An Interdisciplinary Graduate Certificate in the Formal and Natural Sciences—A Proposal

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Abstract

We propose a post-baccalaureate certificate framework in STEM, with an emphasis on soft skills, data science, and integration of disciplinary and other perspectives, with support for internships during or following the program. This program can serve multiple purposes. For STEM graduates, it provides additional breadth and depth, while strengthening communication, teamwork, leadership, and other soft skills. For students from other academic programs or returning students, it provides a bridge into STEM graduate study and careers. And for students from underserved and underrepresented communities, or from less intense programs, who may be concerned about their ability to deal with both technical and external challenges, it provides experience, confidence and support. The certificate can be formally integrated into or as a transition into Master's degree or higher level study STEM, or can be used as a less formal bridge into that study, or can serve as a standalone credential.

1. Introduction.

The United States does not produce a sufficient number of well-qualified professionals in STEM, and in the computing and technology field in particular [19]. The number of students pursuing undergraduate degrees in computer science or related field continues to grow but it is still not pacing industry growth, and similar problems apply across all STEM disciplines. Employers and observers repeatedly suggest that good professional and technical competencies [PTC], including "soft skills", are a major factor in both obtaining and succeeding in STEM careers [4, 7, 9, 16, 26]. Moreover, both the Council of Graduate Schools [6] and National Science Board data in the NSF 2018 STEM Trends document [21] support that these skills are needed for success in the sciences, and it is clear that they not only contribute to academic and professional success, but are increasingly being used to filter candidates with the requisite technical knowledge and experience.

Also, the increasing importance of interdisciplinarity, both in science and in data science, and with the rise of automation, robotics, and the Internet of Things, suggest the desirability of an interdisciplinary perspective [5, 11, 12, 22]. Concurrently, disciplines outside of computing and data science are recognizing the need for integrated, data-centric course work for their students in their major programs. This is often causing challenges and confusion with curriculum issues within universities across academic departments.

Soft skill competencies comprise (1) communication, both oral and written, in technical, business and general settings; (2) working in and leading teams, in a variety of roles; (3) managing business and professional relationships; (4) planning, problem solving, and critical thinking; (5) mathematical capabilities including numeracy; and (6) an understanding of ethical, social, managerial, and economic perspectives; and in addition, responding to recent developments in science and science careers; (7) an interdisciplinary perspective and an overview understanding of data science, as documented in our companion paper in this issue [15]. In this paper, we present a proposal for post-baccalaureate certificate curriculum based on this set of competencies and also providing an overview of STEM disciplines, their nature, and their questions of interest.

In Section 2, we consider the problem, and in Section 3, four possible approaches to providing an interdisciplinary, soft-skills, and data-science oriented education. Section 4 then presents the structure of our solution of choice: a post-baccalaureate certificate. Section 5 looks briefly at some consequences, and Section 6 presents our conclusions.

2. The Problem

STEM (Science, Technology, Engineering, and Mathematics) has become a focus for education, from primary school through post-secondary (university) level. It is increasingly recognized and critically important, academically, economically, socially, and politically. But even with increased post-secondary emphasis and enrollment in STEM disciplines, there are repeated and consistent projections of substantial shortfalls in the workforce in STEM and related disciplines, such as the health sciences and data science, and even more so of a need for those able to integrate other skills and viewpoints with a mastery of their own and a good knowledge of other STEM disciplines. With an insufficient number of qualified graduates in many STEM and related disciplines—and not all of those staying in the STEM sector, a way must be found to bring others into STEM. This group can include graduates from weaker STEM programs, STEM graduates entering or returning to a STEM career after a period of years, and most importantly, those who did not pursue a STEM program upon entering college, or start on one very soon thereafter, or who left a STEM major early, for various reasons [8], but who would like to return. Importantly, this group may also include women and minority students, first-generation college students, and others who encountered challenges during their undergraduate education.

This problem is complicated by the structure of most university STEM programs, with high course loads and deep prerequisite structure, and by, at least in most non-engineering schools in the United States, a large general education requirement, which for those not pursuing a STEM-related major lacks a serious STEM component. Such students may discover late in their undergraduate trajectory a need or desire to pursue STEM: They may change their interests, or wish to integrate STEM with those interests, or see enhanced career or educational prospects. But the structure of undergraduate STEM programs may make it difficult to do so without additional time or cost. and many, especially those from underserved or underrepresented populations—women, minorities, first-generation college, financially disadvantaged—who too often face external economic, family, and social challenges, this may be next to impossible. This is one of several factors that contribute to the lack of diversity in many STEM fields, which is seen by many as a serious problem for the future [1, 2, 3, 10, 25].

In this study, we primarily focus on non-profit, private and public academic institutions. In this paper, we present a possible route, a post-baccalaureate certificate that can serve as a bridge into graduate education in STEM, or stand as a credential on its own. For various reasons, we do not directly here consider its use in engineering, nursing, or medicine, but do consider in passing other health professions. While our background and primary emphasis is on the formal sciences (mathematics, computer science, data science, and logic), our conversations with others at our institutions and elsewhere have reinforced our belief that this proposal is more broadly applicable.

3. Four approaches

In our companion paper [15], we identified a set of facets as a basis for a solid STEM degree, building on a strong disciplinary capabilities, resting on a solid baccalaureate background, with broad intellectual, skills, and interdisciplinary focus, including both business and data science perspectives. Once these desirable components and complements have been identified, we can ask: To what extent is such an education feasible? How can it be brought about? And what stands in the way?

Four possible routes suggest themselves: an interdisciplinary bachelor’s degree, a focused bachelor’s degree with a general education component chosen to enhance the degree, an interdisciplinary graduate degree, or a post-baccalaureate credential such as a certificate or a module in a micro-curriculum framework.

Each has its advantages and difficulties. The first two baccalaureate alternatives will of course be quicker and most likely less expensive, and can address all of these perspectives over a four-year timeframe. However, the first alternative, an interdisciplinary baccalaureate major, would require either formation of a new program, and probably new department, competing for faculty and students with existing disciplinary programs. The second has the advantage of complementing a full STEM major program, while selecting appropriate general education courses, but runs into at least three problems.

The graduate alternatives offer different tradeoffs. The third approach, an interdisciplinary graduate degree, could either have a content- or problem focus, or be fully interdisciplinary, or be modeled on a Professional Science Master’s (PSM) degree with a somewhat broader focus [18, 24]. The advantage is that students will have had a full undergraduate degree—although this may preclude or offer obstacles to those without a suitable STEM undergraduate program--and may also allow students to be employed in career-relevant positions while seeking their degree.

This approach to a master’s degree in discipline can be successful with substantial support, particularly in disciplines such as computer science, in which a transitional year will suffice for most applicants [13]. As an alternative, a PSM degree could leverage existing structures, and would address soft skills, but a discipline-specific PSM would be limited in breadth and in possible audience, and would typically target certain career niches (often technical or process management), which may be of less use to returning students or more difficult for those making a big transition from their undergraduate program.

The fourth and final approach, a post-graduate credential such as a certificate, of perhaps 3-6 graduate courses, arguably cannot by itself completely solve the problem, but has the possibility of leveraging a student’s prior education—and with luck a diverse cohort of students, and planting the seeds of a good interdisciplinary perspective, without the need to cover the full scope of a graduate-level academic discipline.

Each of these alternatives relies on a substantial institutional commitment and investment, and change in institutional perspectives, policies, and processes. Except to some extent for the second, they are impractical for an individual to otherwise pursue. In most cases, this will mean faculty will need to commit to change (to varying extents) their approach to teaching, and to commit to more involvement in advising and interacting with students. This can be problematic for non-tenurable faculty unless the program is well-established, and for probationary faculty in the face of ever greater institutional demands for greater research and grant productivity. For tenured faculty, there is more of a tradeoff: it risks interrupting grant and research programs, while opening up other research opportunities and supporting early identification of promising students. Departments, and offices such as Career Services and Admissions, will also be affected. One would also need to persuade employers--including management, technical, and personnel departments--of the enhanced value of applications with such a credential.

We will note that, although we have presented these as alternatives, these could in principle be used in various combinations as components of a broader interdisciplinary yet focused education. But this would appear to require even more changes in institutional structure, and an agreement among multiple institutions and their faculty, so as to make the components reinforcing rather than repetitive.

4. Structure of a certificate program

The post-baccalaureate certificate option can offer an interesting pathway, especially in a time where micro-curricular options at the graduate level are becoming more attractive to students. It offers the most benefit to the widest audience in the least amount of time, and can often utilize existing academic and support structures. A properly structured and properly marketed certificate would be accepted by both employers and graduate schools as adding value, and that it would substantially facilitate a transition to and success in STEM graduate study. The certificate must be designed so students not only gain or refine technical competence and soft skills, but gain confidence in approaching difficult material, in dealing with technical communication, and in being a part of a functioning team. For this reason, it may also be attractive to recent graduates who feel less confident and wish to enhance their credentials for careers or graduate school, without the time, financial, or academic commitment of a Master's level degree.

Currently, according to NSF Data Sets [20], over 20% of the STEM workforce comes from disciplines tangential to or outside of STEM.. Some STEM programs—particularly in computing, earth science and sustainability, and Master's level programs in mathematics and statistics—currently attract applicants from other disciplines within and outside STEM. But these students often not only lack subject knowledge, which for many can be remedied by a set of "bridge" transitional courses, taking perhaps one year for computer science (for example) for a student with an adequate (precalculus) level of mathematics, but quite a bit longer in disciplines such as chemistry or physics if the student has not seen basic courses or acquired laboratory technique. As importantly, many such students do not have a solid understanding of the nature of communication and teamwork in science, of the nature of problem solving and critical thinking in the formal and natural sciences, or of applications of STEM from a STEM perspective.

Many in this situation, in spite of their intention to change field, explore interdisciplinary opportunities, or enhance their credentials, may be hesitant about graduate study. However, many of these same students will have acquired soft skills, some cases impressively so. A post-baccalaureate certificate program can look at the fundamentals of a discipline or, as appropriate, at interdisciplinary problem solving,, together with a focus on soft skills can leverage the strengths of both in-major and transitioning students, thereby providing multiple viewpoints and perspectives to the benefit of all.

For a number of reasons, data science provides a natural vehicle and emphasis, especially due to its ubiquity [14, 23]. The connection to the other formal sciences is straightforward: software engineering, databases, privacy and security, artificial intelligence, architectures and distributed computing, mathematical modeling, statistics and graph theory, as well as knowledge management and technical management. Data science is now utilized throughout science [17], in areas including the health sciences/professions, genetics, climate science, and chemical structure analysis and prediction, and is likely to become even more pervasive. These issues help to develop a well-rounded student, beginning their journey to both technical competency as well as professional awareness.

Such a certificate might entail, as we suggest above, three-to-six courses. A four-course certificate might consist of the following.:

1. A course in scientific and technical communication, looking at introductory or historical material, survey papers, and accessible research papers. Each student would be expected to read, discuss, and present a small number of summaries or reactions to this material, and to create an annotated bibliography on a topic, including a brief synthesis. Student groups would collaborate in developing a more extensive poster presentation of a paper or a synthesis of a set of papers. One course module would consider teams and teamwork—with examples from software engineering, data science, and scientific research and development, and the processes and practices needed for teams to form, function, and be self-sustaining.
2. An overview course in data science, data analysis, and data visualization, covering some of the aspects mentioned above, including assignments related to from commerce, management, scientific, and other applications, and specifically including at least one team project and at least one presentation.
3. A course dealing with ethics, security, privacy, intellectual property, and the philosophy of science (and perhaps a little on the philosophy of mathematics). With the exception of the philosophy of science and of mathematics, this course would be driven by case studies, with discussion, written responses and presentations. Some programming could be involved.
4. A discipline-focused course, which depending on student mix, might have to be specialized. In the formal sciences, this could cover some of the mathematical and programming foundations of computer science, and/or an introduction to computational linear algebra and/or statistics. In the natural sciences, this could be discipline-focused coverage of some basic themes with laboratory experiments designed to develop or refine laboratory technique. Alternatively, if this is impractical, or if a fully interdisciplinary focus is desired, this fourth course could be a problem-solving interdisciplinary course, which in the process lightly covers some of the above topics, skills, and issues. Whichever alternative is selected, this should involve additional team assignments and technical writing.

A five-course certificate could add a practical component, with the default an internship for credit, and other options including working with a faculty member.

The certificate could, either as a structure or as an option, be coupled with a graduate subject degree, or serve as a stand-alone credential. By itself, it can be ideal for those who wish to combine an understanding of STEM and data science with their existing interests, for example, in law, digital humanities, business analytics and decision science, or virtual reality graphic design. It also suits STEM graduates who feel the need for a more rounded perspective, better exposure to data science, or better soft skills. Students seeking to enter a STEM field with minimal prior background might still need bridge courses, though hopefully fewer of them, but would be better prepared to make the transition and to see the point of and succeed in their graduate education.

5. Benefits and Tradeoffs

An expected benefit of this design will be that all students become more interdisciplinary: Transitioning students by combining knowledge and perspective from their prior background with their new STEM discipline, in-major students by learning how to explain their thinking and processes in less technical terms, and all by interacting with students with diverse academic and social backgrounds. As a secondary effect, more students may be attracted to interdisciplinary studies or research.

The most obvious benefit to institutions and departments from students who complete the certificate and then enter Master's (or higher-level) programs will be a student population with increased communication, teamwork, and critical thinking skills, plus a knowledge of data science, which as a body also possesses increased diversity, demographically, socially, and academically.

Several opportunities present themselves. The offering institution could also use this certificate as a means of broadening the potential student base for interdisciplinary, data science, or PSM programs, or for programs with low enrollment or low diversity. Another exciting possibility is that states or school districts could encourage teachers to take this certificate, to increase the quality and depth of their STEM, STEAM, STREAM or SHTREAM programs [15]. For these students, a Master's degree program could be designed that integrates the certificate with courses in the institution's School of Education.

However, as suggested in Section 3, implementing the certificate does not come without risks and costs for institutions, departments, and faculty. Investments will need to be made in:

- Finding/recruiting and retaining interested faculty, and having them develop courses, assignments, and other supporting material. These faculty would need to be compensated, especially with released time and, for provisional faculty, documented modification of standards for tenure and promotion. It is unlikely that such a program can be sustained without the involvement of permanent, full-time faculty, although involvement of qualified practitioner adjuncts and visiting or term-hire specialists can also contribute significantly.
- Placing additional loads on Career Services and other university offices, and locating industrial partners who are willing to advise the program and offer internships to its students.
- Developing and funding advertising and recruiting, including outreach to other regional universities, companies, and organizations.

It will also be highly desirable to have a venue (perhaps as part of a student research exposition) at which the students in the program can present or demo work products from the certificate courses, work with faculty members, or perhaps academically related material from internships. This may have minimal cost if such a program is already well-established.

A noticeable tradeoff was mentioned in discussing the fourth course in the certificate, but is implicit throughout. Even though the certificate is explicitly interdisciplinary, narrowing the focus (for example, to the formal sciences, the physical sciences, or the biological and earth sciences) will allow the coursework to be more focused and seem more relevant to those from those disciplines or attempting to transition into those disciplines. On the other hand, if the institution pursues only one such program, the narrower focus will limit the student base and its diversity, and will limit the faculty pool. However, if it offers separate programs for each focus, it will increase the expense and most likely need additional faculty. Finally, if some courses are broad-based, and some are focused, it may disrupt cohort and team formation.

Another tradeoff lies in how wide the recruitment net is cast. Students with less related background, and others with varying complications are likely to require more assistance, both from faculty and from institutional offices and resources. But the result will be a more diverse cohort with a wider breadth of skills and perspectives, and a greater contribution to the workforce and knowledge economy discussed in Section 1.

In addition to the interaction between the certificate and interdisciplinary graduate programs and research, and enhancement of its internship program and relationship with companies and organizations, the certificate program offers opportunities for faculty development. A successful program will also promote the reputation of the institution and the employability of all its STEM graduates, and increase the demographic and social diversity of its STEM programs.

Finally, the certificate program, if widely implemented, will provide a larger, more skilled and more knowledgeable, and more diverse STEM workforce.

6. Conclusions and Future Work

We have outlined an interdisciplinary STEM certificate program founded on four pillars: soft skills including communication and teamwork, problem solving and critical thinking, data science, and an applied view of ethical and philosophical issues in STEM. The program is designed to increase and improve the STEM workforce, and to result in greater diversity, demographically, socially, and in terms of academic background. We have outlined multiple benefits, and also costs, risks, and tradeoffs, for institutions, departments, and faculty. All-on-all, we encourage institutions to explore and implement this proposal.

For future work, we will expand on the content of the courses briefly described above, explore further the use and role of internships, and continue to work for its implementation.

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