decided to keep the textbook because was very accessible resource, both financially and for convenience, because it is open-sourced and because it's content support coursework by introducing systems thinking using examples from the natural-environmental systems and the human-social systems.

Finally, we found from formative evaluation feedback that trainees' favorite aspect of the NRT, for each cohort was the same: exposure to and interactions with faculty and fellow students who have diverse academic and personal backgrounds. The value of these interactions, and how to leverage them for program and research goals, would be interesting to explore further in future research about how NRT programs can be effective.

We learned from informal conversations with NRT faculty that co-teaching and developing an interdisciplinary curriculum requires communication among faculty from different disciplines, so that lessons are sure to relate to each other, and to course objectives. Developing interdisciplinary courses requires faculty to move beyond their own comfort zone of teaching and to connect lecture material to other topics in the course.

Insights from faculty for best interdisciplinary practices

To generate a list of best practices for training students to excel with interdisciplinary research projects, the NRT program external evaluator interviewed all seven members of the NRT leadership team between August 17 and September 13, 2021. To prepare, the interviewer collaborated with the NRT Director and Program Coordinator to develop and test the interview protocol. For data analysis, responses were described in aggregate, as themes and patterns, following Patton [17]. After an initial analysis, the external evaluator held a collaborative interpretation session with core NRT leadership team to identify topics to further clarify or exemplify.

Faculty interviews highlighted a handful of approaches for training graduate student to do excellent interdisciplinary research: Get practice (do interdisciplinary research); Have experiences in the field; Reframe expectations each time students start a new project; Embrace a professional paradigm; and Work to develop knowledge and skill for interdisciplinary work: Communications, Project management, Team skills. The NRT has had these approaches in its program: NRT research is central to students' research, and research activities occur as a part of coursework and outside of courses.

In addition, NRT faculty recommended that an interdisciplinary traineeship help students to develop as perceptive interdisciplinary communicators. This means that students from different disciplines develop a common vocabulary; that they develop common understandings for aspects of research, such as scale, source, and study limitations; and that they know when and how to communicate with different audiences. The NRT program at our university enhanced students' science communication by offering science communication theory and practice sessions during NRT Seminar series each semester. As an example, after a conference presentation, an NRT student received positive feedback from stakeholders – mostly agricultural producers and some banker crop insurance agents – for their clear explanation of carbon credit markets. Other trainees presented the university at the Research and the State event at the state capitol where they share their FEW nexus research with legislators and the public.

Finally, NRT faculty recommended that, for a graduate training in interdisciplinary research to be successful, the leaders should be dedicated to interdisciplinary research. This means that leaders facilitate meetings and communicate with faculty, industry, and students from all disciplines. They set big visions, see projects through, and carry out research outside the structure of courses. In addition, an interdisciplinary graduate training program ideally is housed in an interdisciplinary center, which is a hub for collaborations inside and outside the university. With an interdisciplinary center, students enroll in interdisciplinary courses through the center; interdisciplinary faculty are academic advisors; interdisciplinary research is aligned with other research resources on campus; and the center hosts conferences and workshops. At our NRT program, the NRT was not housed in a center, and we crossed-listed the NRT courses in six departments in three different colleges.

Insights from recruitment

Each year, a core activity of the NRT was recruiting a diverse student cohort, which was supported by the NRT director, NRT faculty, and NRT Coordinator.. To broaden participation, multiple collaborative recruiting strategies were adopted. The NRT's most successful recruitment strategies for broadening participation have been collaborating with university diversity officers, and connecting NRT faculty and current NRT students to prospective students through in person or virtual meetings and email conversations. Collaboration with university diversity officers enabled our NRT program to reach out to students from diverse backgrounds and connect them to NRT faculty and students.

Evaluation feedback shed light on students' motivations for applying to the NRT program. It showed that most students applied to the NRT program primarily to grow as an interdisciplinary researcher. Future research could examine whether students at other universities are also attracted to the interdisciplinary nature of NRT programs. Such research should explore the degree to which interdisciplinary programs attract a diverse student pool.

In addition, due to COVID-19, it took longer than anticipated to approve the INFEWS certificate. As a result, only a handful of NRT trainees have completed the INFEWS certificate, most of whom were doctoral students. The NRT leadership team noticed that the 12-credit graduate certificate fits better into the doctoral program of study schedule than the master's program of study. To overcome this challenge and to open this opportunity to more learners, the NRT leadership team is exploring how to change the certificate into a micro-credential, which requires less than 12 credit hours for completion.

Conclusions

This paper offers a detailed description of the NRT program at our university and how feedback, derived through systematic evaluation supported program leaders as they refined the program design and operation. We offer it as a guide to existing and future NRT programs, who may benefit from reading about our challenges and opportunities associated with an interdisciplinary graduate traineeship. This paper also provides insight into the elements of the NRT traineeship that were the most effective. The NRT program at our university trained 40 master's and doctoral students to study issues pertaining to the FEW nexus from diverse engineering, scientific, and social science perspectives. Survey ratings and written feedback, along with observations made by NRT faculty, show how the NRT program prepared NRT trainees to thrive as interdisciplinary scholars. Fieldwork and courses were effective in supporting students in learning to do interdisciplinary research and communicating to diverse audiences. We also learned from NRT faculty that training students to do excellent interdisciplinary research students need 1. Practice (do interdisciplinary research), 2. Have experiences in the field, 3. Be aware of expectations each time they start a new project, 4. Embrace a professional paradigm, and 5. Develop skill for interdisciplinary work: communications, project management, and teamwork skills.

Recommended areas for further research are 1. Examining the relationship between interdisciplinary graduate traineeships and diversity of the graduate student body, 2.

Experimenting with how to leverage the valuable interactions NRT students had with other faculty and staff to improve student experiences and accomplishments, and also NRT program culture, and 3. Exploring whether interdisciplinary graduate traineeships could be mechanisms for drawing diverse participant groups to STEM graduate education programs.

Acknowledgment

This work was supported by the National Science Foundation Research Traineeship (NRT) grant # 1828571.

References

[1] E. National Academies of Sciences, The Integration of the Humanities and Arts with Sciences, Engineering, and Medicine in Higher Education: Branches from the Same Tree. 2018. Available: https://nap.nationalacademies.org/catalog/24988/the-integration-of-the-humanities-and-arts-with-sciences-engineering-and-medicine-in-higher-education

[2] K. O'Meara and D. Culpepper, "Fostering collisions in interdisciplinary graduate education," Studies in Graduate and Postdoctoral Education, vol. 11, no. 2, pp. 163–180, May 2020, doi: https://doi.org/10.1108/sgpe-08-2019-0068.

[3] "National Science Foundation Research Traineeship Program | NSF - National Science Foundation," *new.nsf.gov*, Nov. 27, 2020. https://new.nsf.gov/funding/opportunities/national-science-foundation-research-traineeship

[4] Shamir, M., &, M. Sanderson R., & Cors, R., & Derby, M. (2021, July), *How Small, Interdisciplinary Programs Are Contributing to Diversity and Inclusiveness in STEM University Departments in the US* Paper presented at 2021 ASEE Virtual Annual Conference Content Access, Virtual Conference. 10.18260/1-2—36521

[5] Shamir, M., & Hutchinson, S., & Hock, G., & Hansen, R., & Aguilar, J., & Hendricks, N., & Parameswaran, P., & Sanderson, M., & Cors, R., & Derby, M. (2022, August), *Development of a graduate-level capstone course for interdisciplinary researchers: design approaches and lessons learned* Paper presented at 2022 ASEE Annual Conference & Exposition, Minneapolis, MN. https://peer.asee.org/40956

[6] Shamir, M., & Sanderson, M. R., & Cors, R., & Hendricks, N. P., & Hutchinson, S. L., & Parameswaran, P., & Derby, M. (2023, June), *An integrated systems thinking graduate course that prepares students to solve the complex problems of the food-energy-water nexus* Paper presented at 2023 ASEE Annual Conference & Exposition, Baltimore , Maryland. https://peer.asee.org/42631

[7] Joël de Rosnay, The Macroscope. HarperCollins Publishers, 1979.

[8] "LOOPY!," ncase.me. https://ncase.me/loopy/

[9] “Program: Sustainable Food, Energy, Water Graduate Certificate - Kansas State University - Acalog ACMSTM,” catalog.k-state.edu. https://catalog.k-state.edu/preview_program.php?catoid=48&poid=16408 (accessed Jan. 10, 2024).

[10] “Industry Mentor Program,” olathe.k-state.edu. https://olathe.k-state.edu/academics/student-resources/mentor-program/industry_mentor.html (accessed Jan. 12, 2024).

[11] C. Margerison, "Individual development plans," Libr,” Contemporary Issues in Education Research (CIER), vol. 8, no. 3, pp. 147–158, Jul. 2015, doi: 10.19030/cier.v8i3arian Career Development, Vol. 2, no. 1, pp. 4-10, 1994.

[12] Rodríguez-Campos, L., & Rincones-Gómez, R. (Eds.) (2012). Collaborative Evaluations, Step-by-Step. Second Edition, Stanford University Press.

[13] Cors, R. & Bell, C. 2022, April 21, Retrospective pre-posttests are ideal for evaluating many informal learning experiences. Center for the Advancement of Informal Science Education (CAISE), informalscience.org. https://www.informalscience.org/news-views/retrospective-pre-posttests-are-ideal-evaluating-many-informal-learning-experiences.

[14] “Three Minutes Thesis Competition,” www.k-state.edu. https://www.k-state.edu/grad/student-success/research-forums/three-minute-thesis/ (accessed Jan. 19, 2024).

[15] K. A. Holley, "Special issue: understanding interdisciplinary challenges and opportunities in higher education," *ASHE higher Education Report* , vol. 35, no. 2, pp. 1-131, 2009.

[16] R. Reis, " Talkers and Listeners - Tomorrow's Teaching and Learning," Stanford University, [Online]. Available: https://tomprof.stanford.edu/posting/558 (Accessed 16 January 2024).

[17] M. Q. Patton, Qualitative Research and Evaluation Methods, 3rd ed. Thousand Oaks, Calif.: Sage Publications, 2002. Available: https://aulasvirtuales.files.wordpress.com/2014/02/qualitative-research-evaluation-methods-by-michael-patton.pdf