International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

Integrating Cancer Biology into Course-Based Undergraduate Research: A Structured Four-Year Curriculum for STEM Students

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Abstract: ***Course-based undergraduate research experiences (CUREs) are a proven pedagogical approach to enhance undergraduate science process skills, knowledge, and competency outcomes by implementing a course-based faculty-mentored undergraduate research plan. CUREs are budget-friendly teaching and training practices that address the shortage of apprenticeship-style laboratory opportunities resulting from resource constraints. Effective CUREs implementations enable every science, technology, engineering, and math (STEM) major in the course, department, unit, or school to engage in real-world research activities, as CUREs integrate seamlessly into required lecture and laboratory courses within the curriculum. All CUREs encompass opportunities for undergraduates to participate in discovery-based, collaborative, iterative research projects that are important to the scientific community and society. A greater understanding of cancer development and cancer progression remains a significant challenge for society, given the number of cancer-related deaths worldwide each year. Additionally, given the diverse types of cancers that affect men and women, as well as the potential anti-tumor proliferation strategies yet to be discovered, an exploration in cancer biology presents a unique opportunity for undergraduates to produce novel findings that may lead to publications contributing to the field. This article outlines a technique for faculty to facilitate the execution of a cancer biology CUREs project that involves all student classifications. The extent to which participation in CUREs enhances undergraduate career readiness factors warrants further investigation.***

Keywords: undergraduate research, cancer biology, STEM education, career readiness, pedagogy

1. Introduction

Undergraduate research experience is paramount to student development and enhances the ability to succeed in various occupational endeavors after graduation [1]. CUREs is a student-centered research training approach that integrates faculty-mentored, hypothesis-driven research opportunities into lecture or laboratory courses [2-4]. Research findings reveal that student participation in CUREs projects yields consistently positive outcomes, including increased self-efficacy, enhanced collaboration, a deeper understanding of the scientific method, and the development of research skills [5-6]. The reported student outcomes are consistent for STEM majors and non-STEM majors, suggesting that the utility of CUREs in improving career readiness outcomes extends to a large segment of college matriculants. STEM undergraduate career readiness refers to the extent to which students acquire knowledge, skills, and attitudes to pursue STEM careers aligned with their major field of study after graduation [7]. The purpose of this article is to present a structured framework for implementing cancer biology- focused CUREs to improve STEM undergraduate research engagement and career readiness. This article is significant as it addresses the lack of equitable research opportunities in undergraduate STEM education while contributing to the broader goal of preparing students for careers in cancer biology and biomedical research.

CUREs offers a solution to the challenge of introducing large numbers of students to the benefits of applying the scientific method and generating data from carefully designed research projects. Traditional laboratory course experiences typically involve student engagement in experimental activities, where students gain exposure to scientific equipment and procedures. In these engagements, students are almost sure to achieve the desired results because many students have performed the same or similar procedures documented in published laboratory manuals over several decades. In contrast, CUREs are genuine research projects where outcomes are not predetermined, consistent with graduate or workforce-level research environments. CUREs are characterized by five design components, including iterative, discovery-based, collaborative, research-driven, and societal relevance, making this valuable approach applicable to many scientific disciplines [8]. CUREs development strategies could involve a few course sessions (e. g., one module) or occupy an entire semester to complete the research study. More intricate and potentially more fruitful projects involve multiple classes over four years. Longer projects enhance student knowledge and ability to improve student scientific reasoning and analytical thinking [9]. Longer research times allow students sufficient time to resolve misconceptions and gain a deeper comprehension of experimental procedures and underlying scientific concepts. The duration of the CUREs project will determine the complexity of the research questions and methods. The research infrastructure (e. g., lab space, instrumentation, budget, expertise) will also determine the nature of research exploration.

Faculty developers may choose to form student research groups or provide each student with a different research topic that falls under the main research area. Faculty with access to large genomics (i. e., large-scale study of genes), proteomics (i. e., large-scale study of proteins), and metabolomics (i. e., large-scale study of metabolites) datasets derived from next-generation sequencing (NGS) and other technologies are encouraged to utilize molecular datasets for group projects or even individual research projects. NGS is a high-throughput molecular biology procedure that facilitates the determination

of nucleotide sequences for large amounts of nucleic acid material (e. g., DNA or RNA) in a shorter period than traditional sequencing methods [10]. NGS is useful for cancer biology and can rapidly detect genetic mutations responsible for uncontrolled cell proliferation and responses to chemotherapy. A basic NGS study designed to identify aberrant genes involved in carcinogenesis is the examination and comparison of healthy and cancerous tissues. Applications of NGS include methods such as whole genome sequencing, shotgun metagenomics sequencing, and targeted metagenomics sequencing. Acquiring large molecular datasets from novel experiments in cancer biology can be costly. However, using publicly available datasets and bioinformatics tools offers a cost-effective alternative. The search for free-use datasets and bioinformatics software will provide a vastly economical alternative. When using previously published molecular datasets from NGS protocols, ensure you obtain the necessary permissions to avoid intellectual property issues during the later stages of research and publication.

2. CUREs in Cancer Biology

Cancer is a devastating disease with complex symptomatology caused by uncontrolled cellular proliferation in the human body. Cancer is the second leading cause of death in the United States and a top ten cause of death worldwide [11-12]. Ongoing cancer research, implementation of cancer prevention strategies (e. g., diet, lifestyle), and the advent of new medical and diagnostic technologies are crucial to defeating cancer in all its many forms.

Oncoprotective Effects of Anti-Tumor Synthetic Peptides on Breast Cancer Cells

Anti-tumor synthetic peptides exert oncoprotective effects on several types of human carcinomas, although the molecular mechanisms underlying the effects are not entirely understood [13]. Anti-tumor synthetic peptides have a relatively high binding affinity for target molecules, demonstrate low cytotoxicity, and have low production costs. The proposed research project will explore the effects of anti-tumor synthetic peptides on BT-483 breast cancer cells. The objective is to evaluate the impact of synthetic peptides on oncogene expression, signal transduction pathways, and cytokine production in BT-483 cells. Gene expression of critical oncogenes or tumor-suppressor genes will be measured using next-generation sequencing (NGS) experiments. The modulation of cytokine secretion and signal transduction proteins will be analyzed using ELISA and Western blot protocols, respectively. The research question underlying the cancer biology CUREs is: What are the effects of anti-tumor synthetic peptides on the proliferation and molecular profiles of BT-483 breast cancer cells? It is hypothesized that experimental anti-tumor synthetic peptides will inhibit cellular proliferation and reduce the expression of oncogenes in BT-483 cells. NGS experiments, combined with bioinformatics analysis will provide a more detailed understanding of the molecular basis of key biological processes, such as cellular proliferation, cytokine secretion, and other cellular processes. Based on previous observations, anti-tumor peptides may stimulate the production of anti-proliferation molecules that negatively regulate the survival of breast cancer cells.

FRESHMEN
- Learn laboratory safety skills, research ethics, and information literacy skills
- Learn laboratory notebook documentation skills
- Perform computer-assisted background research using scientific databases (e.g., PubMed)
- Learn how to read and critically evaluate a scientific research article
- Perform peptide sequence alignment analysis using the Basic Local Alignment Search Tool (BLAST)
- Perform tricine-SDS-PAGE (sodium dodecyl sulfate-polyacrylamide gel electrophoresis) on peptide

SOPHOMORES
- Learn cell culture techniques
- Culture BT-483 human breast cancer cells
- Perform dose-dependent peptide studies on BT-483 cells
- Perform cell proliferation studies using the trypan blue exclusion test
- Learn the Western blot procedure
- Conduct Western blot procedure to determine STAT3, pSTAT3, and cyclin D1 levels in BT-483 cells

JUNIORS
- Perform assay for IL-6 secretion using the enzyme-linked immunosorbent assay (ELISA) in BT-483 cells
- Conduct Western blot procedure to determine IL-6 levels in BT-483 cells
- Learn the real-time PCR (RT-PCR) procedure
- Conduct RT-PCR procedure to determine IL-6 gene expression in BT-483 cells
- Learn scientific poster presentation concepts and construct a research poster
- Learn oral scientific presentation concepts

SENIORS
- Learn the NGS procedure and prepare peptide-treated BT-483 cell samples for NGS
- Perform the NGS procedure or send samples to NGS sequencing service
- Learn bioinformatics procedures and perform bioinformatics analysis on NGS data
- Present an oral research presentation
- Review the elements of a scientific research manuscript
- Construct and submit a research publication

Figure 1: Four-year cancer biology CUREs project outline.

From an incidence and mortality perspective, based on cancer statistics, men, on average, are the most susceptible to being diagnosed with cancer and dying from cancer compared to women. African Americans in general and African American men, in particular, are most vulnerable to being diagnosed with cancer and dying from cancer compared to other ethnic groups in the United States. Faculty are encouraged to design CUREs to explore cancer development, cancer progression, anti-tumor therapeutic strategies, cancer epidemiology, cancer genetics and epigenetics, cancer bioinformatics, cancer prevention, and psycho-oncology [14-16]. The diversity of major and minor topics associated with cancer biology opens the door for exciting interdisciplinary CUREs projects involving not only STEM students but also non-STEM students from several different academic departments. Figure 1 provides an example of a cancer biology CUREs project suitable for undergraduate students. The research project is presented as a four-year plan, starting with activities appropriate for Freshmen and gradually building in complexity to accommodate Juniors and Seniors.

3. Conclusion

The establishment of undergraduate research experiences for STEM students is critical to student academic and workforce success. CUREs are a cost-effective method for ensuring that students obtain essential research training. CUREs have the added benefit of being adaptable for small or large enrollment courses. Small enrollment courses create opportunities for the development of individual student projects. Formation of research groups is beneficial for large enrollment classes. Utilize course time, learning management system discussion boards, and virtual online meeting platforms to simulate weekly or bi-monthly laboratory meetings that take place in industrial and academic research centers. Embedding question-and-answer sessions and debriefing sessions throughout the research process will help students retain a deeper understanding of the scientific process. Faculty-student communication throughout the entire CUREs project is crucial for promoting meaningful student outcomes.

Allow time for the inclusion of a scientific communication assessment after completing the CUREs module or a multiple-course research project. A one-semester cancer biology-focused research project provides sufficient time for an end-of-semester in-class presentation as a capstone communication assessment. Consider integrating an oral presentation assessment for each course and a publication and poster session component for a multiple-year CUREs program, involving lecture and laboratory courses. Utilizing students as co-authors on research manuscripts enhances ownership of the project and improves career readiness outcomes.

Resume augmentation activities, such as writing peer-reviewed publications, can significantly improve STEM undergraduate students' chances of obtaining employment, entering graduate school, or securing graduate research assistant positions. Scientific communication events are essential resume augmentation strategies and improve students' academic and career self-efficacy. While cancer-related deaths for some types of cancer have attenuated globally, additional research may facilitate a greater reduction in the incidence of cancer and deaths caused by cancer in the future. Establishing and maintaining cancer biology research laboratory facilities is an expensive endeavor, which is why colleges and universities with cancer research facilities are unable to employ large numbers of students to investigate critical issues that may lead to new cancer treatments. Select cancer biology CUREs projects that leverage your institution's physical and human resources to enhance success.

The Classroom Undergraduate Research Experience (CURE) survey and the Undergraduate Research Student Self-Assessment (URSSA) should be employed using a pre-test and post-test design to test the efficacy of CUREs for undergraduates [17, 18]. Moreover, utilize questionnaires or traditional interviews to conduct a faculty perception analysis and extract potential areas for improvement to strengthen student outcome attainment.

Compliance with ethical standards

Acknowledgment
This work was supported by grants from the National Science Foundation (EES-2205612, EES-2232563, EES-2306512).

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