Board 290: From Resistance to Readiness – Building Capacity to Pilot and Scale Co-requisite Calculus for First-Year Engineering Gateway Courses

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From Resistance to Readiness – Building Capacity to Pilot and Scale Corequisite Calculus for First Year Engineering Gateway Courses

Abstract:

Norwich University, the oldest Senior Military College in the nation and the first private U.S. institution to teach engineering, has a residential program for approximately 2,100 primarily undergraduate students in both the Corps of Cadets and civilian lifestyles. Norwich secured a National Science Foundation S-STEM award in the beginning of 2020 to develop a program to attract and retain highly talented, low-income students in STEM. One of the aims of the project was to support students who enter college with less experience in mathematics as these students were significantly less likely to graduate with a STEM degree.

In the fall of 2020, as a result of the S-STEM award, the mathematics department offered a pilot corequisite calculus course to STEM majors requiring calculus their first semester but placed into precalculus by the mathematics departmental placement test. The corequisite calculus course includes content from precalculus into a one semester calculus course that meets daily for 6 contact hours rather than a standard 4 credit hour calculus course. The Norwich University Civil, Electrical and Computer, and Mechanical Engineering programs are accredited by the Engineering Accreditation Commission of ABET, placing restrictions on the 8-semester engineering degree pathway. The added credits to the first semester corequisite calculus course fit the constraints of the first semester engineering course load and this course has enabled engineering students that place into precalculus to complete an on-time degree plan without taking summer courses. The corequisite course has been approved by the university curriculum committee and is a regular offering at the institution.

The initial offering of the corequisite course occurred during the COVID pandemic necessitating the use of additional instructional technology. There was also an increase in low stakes assessments to encourage students to engage in the material. The added credits also increased the regularity of student interacting with calculus. Since the implementation of this pilot course, there have been several similar changes in other courses required by engineering majors. The pilot corequisite course has become institutionalized and even is now scaling, with the engineering department requesting the course to be offered each semester to benefit students who are out of sync with the intended curriculum pathway.

This project examines how the corequisite calculus course may have influenced changes in the general education courses and engineering first year sequence. Outcome harvesting as well as process tracing are used to determine the strength of evidence linking the corequisite course to institutional change. Qualitative and quantitative data will be examined as well to understand how the S-STEM award contributed to breakdown of the resistance to curriculum change and the readiness to implement and scale corequisite courses in other areas. It is important to understand the mechanisms used for building capacity at the institution to transform STEM education in higher education.

Background:

Science, Technology, Engineering, and Mathematics (STEM) departments has emerged as a promising avenue for promoting upward social mobility and equity [1]. However, many students are excluded from these majors, particularly those from low income, racially minoritized, and first-generation backgrounds [1]. Evidence supports that while attempts have been made to create learning environments that are equitable and inclusive, there is still a needed for greater resources and effort in this area [2]. There is a clear need for institutions of higher education to increase the supports in the STEM discipline to increase opportunities for all students.

While there is increasing attention to remove barriers to STEM education, implementation of programs remains a challenge [3]. Many times, initiatives may face resistance since policies and practices are often developed at the departmental level rather than across campus [3]. The purpose of this project is to examine the process of change at the institution to better serve the science and engineering majors and to understand the impact the NSF S-STEM award had on building capacity at Norwich University (NU).

Norwich University was founded by Captain Alden Partridge known as the first private university to teach civil engineering in the United States. Norwich University is a small, non-profit institution that offers both residential and online programs. The residential program is located in central Vermont with approximately 2,100 undergraduate students. NU is a unique institution in that just over 50% of the residential students are in the Corps Cadets. Of all the residential students, about 13% major in electrical, civil, mechanical, and general engineering.

The curriculum map for engineering requires Calculus I in the first semester at NU. Historically, students were placed into their first semester mathematics course by a departmental mathematics placement test. The institution recently switched to the ALEKS Placement, Preparation, and Learning assessment for the fall 2023 incoming freshmen. Placement levels were determined by the suggested ALEKS cutoffs. Traditionally, about half of the incoming engineering students place lower than Calculus I, typically into precalculus. By not placing into Calculus I the first semester, engineering students are off track with their sequence requiring students to possibly take a math course over the summer.

Over the past 20 years, the engineering faculty have discussed improving the mathematics placement test and improving mathematics courses with the mathematics department; however, no major changes had been made to the calculus sequence. In 2018, when preparing a proposal for the National Science Foundation (NSF) S-STEM program, the PI examined the success of students that were placed into precalculus. At the time, the graduation rate in STEM for students placed into precalculus was about 10% lower than the graduation rate for the students placed in calculus. This followed the national trend of high attrition in entry level mathematics courses which impacts underrepresented populations at a higher rate [4].

As such, reform effort for the calculus sequence have been discussed for over 30 years by the Mathematical Association of America [5]. At the high school level, many students are taking the prerequisite courses for college but are placed in courses below the calculus level at college [6].

Additionally, the success in precalculus in high school does not guarantee success at the college level precalculus level and fail to be successful in calculus [6]. Despite the attention on the need for change, many times change is slow and difficult [3].

Using the S-STEM award as a catalyst for change, the S-STEM team implemented a pilot corequisite model of precalculus and calculus the fall semester of 2020 and 2021. The pilot program studied and compared the performance of cohort of students in the corequisite course in comparison to similar cohort of students in a precalculus course [7]. This study was done with two sets of incoming first year engineering and science students. In general, it was found that students had a positive view of the corequisite course, and the course did not hinder students' progress through the calculus sequence [7]. In 2022, the University Curriculum Committee approval was given to list this course in the catalog as a bona-fide course. Since 2020, two sections of this course continue to run each fall semester with requests from the engineering program to offer one section in the spring semester.

Research question:

The corequisite calculus course was one strategy in the S-STEM project designed to support retention and graduation of low-income high promise STEM majors at Norwich University. It is interesting that, while there were some challenges offering the pilot corequisite course and implemented the study, it seemed fairly straightforward to move the course to the formal catalog of offerings in 2022. We seek to understand the institutionalization process in this context.

> *Research Question: What factors contributed to an environment conducive to institutionalizing the corequisite calculus course at Norwich University?*

To answer the research question, we engaged in the process tracing method; a retrospective method whereby people work to: a) identify a change, b) gather evidence of the change, c) document the change, d) list alternative explanations, e) weigh evidence [8].

Methodology:

For this project, we identified the change as the formal institutionalization of the course, meaning it was being offered on the books and would continue to be a viable option for students in the long term beyond the grant-funded timeline. Our evidence gathering and documentation began simultaneously as we drafted an initial timeline and moved to document collection and elite interviews. This means we reached out for interviews with key stakeholders involved in the process of designing the curriculum, teaching the pilot, proposing the course to faculty at the department, college and/or university levels, and advising students to take the course[9] [10]. Documents included email correspondence, the course proposal and revisions.

Elite interviews included questions about: institutional roles, relationships to the process of course development and approval, perspectives on corequisite courses over time, observed outcomes small and large, future of corequisite courses at Norwich, recommendations on documentation and stakeholders with divergent perspectives and roles on corequisite courses.

Initial coding involved adding events and event detail to the timeline from course proposal to approval, identifying patterns in interviewee timelines, harvesting outcomes, weighing links

interviewees made between actions or events and outcomes. Initial coding was open, but also included some apriori codes like: outcomes, key stakeholders, problem, solution, link, etc.. See Appendix A for a complete list of codes used and developed during initial analysis.

Limits of this method at any university, but especially as related to this course at NU were churn and disruption in part due to COVID and in part due to the shifting employment landscape of higher education. One elite interviewee explained:

> *"Part of the problem is that we've had an enormous amount of turnover since COVID. Not only is Addie not IRB chair, she's not at the university. Joe and Christine were both in the math department tenured. They're both gone. Rob was the chair then, he's gone. The dean is gone. I named a lot of the people that I think might be involved. They're not here. A lot of the turnover was COVID related for sure" (443573)*

Given that multiple actors integral to the course's early implementation had left NU, tracing a detailed and accurate process of a recent history was complicated and we relied on email just as much as interview transcripts.

Preliminary findings for the phases of implementation:

Building the timeline and assessing the artifacts available for the process tracing, the analysis focused on the negotiations between the stages of the implementation process. The change process can be understood by using defined steps to move a concept into reality [11]. Understanding the implementation steps builds the institution's capacity to scale change [11]. The 5 steps examined follow Smith's framework of the implementation process are shown in Figure 1.

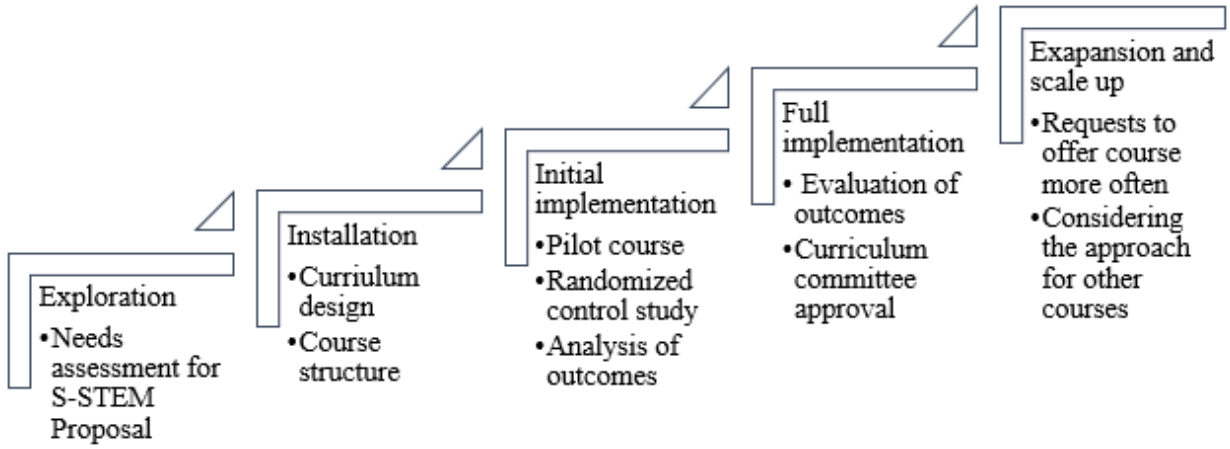

Figure 1. Smith's [11] five implementation steps to build an institution's capacity to scale change with the actions to implement each step.

For the exploration step the PI of the NSF S-STEM award examined institutional data to assess barriers to retention and graduation of STEM majors. Evidence was found that suggested incoming students' declaring a STEM major and with less preparation in mathematics as determined by the institution's Math Placement Test, were less likely to graduate with a STEM degree. This particularly impacted low-income students. The literature review for the NSF S-STEM proposal suggested that corequisite courses had been found to improve outcomes for

students. As such, the proposal outlined a potential design for a randomized control experiment to assess outcomes for a corequisite course of calculus and precalculus.

Only a handful of stakeholders at the university were involved in writing the proposal. Since it was only a proposal, there was no resistance to exploring the idea of the corequisite course. The NSF S-STEM was awarded after the second submission. The process of planning the corequisite course began soon after the notification of the S-STEM award in January of 2020 as supported by emails from the Chair of the Mathematics Department. There was no resistance to offering the course in the Fall of 2020 since it was a strategy for the S-STEM award.

The installation step began during the beginning of the global pandemic, the spring and summer of 2020. The planning of the corequisite course curriculum and design was only discussed by email.

The curriculum of the corequisite course was designed to teach calculus with review of precalculus topics imbedded throughout the course. The intent was not to teach precalculus followed with calculus but integrate key topics of precalculus within the calculus concepts. The Norwich University precalculus curriculum works through examining functions from simple algebraic functions to transcendental functions such as the exponential, logarithmic, and trigonometric functions. While calculus classes typically include transcendental functions early and throughout the semester, the corequisite course covers transcendental functions after the main topics of calculus are taught. This provides an opportunity to do a in depth instruction of transcendental functions in the context of calculus. This resulted in a cyclic approach to teaching calculus where limits, derivatives, and integrals were used to motivate precalculus topics (Olsen et al., 2021). Co-PIs planned the structure of this course assuring stakeholders that the course would meet "*the department's standard assessment for Calc I*" (email from PI to Registrar, 4/26/2020). Norwich's policy allows for pilot courses to run two times before requiring formal approval from the University Curriculum Committee.

The course design considered that both precalculus and calculus at Norwich University are 4 credit courses that typically meet 50 minutes a day, four days a week. The corequisite course needed to incorporate more course material so 4 contact hours was not enough time. However, the intent was to decrease the credit load required and not to overburden the student so 8 contact hours was too heavy of a load for engineering students, especially those in the Corps of Cadets. The team needed to work with the Registrar's office to answer the many questions about the course.

Concerns from the Registrar as documented in emails included:

- Students' inability to use the grade repeat rule since it is a pilot course
- Using a pilot course to meet a degree requirement
- Title of the course
- The ability for the course to transfer to other institutions
- The ability for the course to count towards the general education requirement

Emails suggest that using the NSF S-STEM as collateral, the Registrar was willing to work through the issues. In an email with the Registrar, the Dean explicit states "*This is a course based on the NSF S-STEM grant we received*." (email Dean to Registrar, 2/25/2020).

Additionally, in email discussions with the Chair of the Mathematics Department had "*re: S-STEM project*" in the subject headings (emails between the Chair and team, 1/21/2020).

As a result, the course is offered at 6 credits meeting 5 times a week for 50 minutes on Monday, Wednesday, Friday, and 75 minutes on Tuesday and Thursday. The course is listed as two courses on student transcripts, a 4-credit calculus course and a 2-credit math supplement course. Having the students complete a course listed as the standard calculus course made it easier to count it as a prerequisite to other calculus, engineering, and physics courses. It also made it easier to transfer to other institutions. The two-credit mathematics supplement course is considered an elective and does not count towards any graduation requirements.

The initial implementation step began in the summer of 2020. The S-STEM proposal outlined a randomized control experiment for assessing the corequisite course in comparison the traditional precalculus followed by calculus. The two major challenges in the initial implementation of the randomized control study were the COVID restrictions for the fall 2020 semester and randomly assigning students into the experimental group (corequisite course) versus the control group (precalculus) for the fall semester.

In April 2020, the team discussed postponing the study as the institution was discussing various hybrid and online options for the fall semester. One of the requirements for the S-STEM program is that the curricular practices be offered to the scholarship recipients. In an agenda item proposed by the PI to the team regarding planning over the summer and uncertainties:

> *Should we postpone? (Probably not since we will have the scholarship recipients enrolled and the purpose is to have them in the co-req course). (Email from PI to planning team, 4/22/2020)*

Incoming freshmen first semester registration is done by a team at the institution and not by the students. The registration issues were addressed by the team that registers incoming students in June, prior to the students' arrival on campus. The PI worked with the team to ensure that random allocation of the eligible students occurred among the control precalculus classes and the 6-contact hour corequisite course.

Challenges for the registration teams included:

- Dense schedules for the Engineering students
- Courses needed overrides for enrollment since restrictions were placed on the courses to prevent anyone from enrolling
- Rolling enrollment that was dependent on when the incoming students took the mathematics placement test

Full implementation of the corequisite course occurred after the pilot course was offered for two semesters, Fall 2020 and 2021. Norwich's policy is that pilot courses could only be run two times with the University Curriculum committee (UCC) approval. During the fall 2021 semester, the PI wrote a proposal for the course that needed to be approved by the Mathematics Department, the College of Math and Science curriculum committee, and the UCC. This course is the first corequisite course that has been approved by the UCC.

> *"Well, it started when, believe, the PI applied for the S-STEM grant, and it was a consequence of that. We didn't have it before that." (443573*)

The team evaluated the outcomes for the Fall 2020 offering of the corequisite course for both reporting to the NSF and for an ASEE paper. The preliminary findings suggested that the course did not decrease retention and completion of calculus II for the students in the corequisite course [7]. Using the results from surveys and institutional data, the course was presented for approval to the mathematics department. NSF funding and the emphasis on "studying" the course certainly incentivized continued focus on the course and its potential merits.

> *"We knew the PI's grant was continuing but also that we needed more data for the course, so we went ahead, and since it had run twice, we had to run it through the university curriculum committee." (443572)*

It was approved and went through the CoSM college committee and UCC. The UCC wanted the course for all students not just engineering students. Current sections of the course now include students in naval science, engineering, and students showing early signs of struggle in calculus I who transfer over for the integrated precalculus content and extra instructional time.

> *"We ran it through the university curriculum committee, and they were a little bit concerned about keeping the course just to engineers. The membership for the course is a little bit more open at this case, but still, we try to keep the course two sections at this point period." (443572)*

The course has been expanded and scaling-up in a bona fide course endorsed but the engineering faculty.

> *When I heard about this course, I was like, "Why is it just a pilot?" When it first got rolled out, I was like, "We need more people in that course." That's really my relation, is to try to get students so that they can get to that first mark of...because 107 is credits for them, that's our precalculus, but it doesn't go towards meeting the degree requirement. It meets a gen ed requirement. Any other student could take a precalculus and have it count for graduation requirements, but we don't count it under engineering, it has to be starting with Calc 1.*

It has been offered only in the fall semester but the engineering faculty would like the mathematics department to offer it both semesters.

> *When I met with the engineering faculty a couple of months ago, again, they don't have really good data either. They like this idea that their students who just weren't quite there could start in calculus if they had this extra course. They love it. Everyone seems to think it's a good idea. (443573)*

While the co-requisite calculus course is currently the only corequisite math course being offered, one interviewee noted that there are initial conversations about designing a precalculus algebra prerequisite in the future.

Discussion:

Process tracing yielded a more nuanced recent timeline as all interviewees started talking around the pilot year, i.e., initial implementation. The PI is the only person with the longer arc of history that goes back prior to 2020.

No interviewees recalled any opposition to providing the corequisite calculus course. However, no one recalling opposition is insufficient to enable a sustainable corequisite calculus offering and future corequisite offerings. And elite interviews can be a challenging method of data collection in process tracing if there are political disincentives to recalling past barriers that have been eliminated [10]. In fact, emails surfaced registrar negotiations (listed above during installation and initial implementation) that may have remained barriers without the external incentive of the NSF S-STEM funding. And the project proposal included institutional agreements to pilot and study the impact of the corequisite course on student retention; agreements the PI and administrators referenced in emails during installation and implementation. NSF grant funding enabled extended registrar negotiations that may have otherwise served as barriers to installation as time wore on.

Moreover, NSF funding and research on the course assuaged faculty concerns when the pilot was proposed. While COVID compromised data and capacity built in the original design and teaching team, it also compromised students' readiness for a traditional calculus sequence thereby increasing the need for alternative onramps and modified degree-fulfilling credit bearing offerings. And while original administrators left, new administrators (provost, faculty/admin) arrived and created a policy environment eliminating non-credit bearing math offerings or non-degree fulfilling math courses. These policy changes incentivized formalization and sustainability of courses like corequisite calculus.

Data collection to study the course's impact on retention initially motivated faculty to endorse the pilot. However, several noted that COVID compromised the data. After two years of piloting, with "good enough" data, the ethical commitment to meet students where they are, a long-term NSF grant encouraging the course pilot, knowing COVID had set students back and a drop in enrollments, faculty endorsed the move to propose formalizing the course.

All interviewees agreed that the University Curriculum Committee requiring the course be open to all was a link to its approval. This is also an opportunity for increased sustainability as other programs beyond engineering, including, for example, chemistry and naval science, may rely on the corequisite offering to maintain retention and 4-year graduation. However, one interviewee noted that faculty available to teach it constrain its scaling or expansion.

All interviewed faculty and administrators agreed that retention and moving students closer to 4-year graduation are central outcomes of the corequisite course offering important to all.

Conclusion:

As institutions continue to make a college education accessible to all students, it is important to understand factors that influence change. The process of change at institutions are often met with challenges and take a considerable amount of time to implement. The first submission of the S-STEM proposal in 2018 to the approval of the corequisite course by the UCC in 2022 span only 4 years. In fact, the initial planning of the corequisite course with key stakeholder began in January 2020 and was approved as a bona-fide course in 2022. This provides strong evidence that the S-STEM award was a key factor in implementing change in the calculus offerings for engineering and science students at Norwich University.

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