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A technology pathway program in data technology and applications

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A Technology Pathway Program in Data Technology and Applications

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Abstract

With an exponential increase in user-generated data, there is a strong and increasing demand for employees possessing both technical skills and knowledge of human behavior. Supported by funds from the National Science Foundation Division of Undergraduate Education, we have begun to address this need by developing a technology pathway program in data technology and applications at a large, minority-serving public university. As part of this program, an interdisciplinary team of faculty created a new minor in Applied Computing for Behavioral and Social Sciences. A large number of diverse students are studying behavioral and social sciences, and the ability to model human behaviors and social interactions is a highly valuable skill set in our increasingly data-driven world. Applied Computing students complete a four-course sequence that focuses on data analytics and includes data structures and algorithms, data cleaning and management, SQL, and a culminating project. Our first full cohort of students completed the Applied Computing minor in Spring 2019. To assess the success of the minor, we conduct student surveys and interviews in each course. Here, we focus on survey data from the beginning and end of the first course, given that it served as a particularly important feedback loop to optimize the course and to inform the design and execution of subsequent courses. The data reflect a significant increase in confidence in programming abilities over time, as well as a shift in attitudes about programming that more closely matches those of experts. The data did not show a significant change in mindset over time, such that students maintained a growth mindset across the semester. Finally, with respect to goals, students placed a greater emphasis on data and tech at the end of the semester, highlighting specific career paths such as user experience and human factors. In the future, we plan to administer this same survey to social science students not involved in the minor to serve as a control group and to begin exploring the large dataset obtained from other courses in the minor. We believe that embedding computing education into the social sciences is a promising means of diversifying the technical workforce and filling the need for interdisciplinary computing professionals, as evidenced by high rates of female and underrepresented minority enrollment in our courses, as well as promising shifts in student confidence, attitudes, and career goals as a result of taking Applied Computing courses.

Introduction

In an economy increasingly driven by user-generated data, there is a strong need for interdisciplinary computing professionals who possess both technical skills and knowledge of human behavior [1], [2]. As reported by McKinsey Global Institute [3], [4], although companies have placed a strong emphasis on data and analytics to adapt to this era of data-driven decision making, they are struggling to develop the necessary talent. Similarly, analyses conducted by the US Bureau of Labor Statistics suggest that by 2024, only 450,000 college graduates will be available to fill nearly 1.1 million job openings in computing and information technology [5], [6]. To address this need, we developed a technology pathway program in data technology and applications at a large, minority-serving public institution. As part of this program, faculty from the Colleges of Social Sciences, Engineering, and Education created a minor in Applied Computing for Behavioral and Social Sciences. These efforts have been supported by a grant from the National Science Foundation Division of Undergraduate Education (NSF DUE 1626600).

Program overview

With the emergence of big data, the ability to model human behaviors is a highly desirable skill. Students majoring in the behavioral and social sciences are well trained to understand human behavior, ranging from that of an individual to behaviors of societies and entire economies. By providing these students with programming and data analysis skills via the Applied Computing minor, we aim to create career paths in interdisciplinary computing fields such as econometrics and user experience research. Indeed, a recent report indicates that students who supplement their domain expertise with computing skills can double the number of available jobs and raise their salaries significantly [7], [8]. Additionally, a large number of diverse students are studying behavioral and social sciences, whereas computer science and engineering majors tend to lack such diversity, particularly with respect to gender [9], [10]. The goal of the Applied Computing program is thus to provide our students with a skill set that will expand their career opportunities and increase their income, in turn helping to address the need for a diverse workforce of interdisciplinary computing professionals.

Universities that share a similar goal often offer a CS + X major degree (e.g., University of Illinois), in which students enroll in existing CS courses alongside CS students, as well as in additional courses in a chosen domain. However, we opted to take a different approach and develop a minor degree specific to social science students given that (a) prior programming experience and mathematical background have been shown to predict success in introductory programming courses, e.g., [11] - [13], and (b) social science students typically have no programming and very little math background relative to CS majors. As such, we developed an entirely new series of four courses with content crafted specifically for these students, such that classes are taken only with fellow social science students (similar to the computational social science minor at UC San Diego). Courses are designed to be taken serially, creating a cohort structure that helps provide students a sense of community and belongingness, thus enabling them to network and support one another throughout their academic careers. Brief descriptions of each course are as follows:

- ENGR 120. This course is designed to gradually introduce social science students with no programming background to basic Python programming concepts (e.g., data types, conditional execution, iteration, functions, data analysis, web scraping) and is taught in a hybrid lecture-lab format to encourage active learning of concepts and skills.
- ENGR 121. Data Structures and Algorithms, also taught in Python, teaches students to represent and analyze social science data, to use data structures such as linked lists, trees, and graphs, and to use related algorithms to solve social science problems.
- ENGR 122. Data Technology introduces students to R with an emphasis on data frames and data analysis. Content includes basic statistics, linear and non-linear curve fitting, clustering, natural language processing, neural networks, databases, Structured Query Language (SQL), and data cleaning and management.
- ENGR 195E. As a capstone project course, students apply computing skills acquired in the minor to solving problems or generating insights in their chosen area of study. Students work in self-selected teams and define their own project topics.

Student Profile
A demographic profile of students enrolled in ENGR 120 (the first course in the minor) and ENGR 195E (the final course) can be found in **Table 1**, reflecting averages across all semesters that these courses have been offered. Relative to students taking other courses in the College of Engineering, a higher percentage of Applied Computing students are female and underrepresented minorities (Engineering: 19% female, 22% URM) [10]. The most popular major among Applied Computing students is Psychology, followed by Economics and less common majors such as Sociology, Behavioral Science, Communication Studies, and Business. Additionally, the majority of Applied Computing students have limited or no programming experience prior to enrolling in the minor. Via an informal survey given at the beginning of ENGR 120, 68.4% of students report no programming experience, 22.5% report limited programming experience, and only 9.1% report moderate programming experience.

Table 1: Student profiles for the first course (ENGR 120) and final course (ENGR 195E), averaged across semesters

Demographic	Category	ENGR 120 (2016-2019)	ENGR 195E (2018-2019)
# Students		260	31
Gender	**Female**	56.9%	48.4%
	Male	43.1%	51.6%
Ethnicity	**URM**	36.9%	29.0%
	non-URM	56.5%	71.0%
Major	**Psychology**	50.0%	32.3%
	Economics	21.5%	29.0%
	Other	28.5%	38.7%

Note: Percentages may not sum to 100% given that some students prefer not to disclose demographic information

Assessment

Our assessment approach consists of two main components: internal evaluation by faculty and external evaluation by a nonprofit education research agency. External evaluators conduct individual and group interviews with students, and our faculty team administers surveys to students, faculty from other universities offering similar degrees, and industry partners. Here, we focus on student surveys, which include questions pertaining to growth mindset [14], attitudes towards computer programming [15], confidence in programming abilities, and satisfaction with courses.

As the Applied Computing program was being rolled out, survey data from the first course, ENGR 120, served not only as a means of assessing student learning, but as a particularly important feedback loop to improve the course course and inform the design and execution of subsequent courses. Accordingly, the focus of the current paper is on analysis of this data set, which includes survey data from each semester that the course has been offered. As described in greater detail below, ENGR 120 students are asked to complete the survey at both the beginning and end of the semester, enabling comparison of responses over time.

Methods

Participants

Participants included students enrolled in the first course (ENGR 120) in the Applied Computing minor at a large, minority-serving public university. Students were invited to voluntarily complete a pre-course survey, administered at the beginning of the semester, as well as a post-course survey, administered during the final class meeting. Participants gave informed consent in line with procedures approved by our university's Institutional Review Board. 156 participants completed the pre-course survey, 185 completed the post-course survey, and 100 completed both surveys. See **Table 2** for demographic data, reflecting strong similarities between survey respondents and the broader population of students enrolled in ENGR 120 (**Table 1**).

Table 2: Demographic data for participants completing the pre-course, post-course, or both surveys.

Demographic	Category	Pre-course survey	Post-course survey	Both surveys
# Participants		156	185	100
Gender	**Female**	59.0%	56.2%	63.0%
	Male	34.6%	41.6%	35.0%
Ethnicity	**URM**	34.6%	33.4%	36.0%
	non-URM	56.4%	61.6%	57.0%
Major	**Psychology**	50.6%	56.8%	57.0%
	Economics	15.4%	17.8%	14.0%
	Other	26.9%	23.2%	26.0%

Note: Percentages may not sum to 100% given that some students prefer not to disclose demographic information

Pre-course survey

The survey was administered online via Qualtrics and included five sections. The first section contained a series of eight questions pertaining to growth mindset. Three were taken from Dweck [14], and the remainder were filler questions from Fabert [16]. The second section contained a series of 26 questions adapted from the Computing Attitudes Survey [15] to use the word "programming" rather than "computing." This change was made to clarify that questions referred specifically to computer programming rather than computer skills more broadly. The third section contained a series of five questions regarding confidence in programming abilities. The fourth section included three open-ended questions: what are your long-term goals, what was your motivation for taking the course, and did you have any hesitation in taking the course? Finally, the fifth section included a series of demographic questions pertaining to gender, ethnicity, and major.

Post-survey

The survey was administered online via Qualtrics and contained six sections. The first three sections (mindset, attitudes, confidence) and the final demographic section were identical to those of the pre-course survey. The fourth section included a series of nine questions pertaining to satisfaction with course materials and the course itself. The fifth section contained open-ended questions that differed from those of the pre-course survey: what aspects of the course did you enjoy the most, what suggestions do you have for improving the course, and what are your long-term goals and have they changed as a result of taking this course?

Results

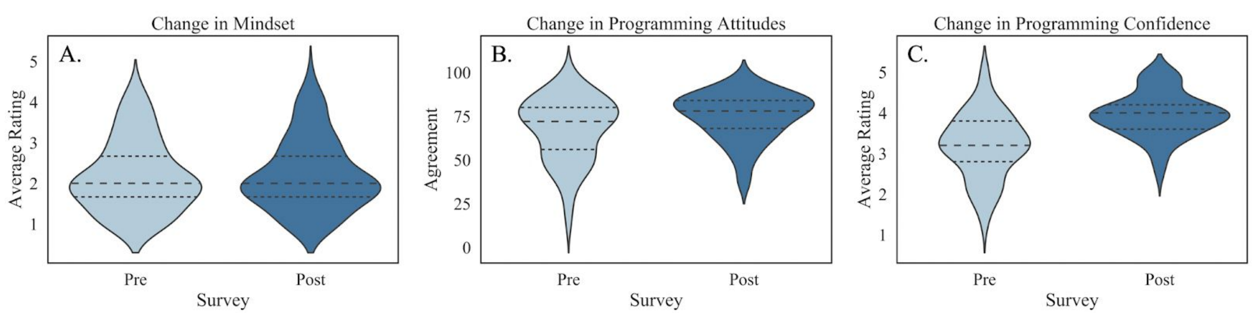

Figure 1. Pre- and post-survey changes. Dashed lines indicate quartiles. 1A: Change in mindset; lower ratings indicate disagreement with the questions posed, indicative of a growth mindset. 1B: Change in programming attitudes; higher levels of agreement indicate greater similarity with experts in programming attitudes. 1C: Change in confidence in programming abilities; higher ratings reflect greater confidence.

Growth mindset

To determine whether there was a change in mindset over time, we compared pre- and post-survey responses averaged across the following three questions: (a) you have a certain amount of intelligence, and you can't really do much to change it, (b) you can learn new things, but you can't really change your basic intelligence, and (c) your intelligence is something about you that you can't really change that much. Lower ratings reflect disagreement with these statements and are indicative of a growth mindset. Among respondents who filled out both the pre- and post-survey, 99 fully answered these questions. The results indicate that there was not a significant change in mindset over time ($t(98) = -0.49$, $p = 0.62$), such that both pre- and post-survey ratings were similarly low and indicative of a growth mindset (see **Figure 1A**).

Attitudes towards programming

We next examined changes in attitudes towards programming over time. For each question, answers were compared to those of experts to obtain a total score indicating percentage agreement with programming experts [15]. Among respondents who filled out both the pre- and post-survey, 90 fully answered these questions. The results demonstrate a significant change in attitudes towards programming over time ($t(89) = -4.70$, $p < 0.001$), such that there was greater agreement with experts on the post-survey relative to the pre-survey (see **Figure 1B**).

Confidence in programming abilities

To assess whether confidence in programming abilities changed over time, we compared pre- and post-survey responses averaged across the following five questions: I believe I am able to (a) solve a programming task, (b) explain a programming concept to someone else, (c) develop a programming algorithm, (d) follow logical steps necessary to complete a programming task, and (e) demonstrate my programming skills for a job interview. Higher ratings reflect greater confidence. Among respondents who filled out both the pre- and post-survey, 95 fully answered these questions. The results show a significant change in confidence over time ($t(94) = -9.45$, $p < 0.001$), such that students reported greater confidence on the post-survey relative to the pre-survey (see **Figure 1C**).

Course materials

In addition to evaluating changes over time, we also analyzed responses ($n = 182$) to a series of nine questions appearing only on the post-survey. These questions related to student opinions regarding course materials (questions 1-5) and the course in general (questions 6-8), with higher ratings indicating greater agreement with each question. As can be seen in **Table 3**, students agreed that course materials were interesting and different, causing them to think in new ways and to consider new career options. Student responses regarding difficulty were neutral, suggesting that they found the material appropriately challenging. Students also agreed that they were glad they took the course, it related to their major, and it provided a positive learning environment and sense of community.

Table 3: Student ratings of course materials and the course in general

Question	Mean ± standard deviation
1. The material was interesting	4.65 ± 0.65
2. The material was hard	3.14 ±1.03
3. The material was different from the kinds of things I've studied before	4.32 ± 0.95
4. The material made me think in new ways	4.50 ± 0.66
5. The material made me think of career options for myself that I hadn't really thought of before	4.37 ± 0.81
6. Overall, I'm glad I took ENGR 120	4.74 ± 0.66
7. Overall, I see connections between that I've learned from courses in my major and what I learned in ENGR 120	4.44 ± 0.79
8. The class provided me with a positive learning environment	4.68 ± 0.69
9. The class provided me with a feeling of belonging to a community	4.18 ± 0.97

Note: Agreement rated on a scale of 1 (strongly disagree) to 5 (strongly agree)

Long-term goals

With respect to open-ended questions, here we focus on changes in student responses (n = 100) to the following question: What are your long-term goals? Figures 2 and 3 demonstrate commonly used words on the pre- and post-surveys, respectively. At both time points, students frequently used the words "programming," "research," and "psychology." At the end of the semester, however, students more heavily used the words "data" and "tech," and also included more detailed career paths such as "Human Factors" and "UX" (user experience).

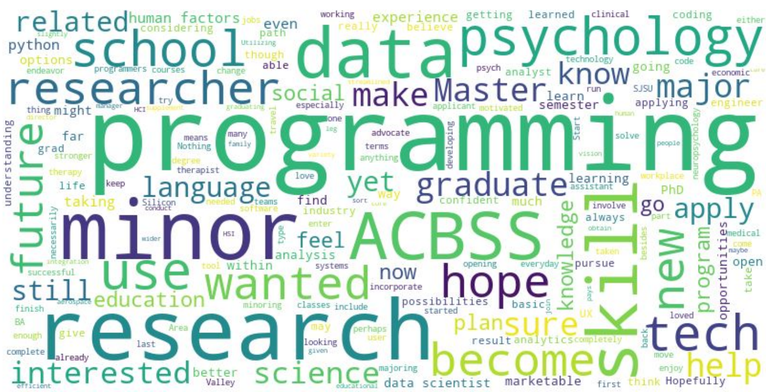

Figure 2. Pre-survey long-term goals. The word cloud reflects commonly used words in the pre-survey in response to an open-ended question regarding long-term goals.

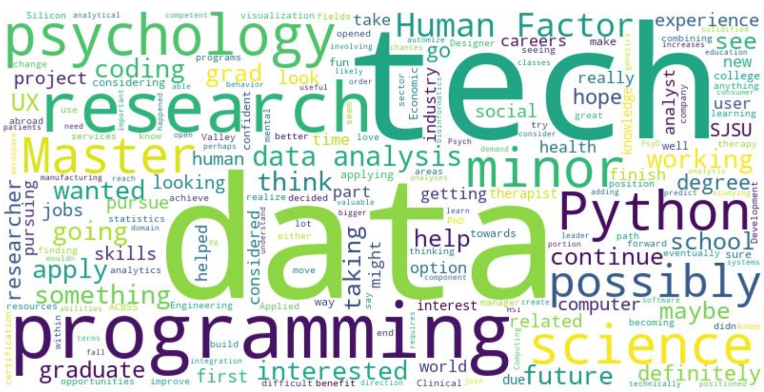

Figure 3. Post-survey long-term goals. The word cloud reflects commonly used words in the post-survey in response to an open-ended question regarding long-term goals.

Discussion

The first course in the minor, ENGR 120, was introduced in Fall 2016, with additional courses added each semester until all four courses were in regular rotation in Spring 2018. However, many early adopters of Applied Computing courses graduated before being able to finish the minor, and thus our first full cohort completed the minor in Spring 2019. Given that our analysis of the larger program is in progress, here we have focused on assessment data from ENGR 120, which has been key to both improving this foundational course as well as informing the development of subsequent courses.

Specifically, our analyses focused on changes in mindset, attitudes towards programming, and confidence in programming abilities as a result of taking the first course in the minor. The data demonstrate that students' attitudes significantly shifted over the semester, such that their responses better resembled those of experts at the end of the semester. In the future, we plan to compare the magnitude of this shift to that experienced by major and non-major students taking a standard introductory computing course. Prior research indicates that non-majors' attitudes towards programming better match those of experts when they take an introductory course designed specifically for non-majors rather than a standard introductory course with CS majors [17]. Students similarly demonstrated significantly higher confidence in their programming abilities at the end of the semester relative to the beginning. We are encouraged to see that, after only 3.5 months of instruction, students with little to no programming background showed such a significant shift in their attitudes and confidence. These changes are particularly important in motivating students to continue with additional courses in the minor, which increase in difficulty.

Although our findings did not show a significant change in mindset over time, they do indicate that students maintained a growth mindset across the semester. In the future, we are interested in exploring whether social science students with a growth mindset are more likely to enroll in the minor relative to those with a fixed mindset, which would align with a rich literature suggesting that students with a growth mindset are more likely to seek out challenges [18], [19]. To this end, we plan to administer the pre-survey to a group of social science students who have been exposed to Applied Computing recruitment materials, but nonetheless have chosen not to enroll.

With respect to the post-survey, students indicated that course materials were interesting and different, causing them to think in new ways and to consider new career options while also showing clear relevance to their majors. We were particularly encouraged to learn that students were considering new career options, given that this was one of our primary goals in creating the minor. To more directly assess students' career interests, we created word clouds indicating commonly used words in response to an open-ended question regarding long-term goals. The word clouds indicate that students placed a greater emphasis on data and tech at the end of the semester relative to the beginning. They also mentioned specific career paths such as user experience and human factors at the end of the semester, rather than simply "research," as was found at the beginning of the semester. This shift was likely driven by the emphasis that instructors place on exposure to different career paths in the tech industry. At the beginning of each lecture, for example, instructors include a spotlight segment that introduces students to different fields, approaches, and career paths in tech, e.g., natural language processing, data science, and user experience research.

We are keen to follow the career trajectories of Applied Computing graduates, to which end we recently created a LinkedIn group for current students and alumni. Although our first cohort only graduated a few months ago, we are delighted to see that many of them have taken on roles as data analysts, technicians, and consultants, as well as user experience researchers and designers. Several have also gone on to pursue Master's degrees in fields such as human factors, applied economics, research and experimental psychology, and information systems.

Another goal in developing the Applied Computing minor was to enhance diversity in computing education. To this end, the demographic data for the first course in the minor (ENGR 120) clearly indicate greater participation of both women and URMs in the course relative to other courses in the College of Engineering. We are optimistic that these numbers will improve for the final course in the minor, as well, given that many of the diverse students in ENGR 120 will continue forward with the minor over time.

Finally, as more students complete the minor and our sample size increases, we look forward to performing similar analyses of survey data from subsequent courses in the minor, with a particular emphasis on an exit survey given to students completing the minor in full. We also look forward to performing qualitative analyses of the student interviews conducted by our external evaluator, which should help us better understand the needs and goals of our students.

We believe that inserting computing education into the social sciences is a promising means of diversifying the workforce and filling the need for interdisciplinary computing professionals, as evidenced by high rates of female and URM enrollment in our courses, as well as promising shifts in student confidence, attitudes, and career goals as a result of taking Applied Computing courses.

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