A Study of Course-based Undergraduate Research Experiences and the Challenges and Opportunities for Computer Science

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***Abstract*—A course-based undergraduate research experience (CURE) involves the incorporation of research at the undergraduate level, typically as a replacement to the lab portion of the course. A motivational driver for incorporating research in the classroom is to ensure greater participation and retention of undergraduate students in science, technology, engineering, and mathematics (STEM). Studies have also shown that students who engage in undergraduate research experiences gain a better understanding of the scientific process and are more likely to pursue graduate studies. The CURE model is regarded as a pedagogical paradigm that originated in the life sciences, resulting in numerous research studies and support networks. Computer science can be regarded as a singular discipline and as a discipline that spans all areas of science, technology, engineering, and mathematics. Interestingly, it was the STEM Education Act of 2015 that resulted in the official inclusion of computer science to the definition of STEM disciplines. This paper provides a review of undergraduate research experiences in STEM from the research literature, identifying the unique challenges and opportunities associated with incorporating CUREs into an undergraduate computer science curriculum. In addition, this paper entails an evaluation of an upper-division Artificial Intelligence (AI) course incorporating course-based research.**

***Index Terms*—course-based research; course-based undergraduate research experience; computer science education**

I. Introduction

According to the Council for Undergraduate Research (CUR), undergraduate research is ”An inquiry or investigation conducted by an undergraduate student that makes an original intellectual or creative contribution to the discipline.”[1] Some of the benefits of undergraduate research according to CUR includes the enhancement of student learning via mentoring with faculty, increasing student retention and graduation in academic programs, and increasing enrollment in graduate education along with effective career preparation.

Pedagogical paradigms with a student-centered learning approach incorporate active learning [1], research-based learning [2], and project-based learning [3]. Pedagogical interventions inspire students towards the study and pursuit of science, technology, engineering, and mathematics (STEM) by incorporating research experiences early on, use of active learning in introductory courses, and fostering a sense of community in STEM [4].

Active learning is considered a viable paradigm to increase the number of students receiving STEM degrees by partially or entirely abandoning traditional lecturing in favor of active participation of students in the classroom [5]. Since the founding of universities almost a thousand years ago in Western Europe, lecturing has been the predominant mode of instruction [6]. Active learning replaces the passive engagement of students in the lecture aspect of teaching by involving students in being fully engaged and thinking about what they are doing. Research in active learning has shown that the failure rates under the traditional lecturing approach increases by 55% over the rates observed under active learning which has also shown to further increase examination performance [5].

Project-based learning emphasizes a project-oriented approach for STEM education especially in computing and engineering due to the problem-focused nature of technology-oriented disciplines [7]–[12]. A review of 500 projects in computer science identified four critical success factors involving project management, student motivation, student-instructor engagement, and project idea originating with the student results in greater success [13]. In 2018, the White House released a report entitled ”Charting a Course for Success: America’s Strategy for STEM Education,” which includes a five-year strategic plan for ensuring that the United States is the STEM global leader in terms of literacy, innovation, and employment [14]. The aforementioned report recommends the use of project-based learning for solving real-world problems with collaborations between academia and industry to bolster work-based learning. Worth noting is that the five-year strategic plan puts special emphasis on computer science and mathematics as important STEM skills.

Research-based learning originated in the life sciences and is the inclusion of research into an undergraduate course, which is better known as Course-based Undergraduate Research Experience (CURE). In fact, CURE is considered an

[1] https://www.cur.org/who/organization/mission/

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innovative pedagogy with the integration of authentic research experiences into individual courses and biology programs [15]. In 2012, The President's Council of Advisors on Science and Technology (PCAST) proposed several recommendations for the first two years of undergraduate STEM education, which is to "Advocate and provide support for replacing standard laboratory courses with discovery-based research courses [16]." A CURE is the transformation of a laboratory-based course where students learn and work on research problems that are of interest to the broader scientific community [17], [18]. Incorporating Course-based Undergraduate Research Experiences (CUREs) at the beginner level can be particularly beneficial as they have a greater potential to shape academic career trajectories. This is in contrast to research internships that are usually tailored to upper-level students [18], [19]. The incorporation of research at the undergraduate level have been shown to be especially advantageous for increasing graduation rates in STEM careers [20]. According to the research literature, some of the benefits of exposing undergraduates students to undergraduate research experiences ensures a greater likelihood of completing their undergraduate degree, acquiring the necessary skills in learning to think like a scientist, and continuing academic studies in the pursuit of a graduate degree [21]–[23].

Research experiences are considered especially beneficial for women and underrepresented minorities, presumably due to the cultivation of relationships with senior scientists, as well as the development of a critical support system [18], [22]. However, there are barriers with the traditional independent research approach particularly for first-generation or economically disadvantaged students, such as the lack of awareness of the importance of research for a scientific career or lack of information in how to proceed in engaging faculty in research opportunities [21], [24]. In addition, adopting a purely independent research approach for engaging undergraduates in research poses other barriers as well. For example, there are a limited number of undergraduate research positions that are available in faculty labs and the limited time of the faculty to engage numerous undergraduate students on a personalized basis [19], [25], [26].

Computer science can be regarded as a singular discipline and as a discipline that spans all areas of science, technology, engineering, and mathematics. Interestingly, the STEM Education Act of 2015 resulted in the official inclusion of computer science to the definition of STEM disciplines. However, the incorporation of CUREs in computer science courses is scarce in comparison to the plethora of CUREs that are infused in courses from the natural sciences, especially biology. This study entails a review of undergraduate research experiences in understanding the success of CUREs in the life sciences and explores the challenges and opportunities for incorporation into a computer science curriculum.

II. Motivation of CURE in the Life Sciences

The biological sciences sought to transform the predictive nature or "cookbook approach" of the traditional lab portion of the courses where the answers are known in advance [17], [18], [27]. The key differentiation of CUREs from traditional laboratory experiences includes the use of scientific practices, discovery, broadly relevant work, collaboration, and iteration [18]. As a pedagogical paradigm, CURE has been demonstrated to not only boost confidence and perseverance among science students, but also foster a stronger identification with the role of a scientist. CURE increases the likelihood of students enrolling in more science classes and ultimately completing a science degree [2]. In addition, the presence of CUREs at the introductory level has a greater influence of retention and influence on career paths. This section explores the reason for the success of CURE in the life sciences. These include the question-based focus of science which makes CURE especially applicable, the availability of numerous support networks, and academic institutional implementations of CURE with emphasis in the life sciences.

A. *Inquiry Nature of Science*

Authentic research pertains to identifying novel questions and student-generated questions, developing a hypothesis, designing experiments, collecting and analyzing data, presenting and publishing the research [17], [18], [28], [29]. "Engaging in undergraduate research exposes students to scientific practices, which essentially is about asking questions" [18]. Also, the recognition that each fact emerges from a series of questions and systematic attempts to find the answers to those questions is applicable [30]. Scientific inquiry often begins with a question such as in the following examples:

1) Do preservatives such as parabens and formaldahyde releasers in cosmetics cause estrogen disruption?
2) Does telomere shortening cause aging?
3) Can the ketogenic diet affect kidney function?
4) Did COVID-19 come from a lab or nature?

The aforementioned emphasis on inquiry is in the form of questions, most amenable to CURE. To transform this approach into being problem-focused would renders it more as an applied science:

1) A paraben-free preservative for cosmeceuticals.
2) Reducing telomere shortening with B12 and resveratrol infusion.
3) A minimally invasive test for assessing kidney function.
4) A pharmacological treatment for COVID-19.

The development of CUREs have been further divided into two categories of inquiry in both biology and chemistry as being either discovery-based or hypothesis driven [28]. This systematic approach is what makes the life sciences most amenable to the incorporation of CURE at the undergraduate level. In addition, numerous support frameworks and implementations of CURE have been developed, with the majority appearing to be in the field of biological sciences. This primary focus on the biological sciences are driven by improvements in biological education [31].

[2]https://serc.carleton.edu/curenet/pedagogy.html

B. Support Frameworks for CUREs in the Life Sciences

The growth of CUREs in the life sciences has been due to the numerous support networks providing resources in terms of financial funding as well as established knowledge base frameworks for CURE incorporation. Some of the support entities for making CURE successful in the life sciences are stated below (1-4):

1) Howard Hughes Medical Institute (HHMI): Considered one of the world's largest philanthropy and major funding source for research in biological science and biology education, HHMI supports scientists and students in the pursuit of fundamental questions in basic science. HHMI's chartered purpose is the advancement of knowledge within the basic sciences and the effective application of that knowledge for the overall benefit of humanity[3]. In fact, HHMI has been instrumental in providing resources for various support networks of which all have institutional frameworks for the life sciences for various academic institutions.

2) Science Education Alliance Phage Hunters Advancing Genomics and Evolutionary Science (SEA-PHAGES): The engagement of a large number of undergraduate students in authentic scientific discovery is certainly a nontrivial task. The SEA-PHAGES course provides a general model in training faculty and teaching assistants from diverse academic institutions for implementing a research course for first-year undergraduate students with the focus on bacteriophage discovery and genomics. To date, the course has been taken by over 4,800 students at 73 institutions [4].

3) Genomics Education Partnership: The Genomics Education Partnership is a nationwide collaboration of over 100 institutions that integrates active learning into the undergraduate curriculum through the use of CUREs with a focus on coursework in bioinformatics and genomics [5]. The GEP currently comprises several hundred undergraduate students at more than 60 institutions of higher education across the United States who are involved in laboratory studies of Drosophila genomics and bioinformatics in laboratory class settings. Students participating in this program report outcomes similar to students in other course-based research models.

4) VisionAndChange.org for Transforming Biology Education: Vision and Change in Undergraduate Biology Education is an initiative with support from the National Science Foundation, Howard Hughes Medical Institute, the National Institutes of Health, and the United States Department of Agriculture. Vision and Change has involved stakeholders from educators to professional society partners to policymakers. The objective is the unification of the undergraduate biology education community under a set of common principles, which incorporates research experiences as an integral component of biology education for all majors [6].

C. Academic Institutional Implementations of CURE

Numerous academic institutions have initiated and continue to incorporate authentic research experiences as part of undergraduate study. This section provides an emphasis on the most influential and longest running CURE programs in the United States.

1) Freshman Research Initiative (FRI), University of Texas (UT) at Austin: [7] Spearheaded by the College of Natural Sciences at UT-Austin, FRI is regarded as the largest and longest-running (since 2005) university undergraduate research program. The CURE model is defined as research streams where students select their research interest. There are 30 active research streams, which are mostly multidisciplinary where the research stream spans several academic disciplines. Recently announced is their Accelerated Research Initiative offering a parallel experience to upperclassmen and upper division students.

2) First-year Research Immersion, Binghamton University: [8] The Immersion program is modeled after the Freshman Research Initiative (FRI) at UT-Austin, with greater interdisciplinary academic topics. The program currently has 10 active research streams with an interdisciplinary focus. For both the First-year Research Immersion and FRI, biology and chemistry are the most utilized disciplines across research streams.

3) First-Year Innovation and Research Experience (FIRE), University of Maryland: [9] Also modeled after FRI, FIRE started in 2014 and currently have four general research streams with slightly different goals over FRI by broadening the focus and including research streams in the social sciences, arts and humanities.

4) Course-based Research Experience (CRE), Lawrence Technological University: [10] CRE draws similar comparisons to both FRI and FIRE with over 30 courses incorporating course-based research and extending beyond the natural sciences to include the social sciences and the humanities. Implemented in 2017, the inclusion of course-based research in undergraduate courses varies from one week, several weeks, or the entire course immersed in a research experience.

III. Computer Science inclusion in STEM

The STEM Education Act of 2015 solidified the role of computer science as part of STEM, which means the recognition of affiliation across science, technology, engineering, and mathematics [11]. Worth noting that several years preceding the official declaration of computer science in STEM, there had been a growing interest in having the arts incorporated in STEM and adjusted to STEAM with the 'A' denoting the arts (i.e., liberal arts, fine arts, etc.) [32], [33]. As far as funding opportunities with STEAM, funding organizations have started to recognize STEAM and proposals are being

[3] https://www.hhmi.org/programs
[4] http://www.hhmi.org/grants/sea
[5] https://gep.wustl.edu/
[6] https://visionandchange.org/
[7] https://cns.utexas.edu/fri
[8] https://www.binghamton.edu/first-year-research-immersion/
[9] https://www.fire.umd.edu/
[10] https://www.inclusivity-cre.org/course-summary
[11] https://docs.house.gov/billsthisweek/20150223/SMITTX_1020_xml.pdf

funded that connect the arts to STEM [12]. Computer science is an interesting discipline that crosses all areas of STEM or STEAM, as well as stands alone as its own discipline. Sections A-F explore the interdisciplinary that computer science has across each discipline as well as computer science as a singular discipline.

A. Computer Science and Science

In 2012, an article in Communications of the ACM (Association for Computing Machinery) by the president of the ACM sought to find the science in computer science. ”In the physical world, science is largely about models, measurement, predictions, and validation,” stated Vinton G. Cerf and further added that models surrounding prediction on software behavior and performance has less capability [34]. The ’S’ in STEM does appear to receive too much of a focus on the natural sciences. In fact, funded proposals for STEM from the National Science Foundation (NSF) where STEM is stated seem to have a focus on the biological sciences. Many critics have viewed computer science primarily as technology or mathematics and not as a genuine science [35]. However, the growth of interdisciplinary fields like bioinformatics, chemoinformatics, and quantum computing gives credibility to computer science as being instrumental to science.

B. Computer Science and Technology

In a 2005 article in the Communications of the ACM, another perspective is viewing computer science as a technology, specifically information technology over being a science [36]. Considering that a significant part of computer science deals with information processing, this view certainly has merit. However, this classification provides overlap with information systems which typically entails a business administration emphasis especially when it delves into IT governance and policy. Recent technologies such as blockchain certainly gives computer science a technological focus.

C. Computer Science and Engineering

Computer science is often thought as being a field about building things. This applied aspect of computer science aligns very much with engineering. In fact, many computer science programs are in engineering colleges with the closest being computer engineering. Traditionally, there has been a distinct computer engineering field in the engineering space, where those interested in the ”hardware aspect” tended to gravitate towards engineering and the ”software aspect” associated with computer science, also known as software engineering. However, with the integration of software and hardware that computer science has been encompassing, the line is blurring with new areas such as autonomous vehicles, robotics, biometrics, sensors, and the Internet of Things.

[12]https://beta.nsf.gov/science-matters/when-science-meets-art-6-nsf-research-projects-turn-stem-steam

D. Computer Science and Mathematics

Computer science originated in mathematics especially with its early theoretical foundations. Although all of the necessary technology did not exist at the time, the first partially built computer, referred to as the Analytical Engine, laid the groundwork for many fundamental concepts in computing that are still used today[13]. The Analytical Engine was created by Charles Babbage, a mathematician. Several other mathematicians have contributed to theoretical computing including Kurt Gödel, Alonzo Church, Emil Post, Alan Turing, John von Neumann, and Claude Shannon. There are many branches within computer science that are built on a strong mathematical and statistical foundations such as AI, machine learning, data mining, data science, cybersecurity, networks, and algorithms.

E. Computer Science and the Arts

As mentioned earlier, the STEAM initiative was already underway to incorporate the arts prior to computer science becoming officially a part of STEM. Some applications of computing in the arts include automatic image captioning and art creation as well as pattern recognition in paintings and drawings [37]–[41]. In fact, the incorporation of computational methods in digital humanities is leading to a transformative shift in both the humanities and social sciences [42]. Some of these computational methods involve deep learning and word embeddings, please see Section IV for more information.

F. Computer Science

The previous subsections A-E provides a brief overview of computer science as a part of each of the classifications in STEM and STEAM. Computer science can also be regarded as its own discipline, which entails various sub-disciplines from AI to software engineering. In fact, it was the Computer Science in STEM Act of 2017, which upheld the recognition of computer science courses as an integral part of the standard secondary school curriculum [14].

IV. Evaluation of an AI Course Incorporating Course-based Research

In 2017, Lawrence Technological University (LTU) received a grant from HHMI for a new science education initiative challenging colleges and universities to increase their capacity to engage all students in science. LTU stepped up to the challenge with a pedagogical framework for incorporating course-based research experiences into the classroom. The educational framework in the College of Arts and Sciences at Lawrence Technological University extended to other colleges at the institution and anchors its education on the proposed Classroom-based Research Experience (CRE) model. All academic departments and programs across the college have adapted one or more courses to incorporate CRE, thereby ensuring every student receives research experiences as an integral part of their curriculum.

[13]https://www.britannica.com/technology/Analytical-Engine
[14]https://www.congress.gov/bill/115th-congress/house-bill/2305

The course selected for this study is in computer science entitled Text Mining and Analytics, an upper undergraduate course and a required course in the Bachelor of Science in Computer Science for the AI concentration. This course covers various machine learning methods and students gain hands-on experience with various machine learning libraries. The original course was designed and commenced during the Fall 2018 semester and will enter its sixth year in Fall 2023. Course-based research inclusion began in Fall 2020. The following sections elaborate on the original course design and the modification for incorporating course-based research using the research topic from Fall 2020 as an example.

A. Course Design (Original Course)

The course starts with an overview of key mathematical concepts from linear algebra and statistics with code application to get acclimated with the Python programming language. The key topics for the course entail data collection, text preprocessing, numeric representations for text, linguistic concepts, classification methods from statistical to machine learning, clustering methods, information retrieval, and extraction. The original core course outcomes are the following:

- Become conversant in the terminology of text mining and analytics.
- Learn and work with state-of-the-art tools for doing effective text mining and analytics.
- Learn and work with the various statistical and machine learning methods for gaining insight from text.
- Understand the various sources for obtaining data for text mining and analysis.
- Work with various API's and state-of-the-art methods for extracting and analyzing text from social media applications.

One of the reasons for the focus on social media applications is due to the abundance of data available in this domain. This could include data collection using available application programming interfaces (API's), web scraping, or accessing publicly available datasets for further study.

B. Course Design (Research-based Modification)

Collecting data from social media was a part of the initial course design making it amenable to social media research. Research in this space can be regarded as an interdisciplinary field with the humanities and social sciences. In addition, social media presents various ethical, political, legal, and social issues that have a liberal arts orientation. The course core outcomes retain the original objectives with an additional three, as follows:

- Develop an understanding in conducting research, project research development(with code repository), and research paper creation.
- Identify potential ethical, political, legal, or social issues.
- Contribute constructive feedback in the form of peer review for up to three classmate papers.

Incorporating research experiences into a course can range from one week to a full course immersion in research. The same topics are covered from the original course and four weeks are allocated to the research experience out of the 16 weeks for the semester. Over the course of four weeks the topics cover an overview to research, exploring research topics and literature review, understanding research design and methods, and creating the research paper. The following subsections elaborate on each of these topics covered during the research portion of the course:

1) Research Overview: Beginning week 10 of the semester, an overview of research is provided. The introduction of research at a later time in the semester is to allow ample time to build the foundation in the computational methods in text mining. During the first few months, students gain hands-on experience working with various API's and acquire programmatic experience with writing programs for text mining projects. During the research overview, published papers in text mining research are also discussed to analyze the various sections of a paper such as the abstract, introduction, etc.

2) Research Problem/Literature Review: To ensure a consistent and coherent learning experience for students, a research topic and problem is predetermined. One benefit of this approach ensures students are able to better learn from each other. Furthermore, having a preliminary literature review ready by the second week is important considering the condensed four week research experience. This is where students are provided with several accessible papers to get an understanding of the problem and related work. During the first year of transitioning the course to being course-based research, the topic selected was fake news detection. The initial literature review consisted of papers from computing and from media and psychology where students are introduced to concepts such as naive realism and confirmation bias.

3) Research Design/Methods: During the third week, an overview of research design and methods are provided to gain an appreciation of experimental design. Determining the type of data and its acquisition along with a careful study of the various papers from related works provides insight on various paths to proceed. One of the computational methods that is gaining ground in the digital humanities is the use of word embeddings where several of the papers that utilized them are presented in Section III-E. Fake news detection can be framed as a classification problem and considerations for the preliminary methodological approach involve the use of word embeddings and a neural network.

4) Research Paper Construction: The last week of the research experience pertains to the analysis of the results and writing up the paper. Fake news detection can be presented as a binary (i.e., yes or no) or a multi-classification problem (i.e., yes, no, possibly, indeterminate, etc.). The results are analyzed and presented using the traditional evaluation measure of precision, recall, and the weighted F1-score. For the actual construction of the paper, an overview to the LaTeX language and environment is provided. Students also gain experience in presenting their work and reviewing papers. In this process, each student acts as a peer reviewer, critically evaluating the work of up to three of their classmates.

C. *Course-based Research Evaluation*

The evaluations for the course were overall positive in that students enjoyed learning the process of research. Some of the comments are below:

> *Student 1:* "It has peaked my interest in an area of computer science that I didn't think was an achievable thing to learn for me. It developed my skills in a way that I don't think a traditional lecture course could have accomplished."
>
> *Student 2:* "It is definitely less difficult to learn than I thought, but still requires the utmost effort."
>
> *Student 3:* "I really liked the format of CRE courses and it made me feel more satisfied with what I have learned from the class. It also lets me do work that I am proud of to put on a resume and it lets me look into things that I am interested in doing in a career or outside projects."

One critical review expressed disappointment over the postponement of research activities to later in the semester. This poses a bigger challenge to computer science in general for course-based research for undergraduate students in computing. There are several foundational concepts that need to be in place as well as programmatic experience before introducing research. Specific to this course, the advantage of having the research introduction start later in the semester is that students are already exposed to several of the concepts from class lectures. For example, data collection and data partitioning are introduced in the course when using machine learning methods such as neural networks, which entails the random allocation of records to training, development, and testing datasets. In addition, evaluation metrics are already provided early on in the semester so minimal time is needed to review these concepts during the research part of the course. Generalizing to other computer science courses seems to suggest that there would be similar challenges in ensuring the suitable foundation is in place before beginning the research experience part of the course.

One of the promoted advantages of course-based research mentioned in the Introduction is that this type of pedagogical paradigm has shown to inspire students to complete their academic studies when research is introduced to students just beginning their academic studies. This is especially challenging for computer science majors where there is more prerequisite knowledge that must be in place before venturing into research, such as the necessary mathematics and an understanding of programming and algorithms. For the AI course evaluated, there are additional domain-specific concepts that are also needed to be in place before embarking on research in this space. Additional thoughts on this challenge as well as opportunities are provided in Sections V and Section VI.

It's worth mentioning that the research topic for Fall 2021 focused on sentiment analysis, while the research topic for Fall 2022 pertained to the detection of gender bias.

V. The Challenges of Course-based Research in Computer Science

The challenges of course-based undergraduate research experiences at the undergraduate level has been shown to have a positive impact on undergraduate students especially in the natural sciences where this pedagogical paradigm originated. As mentioned in the Introduction, the benefits are especially valuable for increasing women and underrepresented minorities in STEM. As for course-based research in computer science, the following questions were sought from the research literature and explored as separate subsections.

A. *Has course-based research resulted in the retention and graduation of undergraduate students in computer science?*

One of the challenges from the research literature in evaluating the success of course-based research in computer science is that there appears to be just aggregate reporting that is done [20]. That is, computer science is combined with other disciplines. This approach makes it difficult to ascertain the benefits of course-based research for specific populations. The primary reason for the data aggregation is due to the low representation of women and underrepresented minorities in computer science, which makes analysis not feasible due to statistical insignificance.

B. *Is course-based research accessible to lower-level undergraduate students in computer science?*

Interventions such as early research experiences have been identified to inspire students towards the study and pursuit of STEM [4]. One objective of course-based research is to incorporate it at the lower-level in an undergraduate curriculum to ensure a greater chance of student retention. This poses a challenge in computer science, due to the foundational knowledge that must be in place before research experiences can be embarked upon. Preliminary topics include an understanding of algorithms and programming, which are often a significant part of the lower-level undergraduate curriculum in computer science. Research begins with a question and it appears that the question-based nature of the natural sciences makes course-based research particularly accessible to students just beginning their university studies.

C. *Will course-based research increase enrollment in graduate education for computer science?*

Another critical success factor for course-based research is that exposure to research early on encourages graduate study in STEM. However, in some of the research literature, students may be less likely to pursue a graduate degree or a STEM graduate degree [23]. Furthermore, the research on students going on to pursue computer science graduate degrees is also inconclusive due to exclusion from reporting or aggregate reporting [23], [43]. In addition, the research literature has shown that graduate degree pursuit tends to be unlikely in computer science and engineering [21]. This is understandable since bachelor degrees in fields like computer science and engineering are sufficient for entering the job market. The

U.S. Bureau of Labor Statistics publishes 10 year projections of jobs in various careers and computing careers continue to show increasing growth. The labor bureau projected 705,200 annual average openings from 2018 to 2028. More than half of these projected openings are in the computer and information technology group, with software developers being projected to have the most job openings at 134,600 annually [15]. Worth noting, that a bachelors degree is sufficient for these computing jobs. Since the year 2000, the number of degrees awarded in STEM fields has increased, but there are labor shortages that continue to persist in computer science, data science, electrical engineering, and software development [16].

VI. The Opportunities for Course-based Research in Computer Science

Considering the challenges stated in the previous section, it would be advantageous to foster more interdisciplinary studies, promotion of dual degrees, increase of support networks specific to computer science, and measuring the effectiveness of course-based research specific to computer science. These opportunities are further elaborated on in the following subsections.

A. Supporting interdisciplinary programs and dual degrees with computer science

According to the U.S. Bureau of Labor, job openings in the life, physical, and social sciences are projected to be slow as stated in Section V Subsection C. Even if course-based research inclusion results in students going on to pursue graduate degrees in biology or chemistry, the likelihood of obtaining a job pales in comparison to jobs with a computing focus. However, the incorporation of bioinformatics has been beneficial in recruiting and retaining computer science students [44]. Computer-based genomics research has also been advantageous because it is data-driven and computationally intensive, fewer lab resources needed, experiments are repeatable, and results in attitudinal gains are similar to wet lab experiences with some gains in students taking more math and computer science courses [45]–[47]. The interdisciplinarity between the AI course evaluated for this paper and the humanities further deepens critical thinking especially with becoming more knowledgeable in discerning misinformation in social media due to the research topic in fake news detection.

B. Increasing support frameworks for course-based research with computer science focus

As mentioned in Section II, there are numerous support frameworks for course-based research especially in the biological sciences. The Genomics Education Partnership has already included support for bioinformatics with biology combined with computer science. Since it is still regarded as an emerging area, building early support frameworks for quantum computing would also be advantageous. That is, support frameworks combining physics with computer science especially since quantum computing has many applications such as cybersecurity and finance. Building support frameworks for digital humanities with a strong computer science foundation would also be beneficial with developing strong critical skills. Given the pervasive and influential role of social media in people's lives, it would be beneficial to establish support frameworks that encourage further research in this area.

[15]https://www.bls.gov/careeroutlook/2019/article/wages-and-openings.htm

[16]https://www.commerce.gov/news/reports/2017/03/stem-jobs-2017-update

C. Measuring effectiveness of course-based research in computer science

As noted in Section V Subsection B, it is unclear how effective course-based research is in the retention of students in computer science due to aggregate reporting, especially in regards to the impact for women and minorities. One approach would be to incorporate longitudinal studies, that is, measuring the effectiveness over time. Another approach would be to conduct a study across institutions that utilizes course-based research in their computer science courses.

VII. Conclusion

The implementation and evaluation of an AI course in text mining utilizing a course-based research inclusion benefited from an interdisciplinary approach. The challenge of detecting fake news on social media involves fields within both the social sciences and the humanities. Considering the ubiquity of computer science, interdisciplinary approaches for course-based research have the potential to involve most, if not all disciplines. This paper identified some key challenges but more importantly, the opportunities for course-based research in computer science, especially from an interdisciplinary perspective. Course-based research is a pedagogical paradigm that has been primarily utilized in the natural sciences with much success, made possible by numerous support frameworks, which typically have a biological focus. Funding the development of support frameworks in computer science that is comparable to those already present in the natural sciences would be especially advantageous and inclusive for all disciplines.

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