Undergraduate Research Training Workshop

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***Abstract*—Undergraduates perform independent research or use research, regardless of their discipline. For most students, this work is part of a formalized experience. However, formalized training in research methods, biases, and disposition is rare; students acquire these skills through mentoring, modeling, and making mistakes, and in the context and content of the discipline. These methods are not ideal. The purpose of the Research Training Institute (RTI) is to make the invisible world of research visible to new researchers, free from a content focus, through a set of seminars and activities. We conducted three one-day research bootcamps to STEM students. Each bootcamp contained sessions on research planning, experimental design, identification of bias, writing an abstract, proposal summary and other appropriate topics. The culminating experience of the research boot-camp was a discipline independent specific research design exercise where interdisciplinary teams of students created a plan for research on the current topic of interest in the world. The key learning goal of the challenge problem was to demonstrate the applicability of research skills across content areas. We present our findings from three RTI workshops based on students' responses in the workshop evaluation and share a curriculum aimed at broader adoption.**

Keywords—undergraduate research; science and engineering; student team

I. Introduction

Undergraduate research experiences are recognized as a high-impact practice. Such experiences increase understanding of science, confidence in one's scientific abilities, and awareness of the importance of science [1,2]. Further, authentic research experiences positively influence intrinsic motivation and retention within science, especially for students from underrepresented groups [3,4]. It is not surprising then that a typical feature of undergraduate degrees programs is an independent or collaborative research experience of some kind, especially in STEM fields. In addition, many programs express that expected outcomes for their students include competency in research methods or knowledge creation. Further, many STEM programs advertise early research, faculty-student collaborative research, or research thesis requirements in their recruitment materials. These various indicators point to the importance of research in the STEM educational enterprise.

Despite the importance of undergraduate research experiences in developing the skills and identity of a STEM professional, formalized training in research methods, biases, and cognitive disposition is rare at the undergraduate level. For students who participate in REUs, their experiences often include activities like practice with formal presentations and "Responsible Conduct of Research" training, and of course, they often join a project in progress (see example programs from Boston University's Photonics Center [5] and Clemson University's REU in Solid-State Devices [6], chosen for illustration purposes only). Further, the students' expectations for learning during these experiences exceed their actual gains [7]. For students who perform independently designed research, a large burden falls to the mentor to individually teach relevant research-process topics. Students acquire skill in research thinking through mentoring, modeling, and making mistakes, and almost always in the specific context and content of the discipline. For the rare resource that is not disciplinary in focus (e.g., the WebGURU project [8]), the recommendations center on logistics and personnel issues, like how to choose a mentor and networking advice. An obvious gap exists: training in research skills relevant across disciplines that launch students into their experience with the mindset and thinking approaches needed to formulate questions and research strategies. We aim to fill this gap with our one day bootcamp experience focusing on research skills.

In this work, we differentiate between discipline-based skills and basic research competencies. For example, using a pipette (biology), loading samples in a high-performance liquid chromatography machine and interpreting the results (chemistry), constructing a test fuel cell (mechanical engineering), and resetting and calibrating an oscilloscope (electrical engineering) comprise skills related to research conducted in a specific discipline. In contrast, we focus on research competencies like identifying and constructing meaningful research questions, finding relevant research, experimental designs and threats to validity, and structuring proposals. These skills remain relevant regardless of the field in which the research is conducted. This separation of disciplinary skills and research skills allows us to target a core set of outcomes in the Research Training Institute (RTI) program. Our primary goal for students participating in this workshop is to develop a basic understanding of a wide-variety of skills, to serve as a base for further development once "in the trenches" of the research experience.

The RTI is firmly a product of our context. Our institution is small and undergraduate-focused, with less than 2400 students. Faculty at our institution regularly engage in interdisciplinary projects like the training experience described below. Each of us, as advisors of research, struggled (and

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continue to struggle) to increase both student learning and faculty work efficiency with respect to research experiences. We developed the RTI to address the need for students to have a jump-start on their research, and the need for faculty to have students who are research-ready. This program makes an important contribution relating to research skills development, as it can be adopted regardless of disciplinary mix of students, their past research experiences, or the expertise of the faculty facilitators. In these ways, the Research Training Institute is innovative in the world of engineering education.

II. PROGRAM DESCRIPTION

RTI has been developed to attract students with limited research experiences, and approximately 60% of all RTI participants are first and second year students. The program has been offered three times since 2015, as an eight hour Saturday bootcamp. The program was developed and facilitated by three faculty members from fields of biology, physics and optical engineering, and systems engineering. Since its inception, 40 students have successfully completed the RTI. Students are selected based on an application which asks them to describe why they wish to participate in the experience, and how they plan on applying skills learned to future research opportunities. Care is given to ensure that the ultimate group of selected students represents the diversity of majors available at our Institution, so that students can work in interdisciplinary teams. Distribution of majors of RTI participants closely follows the distribution of majors at our Institution, with approximately 75% of RTI participants representing five largest majors at our Institution, namely mechanical engineering, chemical engineering, computer science, electrical engineering, and biomedical engineering. The remaining 25% of participants are science majors (21%) and mathematics majors (4%). Approximately 40% of all RTI participants are female STEM students. Because RTI attracts a multi-disciplinary group of students with limited research experiences, the curriculum has been purposefully designed to focus on general research competencies which are broadly transferable to a wide range of future research opportunities. The RTI experience seeks to provide students with a brief, yet intense and realistic experience that makes the invisible world of research strategies, approaches, and philosophies visible to new researchers.

The curriculum introduces students to several key areas that every novice researcher should be familiar with, namely: identifying possible research topics and questions and formulating focused problem statements; writing project abstracts and identifying relevant existing research to support research claims (by using web tools identified by our librarians); basic principles of experimental design, avoiding bias and reducing internal and external threats to validity; writing and evaluating research proposals through the use of rubrics; and allocation of limited resources to fund research projects.

The RTI curriculum is free from content-based focus, and instead each workshop is focused around a single broad and relevant social problem that can be studied from a variety of technical and non-technical perspectives. Each RTI experience follows the same structure, as described in the following paragraphs.

Students (pre-grouped in interdisciplinary teams of 4-5) are introduced to a very broad and relevant problem (e.g., lack of clean water, cyber security, manned mission to Mars). The problem is described in vague terms through a short narrative and some videos and images that place the problem in context, and enable students to independently establish the relevance of the problem. The following is an example problem statement given to our second cohort of RTI students:

"The goal of your work today is not to focus on technical solutions for cyber security, but to think about how you would organize research to study cyber security so that your research results can influence technical solutions in the future."

The students are asked to develop a summary of a research proposal (not a solution to the problem!) that would study some aspect of this problem. The remainder of the workshop is structured so as to give student teams an opportunity to work on various elements of the research process that would be required in practice to come up with a research proposal.

The students begin their research process by exploring the general problem through a number of lenses. They are instructed to ask a variety of questions about the general problem that broadly fall into the "who?", "what?", "when?", "where?" and "why?" categories [9], see Table I. This approach allows them to better understand the relevance of the problem and to identify what they believe is a critical issue. Students are guided through a process in which they transform the general topic into various research questions and into a specific problem statement. They are encouraged to further focus on research questions that stimulate new thinking and offer a new perspective on the problem.

TABLE I. EXPLORING THE PROBLEM

Exploring the problem	
Who?	Are there specific groups that are affected by the problem? Are any organizations involved? Who are the parties expected to work together to generate solutions? What are the critical features or considerations regarding people?
What?	What happens if the problem isn't fixed? What is the impact of the problem? What are the boundaries of the problem? How can the issue be described via possibilities? What are the consequences of addressing this issue?
When?	When does the problem occur? When does it need to be fixed? Is the problem recurring or singular? Does the problem have a historical component? Will the problem change in the future?
Where?	Where is the problem occuring? What are the local considerations that influence possible solutions? How will solutions reach the location of the problem?
Why?	Why is it important to address the problem? What are the impacts on stakeholders? How many different motivators exist for solving the problem?

Once they identify a research question that they would like to explore in their proposal, students demonstrate the conceptual and practical significance of this question with respect to the original broad problem by writing a first draft of a project summary (abstract). This process is very structured and asks students to briefly identify: the specific question they are exploring and the general research approach they will take, the anticipated results of the research question, the qualifications and limitations of the results, the implications of the results and the meaning of the problem in a larger context, as well as the possible future directions of the research, assuming it works.

The following is a sample initial project summary from one of the student groups that participated in our second RTI bootcamp where the general focus was on cyber security. The summary is presented in the exact form provided by students (in this case a group of non-native speakers).

"The goal of the project is to evaluate and limit the amount of low classification data volunteered over the Internet. Low classification data is defined as information that has little risk in small quantities (pictures, addresses and phone numbers). If this data was amassed in a large quantity, it is potentially dangerous to personal security. By pursuing a tool or technique to reduce the loss of personal information on social media websites including Facebook, Twitter the Internet will be safer. A large quantity of low classification data is currently available on social media sites. The research will attempt to educate a randomly selected group of users on personal security and compare to randomly selected control group of users without the education. The results are expected to show a reduction of volunteered low classification data for the educated group. The success of finding a method for increasing personal security will create smarter individual data sharing and therefore a safer Internet. Further research could lead the off-line situations of low classification data loss."

As is evident from this representative example, initial project summaries typically fall short of meeting the aforementioned goals, and they generally show a lack of focus, lack of specification of proposed research approaches, and a lack of understanding of possible qualifications and limitations of future results.

The development of an initial project summary (abstract) is followed by a session on experimental design, where students are introduced to general concepts like dependent and independent variables, sampling issues and avoiding bias, and several examples of experimental designs. Students are asked to identify data that would have to be collected for their proposed project, and some research approaches that might be suitable to gather and analyze data relevant to their proposed project.

An important component of RTI is the opportunity that students have to interact (either in a face-to-face or virtual manner) with a researcher who is an expert in the general field under study. In the past, our guest visitors have included a cyber-security expert who worked with Mozilla, and an optical engineer who worked on the Mars Rover for NASA's Jet Propulsion Laboratory. Students typically delight in having an opportunity to share their research ideas with experts who may have considered the same ideas in their own line of work, and they are able to ask questions and receive direct feedback on their proposals and concerns. The students integrate the expert feedback to create an improved project summary.

The RTI experience culminates with the presentations of the project proposal summaries. The following is the second version of the initial project summary presented above. Again, the summary is presented in the exact form provided by students (in this case a group of non-native speakers).

"The goal of the proposed project is to evaluate and limit the amount of low classification data volunteered over the Internet. Low classification data is defined as information that has little risk in small quantities, such as pictures, addresses and phone numbers. However, if this data was amassed in a large quantity, it is potentially dangerous to personal security. By pursuing a tool or technique to reduce the loss of personal information from social media, including but not limited to Facebook and Twitter, the Internet will be safer. A safer Internet would be one in which it is more difficult or impossible for companies or hackers to obtain your low classification information indirectly from social media sites or other sources without the consumer's direct permission. A large quantity of low classification data is currently easily available on social media sites to people who are not approved to have access to your information, for example, people not directly on your friends list.

In our research, there will be a test group and control group. Both groups will include randomly selected participants with social media accounts. Neither group will be given a pre-test or told specifics of the research. The researchers will attempt to educate the test group of users on personal security and compare them to the control group of users without the education. The results are expected to show a reduction of volunteered low classification data for the educated group. The control group is expected to display similar habits of volunteering low classification data that they showed when the research began. The success of finding a method for increasing personal security will create smarter behavior and safer habitual Internet use while reducing accidental data sharing of low classification information. Therefore, it will create a safer Internet while still keeping the Internet's convenience for consumers. Further research could be conducted on other areas where low classification data is lost, such as Google search engines and rewards cards, or research could be steered toward the off-line situations of low classification data loss."

While an experienced researcher could identify many additional edits needed in the modified abstract presented above, the obvious improvements that the novice researchers made from the initial abstract are easy to identify. The students are better able to focus their research question, place qualifiers and limitations on their results, discuss a rudimentary data collection method, and propose further research directions. These improvements are not negligible when one remembers that they are achieved in a matter of a few hours, on a topic that the students are not experts in.

In an effort to strengthen their project proposal summaries, the students benefit from immediate feedback from peer participants and faculty facilitators. Each group presents their improved project proposal, and students evaluate other project proposals based on a simplified version of the National Science Foundation assessment guidelines which focus on the intellectual merit of the proposed research, the clarity of the research plan, and the mechanisms for assessment of the proposed results, see Table II. Student teams are then asked to aggregate their evaluation scores for each team and decide how they would distribute limited funding to support the proposed research projects. The team whose project receives the most "funding" from other teams, receives a competitive monetary award. We find that the peer review process is critically important in assisting students with identify gaps in their own proposed research. By seeing other examples they are better able to identify areas where they can add more clarity or more details.

TABLE II. SIMPLIFIED EVALUATION TOOL

	High (3 points)	Medium (2 points)	Low (1 point)
Potential	Narrative specifically explores knowledge gaps; related conceptual elements are interated into the explanation; intellectual motivation for the work is clear, convincing and compelling.	Narrative mentions where the proposed research fits into the field; proposal argues for work based on "unknown"; intellectual merit is understandable given description	Explanation includes minimal conceptual framing; narrative supposes the questions addressed are obvious; intellectual merit is suspect based on description provided.
Research Plan	Proposal motivates the research design and decisions; plan proceeds in a logical flow; major activities emerge from the conceptual system; elements on the plan are considered relative to alternatives	Proposal presents a research plan with underlying decisions described; major activities relate to core concepts; various alternatives have potential for larger impact; plan involves independently operating units	Proposal presents research plan and decisions as obvious; alternative approaches are not explored; major activities are inadequate to address research questions; various aspects of the project appear unrelated
Assessment	Proposal presents the mechanism, markers and timeline by which researchers will know if their project worked	Proposal decribes major outcomes of interest as the primary assessment tool	Proposal provides limited to no description of various markers of success

III. OUTCOMES

The desired outcomes of the RTI workshop are to increase each participating student's research ability, decrease faculty/advisor frustration, and increase overall research output of our Institution. RTI participants are asked to complete online pre- and post-workshop surveys. Students are asked to complete the pre-survey before attending the bootcamp, and they are given some time at the end of the bootcamp to complete the post-survey. The goal of the pre-workshop survey is to assess the students' prior experiences with research, and their confidence in their research skills. The aim of the post-workshop survey is to gather information on how much they believe they benefitted from attending the workshop. Of the 40 students who have completed one of the three RTI bootcamps, approximately 65% responded to the pre- and post- surveys. All assessment activities are coordinated by RTI's instructors and our Institution's full-time assessment staff.

In the online pre-survey, students are asked to specify their major and year of study, and they are then asked the following self-assessment questions:

1) Have you performed independent research before?
2) What is your intention immediately following your graduation?
   a) Find employment in my undergraduate degree field.
   b) Earn an advanced degree in my undergraduate degree field.
   c) Earn an advanced degree in a degree field different than my undergraduate field.
   d) Unknown or undetermined at this time.
3) I have confidence in my ability to do research. (Yes or No)
4) I have confidence in my ability to contribute real knowledge to science. (Yes or No)
5) I have confidence to present research in a formal setting. (Yes or No)
6) I have confidence in my ability to create scientific publications. (Yes or No)
7) I have confidence in my ability to establish a mentoring relationship with a research advisor. (Yes or No)
8) I have confidence in my ability to collaborate with peers on research activities. (Yes or No)
9) Please indicate your self-rating of your ability in the following areas (1 = low ability, 5 = high ability):
   a) Discuss contemporary concepts in your field
   b) Link theory to practice
   c) Make use of the primary scientific literature in your field
   d) Identify a specific question for investigation based on research in your field
   e) Formulate a research hypothesis based on a specific question
   f) Design an experiment or theoretical test of a hypothesis
   g) Design appropriate controls in research
   h) Observe and collect data
   i) Analyze collected data using statistics
   j) Interpret data via comparison to the original hypothesis
   k) Relate results to the bigger conceptual framework of the field
   l) Think independently and creatively about research questions

10) Please indicate your agreement with the following statements (1 = strongly disagree, 5 = strongly agree):

a) Scientists use different types of methods to conduct scientific investigations.
b) Scientists follow the same step-by-step scientific method.
c) When scientists use the scientific method correctly, the results are true and accurate.
d) Experiments are not the only means used in the development of scientific knowledge.

The online post-survey is given to the participants at the end of the bootcamp. In addition to answering again all of the questions from the pre-survey, students are also asked to answer the following questions:

1) To what extent did the RTI meet your expectations?

   a) Greatly exceeded your expectations
   b) Somewhat exceeded your expectations
   c) Met your expectations
   d) Somewhat missed your expectations

2) Please provide an explanation for your response about your expectations.

3) What suggestions do you have to improve the RTI?

4) What questions/needs to you still have for research? What would you like to focus on next?

The data collected through surveys allowed us to examine the effect of RTI activities on student research capabilities. Table I summarizes results of survey questions in which students were asked to assess their ability to complete a research-related task, both pre- and post-workshop. When asked to assess their own confidence to conduct research, we observe a noticeable difference in the pre- and post-workshop survey results. Most notably, the percent of students who reported that they were confident in their ability to create scientific publications increased by 46%.

It is our expectation that students participating in RTI activities will become more confident and competent researchers, as well as more knowledgeable about the nature and process of discovery. To this end, we find that the largest margin of pre-to-post improvement is associated with two notions: 1) Formulating a research hypothesis based on a specific question, and 2) Identifying a specific question for investigation based on the research in a student's field. For the critical question of "To what extent did the RTI meet your expectations?" 80% of students in the first RTI workshop marked: "Greatly Exceeded", "Somewhat Exceeded", or "Met Their Expectations". This leads us to conclude that RTI experience and training provide students with tools and strategies that can be implemented in various scenarios for directed or independent research.

One additional outcome that we expected to see an improvement on is the students' desire to attend graduate school after participating in a research training. However, the student response to this choice of career path after graduation changed insignificantly, Pre-to-Post, from 38% to 43%. The small percentage of juniors and seniors participating in the RTI workshops could be the contributing factor to this insignificant change.

In addition to surveys, another method for capturing the improvement in students' ability to conduct research was to compare the first and final research project summaries (abstracts) created by research teams. The ability to write a cogent and precise project summary requires students to: (i) identify the relevant research question; (ii) identify a research approach and anticipated results; (iii) understand the limitations of the chosen technique; (iv) understand the implications of the results; and (v) identify possible future directions of proposed research. We can capture the change in our students' ability to effectively communicate about research when the first draft research summary (abstract) of a given team is compared to its final form. Students have often commented, in the survey, about the evolution of their project summary writing and explained how each part falls into its right place as they re-write the project summary, as guided by the instructors and procedures spelled out in the RTI workbook. We will share such writing examples during our presentation of this work.

TABLE III. SURVEY DATA FOR WORKSHOPS 2 AND 3

Pre- vs. post- workshop survey data for workshops 2 and 3		
I have confidence in my ability to:	***Pre-workshop***	***Post-workshop***
Do independent research	56%	83%
Contribute real knowledge to science	58%	83%
Create scientific publications	29%	75%
Establish a mentoring relationship with a research advisor	69%	88%
Collaborate with peers on research activities	88%	92%
Present research in a formal setting	62%	71%

Overall, survey results suggest that many students find the RTI experience very rewarding. One workshop student suggested, "I was really excited to be allowed to participate in RTI and I learned so much more than I thought that I would. It was fun, interesting, and eye-opening. Thank you for the opportunity." Others have described their RTI experience as," sparking my interest."

Additional student comments have included:

- "I honestly didn't know what to expect when I signed up for it, but it was definitely a rewarding experience. I learned a lot and I am very glad I participated. All of the information taught today will be very useful for my future."
- "I didn't know precisely what to expect but I wanted to learn something and gain an understanding of research for graduate school purposes. I definitely learned a lot and have a much better understanding of research, as well as more confidence in my abilities."
- "I was not expecting this [sic] nine hours to be this exciting and fun. I enjoyed the experiment and definitely learned about research process through little simulation today."

- “The RTI was a really good experience for me. I got a lot of new ideas that I never thought about during the communication and presentation with my teammates and classmates… Moreover, the consulting time is really helpful, it pivotally refined our design. After the RTI I fill [sic] more confident to do researches [sic], work with teammates, and set up designs. I give this program 10 out of 10. In a word, it is really useful.”

The common criticisms expressed by students were related to the duration of the workshop, the fast pace of teaching and the time allotted to complete the tasks. Some of the students expressed their frustration with the content-free nature of the RTI workshop, desiring instead a more domain specific example. Several students suggested that more time be spent on design of experiments and data interpretation. While valuable, these desires are contrary to the general purpose and theme of the RTI, and should be left for more advanced workshops, or advisor-led research.

While the assessment of the impact of this program depends primarily on student pre- and post- self-reflections, it would be difficult to conduct a full research assessment through an external observer who assesses the actual research skills learned by the participants. Our program is open to all students – those with concrete plans to conduct research at our and other institutions, as well as those who have no current plans to conduct research, but are interested in research as a future opportunity. As such, tracking their research progression, as compared to students who did not participate in RTI, would be nearly impossible. While critically important, the lack of research on assessment of research-focused educational initiatives has been reported [10], and other studies have relied on qualitative pre- and post- program surveys in which students self-reflect on their experiences [11].

On a much smaller scale, our analysis of initial and final project summaries (an example of which was provided in Section III), indicates that after completing the RTI students are able to identify more precise and promising research questions, place qualifiers and limitations on their results, identify and discuss simple data collection methods, and propose further research directions. Future research could include interviews with faculty research supervisors mentoring RTI graduates, asking them to determine whether RTI graduates are more prepared to conduct undergraduate research than students who did not complete RTI.

IV. GENERALIZABILITY

In the introduction, we presented various elements of our local context. In sharing this work, we strongly emphasize that a program like RTI is readily transportable or adaptable to other institutions or colleges/schools within large institutions. In our development discussions with colleagues from a wide variety of disciplines, we noted that “asking good questions” and designing experiments were universal themes (consistent with the emphasis on these skills in research on undergraduate education [7]). Since the RTI emphasizes these research-ready cognitive abilities rather than disciplinary techniques or laboratory skills, any research program can adopt it. We propose that an RTI-like experience would be of significant benefit to students accepted to an REU or other formal research program. Further, the thematic contexts that we chose (e.g., manned mission to Mars) could highlight institutional-relevant topics or events (e.g., sustainability activities occurring prior to Earth Day). Since the topic itself is largely irrelevant, the disciplinary affiliation of the facilitators doesn’t matter, allowing any interested STEM faculty to coordinate the program. The program model is flexible in that if a disciplinary focus was desired, it could be readily generated through the topics and facilitators chosen. Finally, we are happy to share RTI training materials to support workshops at partner institutions. In summary, this innovative training model is adaptable to many contexts.

We have found no similar model to this program in its interdisciplinary nature and focus on future researchers (i.e., students with no experience at all). Given its unique nature, benchmarking isn’t possible, so in considering improvements, alterations, and generalizability for the program, we must consider self-produced data (as above) and student comments to identify their believed needs and real needs. One obvious topic to incorporate is how to find research opportunities. Our institution does not have a centralized undergraduate research support office, and it is clear that the first- and second-year student participants weren’t familiar with on-campus opportunities (e.g. we fund independent projects and part- or full-time summer research through a competitive process). Some students expressed a desire to learn about “designing specific experiments and interpreting those data”; this wish has prompted discussions about follow-ups to the RTI, like a design of experiments institute or statistical exploration institute. We recognized that students’ naivete yielded the comments about specificity - this experience is solidly envisioned as a collaborative learning experience, not a personal consultation with experts. For institutions with a centralized undergraduate research support office, this additional topics might serve as excellent follow-ups for disciplinary-focused experiences.

V. CONCLUSION

Programs like the Research Training Institute present an opportunity to support the professional formation of scientists and engineers, by introducing them to the habits of mind that accompany research endeavors. We think this project is innovative in engineering education since it bridges the gap between logistics and onboarding to research experiences and the daily practice of collecting and analyzing data and later communication practice like poster sessions and resume writing. With a relatively small financial investment, this intentional approach to helping students develop research-ready cognitive skills can increase the quality and impact of student experiences and increase faculty enjoyment and production from undergraduate research.

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