Work in Progress – A Problem-Based Curriculum in Support of Structured Learning Experiences to Prepare Ph.D. Candidates for Independent Research

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Introduction

In engineering, the graduate school experience has focused on developing the research and technical skills of the graduate student. However, to successfully complete their graduate degree, students must also develop additional skills [1]. For example, students must make the critical transition from course-taker to independent scholar/researcher [2, 3]. Graduate education can be daunting to first year students and a stressful transition. The socialization experience into the research community plays a critical role in the overall experience. This socialization process includes the transition from a course taker to an independent researcher [4]. Developing broader skills for the transition can be inconsistent and challenging for an individual faculty working with individual students. To address this challenge at the department level, our Engineering Science and Mechanics (ESM) department is beginning to revolutionize the current graduate curriculum by introducing a required first-semester, problem-based course for all new graduate students to help them with the transition year.

For many students, the transition to independent researcher is particularly difficult and many students report making the transition during the dissertation stage [5]. This delayed transition to independent scholar is not ideal, inspiring this first-year experience to aid in accelerating the transition. Students often feel *unprepared* for the transition to independent scholar. Typically, there is a lack of formal curricular and instructional support [6] leaving students on their own to figure out the expectations of graduate school. Since the transition is influenced by many nested factors, including individual resources, micro- and macro-environments [6], our ESM department aims to implement a problem-based curriculum in support of structured learning experiences that provide first-year graduate students with opportunities to develop individual and collaborative skills in conducting research and socializing with other graduate students and faculty members. Through this course, students will: become familiar with research programs in ESM and available resources; make connections with faculty members and students; develop collaboration skills; identify and use good and ethical research practices; and develop individual abilities including reading, writing, and tool use that are critical to conducting research.

This paper presents an overview of the pilot offering of the course as well as initial evaluation of the data collected to inform future improvements of the course. The below evaluation questions were used to help guide the evaluation efforts:

1. In what ways the course has, or has not, met student expectations?
2. What are the challenges that students reported in taking the course and what are the strategies to resolve the challenges?
3. What are the challenges that instructors reported in teaching the course and what are the strategies to resolve the challenges?

Course Design

The course is envisioned as a first or second semester course to be taken by any incoming graduate student, whether in the M.S. or Ph.D. program. Under favorable recommendation by an academic advisor, the course can be taken by honors undergraduate students as they develop their senior thesis. The course aims at educating any student involved in research about best practices in research. These practices include the skills that would be highly beneficial for those Ph.D. students preparing for their qualifying exams. Because incoming Ph.D. candidates are required to pass their qualifying exams within three semesters, it is then highly desirable that pre-qualifying exam students take the course during their first year.

Departmental context

Research areas in ESM are very diverse, spanning from materials science to photonics, to theoretical mechanics, to neuroscience. This diversity is reflected in the student population that applies for admission into the ESM program. Many ESM students have a physics background, others have a more traditional engineering background, and, more recently, we have students with bioengineering or biology training. The first year for incoming graduate students is typically devoted to taking foundational subjects in their research area (the ESM qualifying exam has five broad areas of concentration: mechanics, materials, electromagnetics, nano- and bio-science, and neural engineering). Students preparing for the qualifying exam typically concentrate their academic plan to include courses that help in preparing for these exams. This said, the program does not mandate a fixed study plan for students preparing for the qualifying exams. Students are also required to attend a graduate research seminar course and to gradually satisfy the required elements of the mandated Responsible Conduct of Research (RCR) program, which, at Penn State, is referred to as the Scholarship and Research Integrity (SARI) program.

Students in the ESM graduate program are not assigned a lab rotation schedule as is the practice in, say, the biology department. The way in which a student becomes involved in research is typically by being recruited by a specific research faculty member (with available research funds) even before the student arrives at Penn State. In other cases, students who are initially supported as teaching assistants will take courses and interact with the departmental faculty and identify a research topic through that interaction. It is the goal of the department that, eventually, all graduate students transition into Research Assistant positions.

Course goals

For the newly created and implemented curriculum being piloted in the 2019 Fall semester, the goals for the new course were:

- to prepare incoming Ph.D. students to quickly become independent researchers,
- to provide structured self-directed learning,
- to develop professional skills, and
- to develop reading and writing skills for conducting research.

In order to achieve these goals, the new curriculum introduces students to a range of good research practices in Engineering. The planned content includes:

1) conducting research, including how research groups are organized, problem identification and solution, connecting innovative ideas from disparate fields, laboratory safety and procedures, data management;

2) communicating research, including literature review, manuscript preparation, grant writing, or oral communication;
3) other critical skills or considerations in conducting research, including collaborative skills, tool use, ethical and responsible conduct of research, the importance of diversity, equity and inclusion in research.

The content for this course was developed by the lead instructors for this course and informed by other faculty within their department. Multiple faculty meetings included discussions of the challenges that new graduate students were facing and how the faculty were having to repeatedly address these challenges for each new graduate student. The course content compiled these elements to best serve the students for a quicker, more consistent transition to the ESM department. This particular department is very interdisciplinary and highly collaborative in their research. The need for independent researchers in the field to have strong teamwork and collaboration skills is critical. Clearly, for the course to be of use for a very diverse student population, the specific course content was selected based on its relevance to all of the research areas reflected in the qualifying exams. Emphasis was placed on tools for creating and maintaining a bibliography, writing tools, and data management tools. In all cases, there was an emphasis on the specific elements of said tools that support collaborative (team) work such as team editing and document/data/code version control. In addition, the course focused on identifying skills needed to critically review papers. These skills can be domain specific in that a paper on, say, imaging techniques has a typical structure that is different from a paper on numerical methods. Nonetheless, an effort was made to distill best practices in identifying essential elements in a scientific paper and/or proposal, such as identifying knowledge gaps and evidence-based assertions. The role of statistics in research design, data collection, and analysis was also emphasized. Finally, an overview of ethical considerations in research was presented that is applicable to all fields, whether dealing with mechanical response of materials or brain physiology.

Course structure

The course met twice a week for 75 minutes. In most cases the class met in one room, but in four periods the students met separately in small groups to discuss different technical articles in a journal club format (2 periods) and to peer-review research proposals (2 periods). Within journal clubs, each student in a small group read the same articles in advance, and then the students took turns leading discussion, the latter being documented by a student scribe.

The course had three primary instructors and one recurring guest instructor. In addition, the class was supported with four senior graduate students, who served as mentors to the students in the course. The mentors helped to build a bridge between students and instructors and were instrumental for the journal club and peer-review panel sessions. The instructors and mentors attended all classes unless they were out on travel. Guest instructors from the College of Engineering's education center led sessions on working effectively in teams and on responsible conduct of research and research ethics.

The first assignment was for students to interview a specific member of the department's faculty and then share what they learned in the interview with their team. The teams then worked together connected faculty collaborators (based on their interviews with different members of the faculty) and themselves with respect to research interests in a diagram and presentation.

The culminating assignment for the course was writing a research proposal. Writing the proposal was directly supported by assignments: reading and writing technical papers, preparing a bibliography, discussing contents of technical papers, identifying knowledge gaps, and creative processes. The structure of a research proposal was discussed along with a standard NIH-style (a common funding agency within the ESM department) request for proposals (RFP), the RFP's section on review criteria, and NIH-style reviewer instructions. The research proposal itself was a written document that was evaluated separately by peer review panels and the instructors as well as an oral presentation. The peer-review panels help students internalize how others read their work, and the oral presentations gave students a chance to address reviewer comments. Other assignments and topics were intended to instill general, good research practices such as: using LaTeX (document preparation software, [7]), sharing documents, reference-management software (Mendeley, [8]), backing up data and work through version control software (Git, [9]), building teamwork skills, standard practice notebooks, lab safety, writing a standard operating procedure, responsible conduct of research, and ethical data management.

Pilot Evaluation

The evaluation of this pilot course aimed to investigate student expectations and experiences with this course to inform course improvement. Due to the small number of students in the pilot course (n = 14), a qualitative evaluation approach was utilized. The qualitative data was analyzed using open coding [10], an established qualitative analysis technique. The results from the qualitative analysis are reported. The course evaluation included feedback from both students (through a formative assessment survey roughly 3 weeks into the course as well as a focus group towards the end of the course) and faculty (through interviews conducted after the end of the semester). The feedback received from the students as well as from reflective interviews with the faculty will be used to inform course improvements moving forward.

There were 14 students enrolled in the pilot course, 11 of which completed the formative feedback survey (Appendix A). Student responses to the open-response questions were open coded for major, reoccurring themes. Near the end of the semester (about 3 weeks until the last day of classes), the evaluation team conducted a focus group after a class session, where the students were encouraged to provide more detailed feedback about the course. The focus group was semi-structured, following the student protocol (Appendix A), and was open coded. Faculty interviews were conducted after the fall semester ended with each instructor (faculty protocol in Appendix A). These interviews were semi-structured, and open-coded.

As this was the first offering of this type of course for the department, all students in their first three years in the program were invited to participate as the course instructors felt it would be beneficial for those students. However, this resulted in a diverse level of student experience with graduate school. There were students in their first semester (the target audience), but also students in their second or even their third year that participated. The diversity of student experience was a challenge in teaching this pilot course as some students had cleared the departmental milestone that the course was meant to prepare them for. Moving forward, the course instructors are taking steps within the department to make this a required first semester, first year course for all incoming students.

Results and Discussion

1) In what ways the course has, or has not, met student expectations?

The student formative feedback survey responses were open coded for expectations. Table 1 reported the expectations that were mentioned at least twice in the total 11 responses. The frequency in Table 1 and 2 refers to the number of references to that topic across all student responses.

Student expectations are fairly consistent with the course goals of developing the ability to conduct research, communicate research, and other critical competencies. The evaluation team further analyzed their responses reporting what they had already gained from taking the class (3 weeks into the course) in helping them be successful in graduate school. Three themes were discussed at least twice (see Table 2): importance of teams, academic reading & writing, and facilitating teamwork.

Table 1.
Expectations and their frequency

Expectations	**Frequency**	**Description**
teamwork	6	Students expected to learn about research groups, group development, how to organize or work in teams, how to communicate in teams.
research preparation (general)	5	Students expected to learn how to conduct research, or about research practice in general.
tools	3	Students expected to learn about tools, including LaTeX, Overleaf, Mendeley, etc.
reading and writing	3	Students expected to learn about reading technical articles, research articles, conducting literature review, and about writing technical articles, research grants or proposals.
relationship building (networking)	2	Students expected to build relationships with their fellow students as well as with professors in the department.

Table 2
Important lessons and their frequency

Important lessons	**Frequency**	**Description**
Reading and writing	4	Students mention or describe the importance of reading literature in efficient ways.
Teamwork	4	Students mention or describe the importance of group or teamwork.
Big 5 plus 3 for teamwork	2	Students mention the Big 5 + 3 mechanisms [11] for facilitating teamwork.

A comparison of Tables 1 and 2 shows that at 3 weeks into the course some of the aligned expectations of students and the course had been met (teamwork and reading & writing), while the course had yet to meet the expectations of research preparation and tool use. However, in student focus group interview (near the end of the semester), many students agreed that the course had provided many opportunities to learn about a variety of tools and resources, including software such as LaTeX and Mendeley, and university resources that will be relevant to current

and future research, indicating that the course did meet students' initial expectations for the course.

2) What are the challenges that students reported in taking the course and what are the strategies to resolve the challenges?

From the focus group interview with students, two major challenges were reported, assignments and diverse topics. For assignments, the students felt "bombarded" with them both because of the unexpected number of assignments and the required effort (e.g., writing the proposal). The students felt that assignments should be allocated more time. Moving forward, a systematic reconsideration of the distribution of assignments for each week is recommended. As this was the first offering of the course, this is an expected refinement now that all of the content has been developed and implemented. Students also suggested the assignments to be closely related to their lab work, even if that meant the assignments would be more challenging. Students noted that creating a strong link to the students' research or lab would help them to find additional value in the assignments and investment in the course. However, how close the assignments could get to a student's research depends on how far that student is in the program. First semester students may not have officially joined a specific lab yet, limiting the specific nature of assignments.

Due to the variety of topics included in the course, as stated in its goals, students recognized the importance of the topics but struggled to shift gears every week (from ethics, to tools, to teams, etc.) and see how all of the pieces tied together. In light of the diverse topics covered in this course and the number as well as the extent of assignments, students suggested to divide this course into two semesters (a 1-credit course in the fall, then a 2-credit course in the spring) so that students would have a more manageable workload and also more time to devote to each unit. Students also noted that, this way, the proposal writing could be allocated more time, which would allow them more time to devote to a proposal relevant to their research and thus be beneficial to the qualifying examination and their research experience more broadly. Dividing the course into two semesters is not a practical suggestion (logistically). However, it has prompted the instructors to think about how the course is structured and how the different course elements are scaffolded to help students see the connections in what they are learning and the time allocated to different assessments.

Both of the challenges outlined by the students (the assignments and the variety of topics) are linked to the students not seeing the connections within elements of the course, including the connections between the content and the major assessments as well as the connections between the different course topics and the students' overall professional development. Moving forward, additional scaffolding (such as a course concept map and an individual professional development plan) will be used to help frame the course and the assessments to help students see the alignment within the course as well as alignment with their graduate careers and overall professional development.

3) What are the challenges that instructors reported in teaching the course and what are the strategies to resolve the challenges?

All three professors agreed (in their interviews) that the implementation went well for the first time, pilot offering. However, three major challenges were consistently discussed by the instructors. The most serious problem was a mismatch between student expectations and instructor expectations. Since the course was starkly different from most other technical courses

that mainly focus on domain knowledge, some students did not fully understand the purpose of some assignments (as noted by the students as a challenge) and the connection between assignments and the final project, or the effort/time required to build the expertise needed to complete the final research proposal. This unexpected situation created a challenge for the instructors in motivating students to complete the learning activities. For the next implementation, instructors and mentors should emphasize the learning objectives of each learning activity/assignment to help students see the connection to the overarching goals of the course.

A second problem was that, though students were grouped, and effective teamwork was encouraged and discussed in class, the students' performance as members of a team still showed room for improvement. There is a need for activities that help develop effective teamwork in next implementation. To aid in more direct development of teamwork skills, the course mentors (more senior graduate students assisting in the course) could be utilized more effectively as they already helped organize some group activities for their respective teams (e.g., journal clubs) in the pilot implementation.

A third challenge was due to the diverse student base recruited for this initial implementation that consisted of first-, second- and third- year students, even though the course was designed for incoming (first year) students only. While second- and third- year students seemed to better appreciate the significance of the learning activities, they already had experience with many of the topics and activities which restricted their engagement in the course. As mentioned earlier, the fact that students were at different stages of the doctoral program created a challenge for the instructors with respect to engagement and meeting the students where they needed support. Moving forward, a stronger effort will be made to ensure that first year students are the only ones enrolled in the course.

Ongoing Work

Providing a first-semester, first-year course for graduate students to help them understand what it means to be successful in graduate school as well as what it means to be successful within their specific department can help students to set clear expectations for success. However, there were challenges for both students and instructors in the initial implementation of the course. From the students' perspective, the course was challenging in that it covered a wide variety of topics, tools, and skills that were difficult to internalize and mesh together. Students also struggled to keep up with the number and scope of assignments. From the instructors' perspective, the course presented significant challenges in helping students see the connections between the different components and how they tie together to be successful in research. In addition, challenges were identified in structuring preliminary assignments to help student build these skills and see their relevance. Such challenges are to be expected in a first time offering of a new course and they provide motivation for the improvements that are necessary for future offerings.

To better plan for the next implementation in the fall for incoming students, the project team has scheduled a meeting with instructors to discuss their challenges and plan to formalize regular teaching and learning activities to improve both faculty and students' experience in the future.

The authors hope to also receive feedback at the ASEE conference by presenting our work-in-progress paper and hearing what other universities/programs have done in the face of these common challenges.

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Appendix A

Student formative feedback survey:

1. What do you expect to get out of this course?
2. What are the most important lessons you have taken away from this course so far to help you succeed in graduate school?
3. What feedback would you offer to the course instructors to help improve this course?
4. An overall rating of the value of this course to them so far on a scale from 1 to 10.

Student focus group interview protocol:

1. What's going well in this course?
    a. How do you see this course being beneficial to your graduate career?
2. At the beginning of the semester, what were your expectations for the workload for this course?
    a. How does the workload for this course compare to other courses you are taking?
3. What changes would you make to this course to improve it in the next offering?
4. Thinking specifically about the course assignments, what changes would you make to better reflect your learning in this course?
5. What (if anything) else would you all like us to know about this course to help inform future course improvement?

Faculty interview protocol:

1. To begin, what was your motivation for creating the ESC 597 course?
    a. How do you think your motivation aligned with, or varied from, the motivation of your co-instructors?
2. How did you all make decisions regarding the course topics, especially the assignments, assessments, and daily instructional activities?
3. Overall, how did you feel the implementation of the course went this semester?
    a. What would you change for the next implementation?
    b. What do you think is most important to maintain for the next implementation?
4. What were some of the key challenges that you faced teaching this course?
    a. What were some of the key challenges you think your co-instructors faced?
    b. What were some of the key challenges you think your students faced?
5. What surprised you most about teaching this course?
6. Is there anything else you think I should know about the course and this implementation of it?