International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Review Article)

Check for updates

POGIL exercise exploring molecular biology

Lawrence O. Flowers *

Associate Professor of Biology, Department of Biological and Physical Sciences, Saint Augustine's University

International Journal of Science and Research Archive, 2025, 15(03), 1624-1628

Publication history: Received on 15 April 2025; revised on 23 June 2025; accepted on 25 June 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.15.3.1617

Abstract

The active learning student-centered teaching approach process-oriented guided inquiry learning (POGIL) is a stimulating peer-based pedagogical method gaining momentum based on reported students' outcomes that align with STEM undergraduate goals and objectives and job market competencies. Specific advanced topics in biology are intractable to many undergraduate students and require innovative, collaborative methods to produce desired learning outcomes. Chemistry instructors originally designed POGIL, and while biology-based POGILs are present in the literature, there is a limited amount of POGILs available in molecular biology. Thus, the current article illustrates a POGIL exercise that explores the central dogma, a fundamental principle in molecular biology. The central dogma of molecular biology provides a framework for gene expression processes and describes the flow of genetic information in living organisms. The central dogma describes how DNA nucleotides are transcribed into RNA nucleotides and translated into proteins. This seminal concept of molecular biology is critical to student understanding in introductory and advanced biological sciences courses. The POGIL exercise is organized based on the learning cycle model associated with inquiry-focused teaching techniques. The learning cycle model promotes gradual concept comprehension and real-world utilization. An increase in molecular biology POGIL exercises is required to improve student understanding and course grades in molecular biology or related disciplines. Examining the efficacy of using the current molecular biology POGIL exercise is necessary from the perspectives of undergraduate students and biology faculty to fortify POGIL usage at colleges and universities.

Keywords: POGIL; Central Dogma; Transcription; Translation; Gene Expression

1. Introduction

Data from undergraduate departments indicates that a large swath of college science, technology, engineering, and math (STEM) majors perform poorly in upper-level courses. Unsatisfactory student performance leads to reduced academic self-efficacy and poor grade point averages. These adverse outcomes ultimately affect student motivation and sometimes lead to STEM undergraduate attrition. Traditional lecture and summative assessment pedagogical approaches are becoming less beneficial to student knowledge growth and assessment. Yet, these methods are still widely used at many colleges and universities. A recent study showed that instructors had better teaching and learning experiences after incorporating student collaboration and active learning techniques [1]. Moreover, the data indicates that undergraduate students are more engaged in courses with reduced lecture periods, and in courses in which student interaction constitutes the primary technique utilized to build knowledge and conceptual foundations. In addition to creating more engaging educational environments, increased student interactions during the course through formal and informal group work better resemble 21st-century workplace settings, allowing instructors to use the instructional period to promote career readiness [2]. The use of active learning modalities such as problem-based learning (PBL) and process-oriented guided inquiry learning (POGIL) are preferred in today's classroom and report higher student satisfaction and higher grades [3-4]. The growth and utilization of POGIL in colleges and universities in STEM departments necessitates the development of quality POGIL exercises adaptable for STEM college classrooms.

* Corresponding author: Lawrence O. Flowers

Historically, POGIL was designed for chemistry disciplines to help students navigate the rigorous course content involving the conflation of concepts and calculations that are problematic to students exposed to introductory chemistry for the first time [5-6]. Recent data indicate that POGIL implementation can positively affect students' critical thinking, problem-solving skills, and cognitive learning outcomes [7-8]. It is important to note that meaningful POGIL experiences typically begin with a brief, approximately 15-minute lecture period in which the instructor conveys fundamental scientific information and discusses student objectives, time limits, submission procedures, instructor's role, reporting procedures, and student expectations before group POGIL interactions commence. Constructing an informative video posted on a learning management system (LMS) about specific STEM concepts with a mandatory quiz assessment is an excellent strategy before the first POGIL exercise to expose students to the content of interest. More detailed information on structuring formative assessments while implementing POGIL online has also been explicated [9]. POGIL is an inquiry-based process. Thus, question development when designing POGIL exercises is essential. Practical POGIL exercises contain quality visualizations (e.g., figures, schematics, flow charts, tables, concept maps, infographics). While there are an increasing number of POGIL exercises for science and non-science majors, except for a few examples, molecular biology POGIL exercises are scarce in the literature [10-12]. The development of molecular biology-centered introductory and advanced virtual labs, virtual reality immersive experiences, AI-focused innovations, and board games for science and non-science biology courses are desperately needed now to introduce more engaging ways of improving teaching and learning of the central dogma and paramount molecular biology concepts, theories, and historical seminal experiments that provide the informational foundation for many of the advances in medicine and biotechnology we enjoy today.

2. Central Dogma POGIL Exercise

The central dogma, gene expression, transcription, and translation are historically complex concepts for undergraduate students. The current POGIL exercise presents an inquiry-based scaffolding approach, driving students first to learn basic terminology and integrated concepts to facilitate the application of knowledge to real-world problems. Application questions may focus on drug development, biotechnology, and human disease. Application questions must reflect current issues and research inquiries investigated in active biomedical and biotechnology research labs and companies for maximal benefits. Exploring classical molecular biology theories and seminal experiments such as the Avery, MacLeod, McCarty Experiment and the Hershey and Chase Experiment are acceptable and potentially rewarding POGIL topics. Within the POGIL exercise, direct students to construct a concept map, flowchart, or process diagram linking pivotal concepts. Research studies have demonstrated that concept maps strengthen knowledge preservation objectives [13-14]. Following initial POGIL group work, each group's concept map could be presented in a public forum. The instructor can use the class concept map presentations to assess student understanding and correct misconceptions. The article's next section presents an example of a POGIL exercise designed to explore the central dogma.

3. Model 1: Central Dogma of Molecular Biology

The central dogma is a fundamental concept developed in the 1950s to describe the flow of genetic information from the nucleic acids deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) to proteins that occur in the process of gene expression (Figure 1A). Both prokaryotic cells (e.g., bacteria) and eukaryotic cells (e.g., human) adhere to the central dogma. The nucleic acids DNA and RNA are large molecules made of nucleotides. Nucleotides have three components: sugar, phosphate, and nitrogenous base (e.g., purine or pyrimidine). DNA is a double-stranded molecule (double helix), while RNA is a single-stranded molecule. DNA replication occurs in the cytoplasm in prokaryotes and the nucleus in eukaryotes. The nitrogenous bases in DNA are adenine (A), guanine (G), cytosine (C), and thymine (T). The nitrogenous bases in RNA are adenine, guanine, cytosine, and uracil (U).

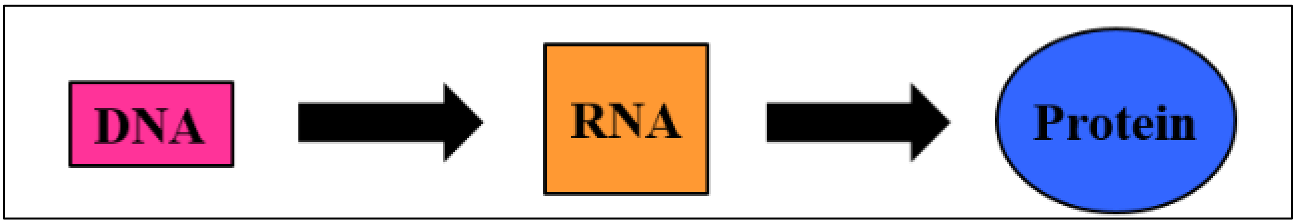

Figure 1A Schematic diagram of the central dogma

Questions

- What is the central dogma of molecular biology?
- Explain the difference between DNA and RNA and purines and pyrimidines.
- What is the significance of understanding the central dogma?

Gene expression is the transformation of genes (DNA) into messenger RNA (mRNA) and functional products (e.g., proteins, non-protein coding RNA). mRNA determines the precise amino acid sequence in proteins. Proteins are biological molecules consisting of chains of amino acids and perform essential human functions, including enzymatic metabolic reactions, muscle contractions, immune defenses, chemical communication, molecular transport, and structural support. Common non-protein coding RNA molecules include ribosomal RNA (rRNA), transfer RNA (tRNA), microRNA (miRNA), and small interfering RNA (siRNA). Gene expression consists of two primary stages: transcription and translation. Transcription involves the conversion of DNA to RNA, and translation consists of converting mRNA to protein. Translation or protein synthesis occurs in the ribosomes. Ribosomes consist of a small subunit and a larger subunit. In prokaryotes, DNA is located in the cytoplasm; in eukaryotes, DNA is located in the nucleus. Transcription and translation occur in the cytoplasm of prokaryotes. In eukaryotes, transcription occurs in the nucleus, and translation occurs in the cytoplasm. Gene expression mechanisms impact the phenotype (e.g., physical traits) of living organisms. For example, human phenotypes include skin color, height, eye color, and weight. Due to the physiological significance of proteins in the body, gene expression is a highly regulated process.

Questions

- What are the two stages of gene expression?
- What is the difference between transcription and translation?
- Explain the cellular locations of gene expression events for prokaryotic cells and eukaryotic cells.
- What is the function of ribosomes in gene expression mechanisms?
- List some major functions of proteins in the human body.
- Explain how gene expression mechanisms impact human phenotypes.
- How can understanding gene expression mechanisms impact the biomedical and biotechnology industries?

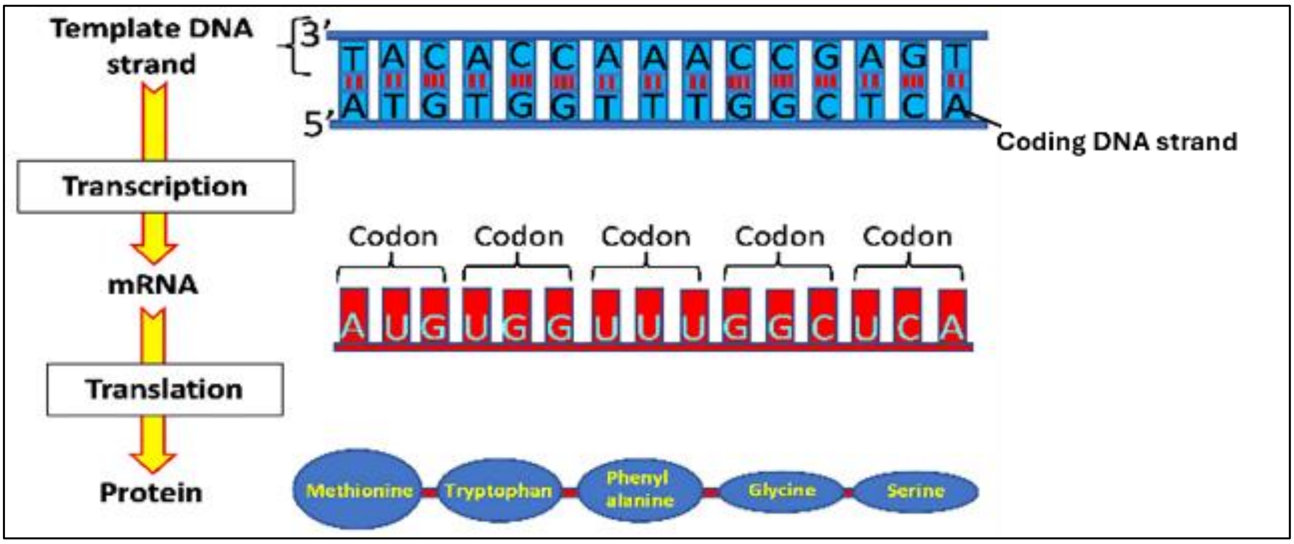

Figure 1B Schematic diagram of gene expression

Figure 1B depicts gene expression in greater detail, illustrating the DNA double helix and single-stranded mRNA molecule. DNA molecules contain a template DNA strand (3' to 5') and a coding DNA strand (5' to 3'). The template strand provides the nucleotide pattern to synthesize an mRNA molecule during transcription. Subsequently, the mRNA molecule provides the message or precise instructions cells need to construct a specific protein. Each mRNA molecule contains three nucleotide sequence domains called codons. tRNA molecules attached to a unique amino acid and bind to codons sequentially, utilizing codon-anticodon binding to manufacture a protein molecule. Helicases, RNA polymerases, and topoisomerases are essential enzymes required for transcription. Several enzyme types, such as aminoacyl-tRNA synthetases and peptidyl transferase, are also necessary for translation to proceed. Problems in gene expression, either during transcription or translation, can produce deleterious functions that may lead to disease and death. Cystic fibrosis, cancer, and Alzheimer's disease are three major human diseases in which defective proteins play a role in disease progression. For example, the formation of cancer cells or carcinogenesis may begin due to malfunctions in gene expression mechanisms. Abnormal proteins that affect cell division processes in the human body are typically the leading cause of carcinogenic transformations.

Questions

- What is the difference between the template DNA strand and coding DNA strand?
- Discuss the major events that occur during transcription and translation in cells.
- What is the significance of codon and anticodon pairing during translation?
- Discuss the role of the protein coding RNA molecule mRNA and non-protein coding RNA molecules rRNA, tRNA, and miRNA in prokaryotic and eukaryotic cells.
- Explain the function of helicases, topoisomerases, and RNA polymerases in transcription. Explain the function of aminoacyl-tRNA synthetases and peptidyl transferase in translation.
- Explain how problems with gene expression mechanisms can lead to human cancer.
- Construct a concept map. Identify key ideas presented in the POGIL exercise.

4. Conclusion

Molecular biology studies the synthesis, structure, and function of biological molecules with special emphasis on processes mediating the construction and regulation of DNA, RNA, and proteins in living cells. The central dogma of molecular biology states that DNA is transcribed into RNA, and RNA is translated into protein. Understanding the central dogma is critical to understanding more complex topics in molecular biology. Students often find discussions regarding the central dogma and gene expression mechanisms confusing. It is believed that employing an active learning approach involving student collaboration, such as POGIL, will facilitate knowledge generation that may improve long-term comprehension and mastery as measured by exams and other assessments. POGIL exercises are applicable for both science majors and non-science majors. Exercises should provide enough background information in the first section of the exercise (e.g., model) to allow students to engage in meaningful discussions to answer questions designed to help students build essential knowledge. Additionally, including highly visual figures, flow charts, images, and descriptive tables will enhance student engagement. Most POGIL exercises involve individual group reporting. However, for particularly inscrutable topics such as molecular biology principles, it may be prudent to make time for the entire class to reach a consensus on key ideas. Due to the lack of quality POGIL exercises focusing on molecular biology, this article hopes to stimulate the development of POGIL exercises in molecular biology, genetics, and bioinformatics. STEM departments would benefit from POGIL training workshops [15]. Effective POGIL training program evaluations and educational research studies examining the efficacy of POGIL workshops, exercises, and teaching methods will improve teaching skills and student outcomes.

Compliance with ethical standards

Acknowledgments

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

References

[1] Nelson D, Bonem E, Fitzsimmons J. Instructor perceptions of teaching in a new active learning building. Journal of Learning Spaces. 2023; 12: 1-12.

[2] White E, Washington E, Flowers L. STEM career readiness at HBCUs to enhance occupational diversity. Journal of Education & Social Policy. 2021; 8: 34-38.

[3] Eberlein T, Kampmeier J, Minderhout V, Moog R, Platt T, Varma-Nelson P, White H. Pedagogies of engagement in science: A comparison of PBL, POGIL, and PLTL. Biochemistry and Molecular Biology Education. 2008; 36: 262-273.

[4] Rodriguez J, Hunter K, Scharlott L, Becker N. A review of research on process oriented guided inquiry learning: Implications for research and practice. Journal of Chemical Education. 2020; 97: 3506-3520.

[5] Moog R. Origins of POGIL: Process-oriented guided inquiry learning. In POGIL. 2023; pp. 23-41. Routledge.

[6] Jummaro M, Mulyani S, Widhiyanti T. Review of chemistry learning strategy based on process oriented guided inquiry learning (POGIL). KnE Social Sciences. 2024; 9: 151-161.

[7] Diniyyah M, Susilo H, Balqis B, Sudrajat A. Improving critical thinking and problem-solving skills through POGIL combined with digital mind map. Journal of Biological Education Indonesia. 2022; 8: 275-286.

[8] Ariyati E, Susilo H, Suwono H, Rohman F. Promoting student's habits of mind and cognitive learning outcomes in science education. Journal of Biological Education Indonesia. 2024; 10: 85-95.

[9] Purkayastha S, Surapaneni A, Maity P, Rajapuri A, Gichoya J. Critical components of formative assessment in process-oriented guided inquiry learning for online labs. Electronic Journal of e-Learning. 2019; 17: 79-92.

[10] Mulligan E. Use of a modified POGIL exercise to teach bacterial transformation in a microbiology course. Journal of Microbiology & Biology Education. 2014; 15: 30-32.

[11] Bénéteau C, Guadarrama Z, Guerra J, Lenz L, Lewis J, Straumanis A. POGIL in the calculus classroom. PRIMUS. 2017; 27: 579-597.

[12] Jin G, Bierma T. STEM for non-STEM majors: Enhancing science literacy in large classes. Journal of College Science Teaching. 2013; 42: 20-26.

[13] Nesbit J, Adesope O. Learning with concept and knowledge maps: A meta-analysis. Review of Educational Research. 2006; 76: 413-448.

[14] Jackson A, Barrella E, Bodnar C. Application of concept maps as an assessment tool in engineering education: Systematic literature review. Journal of Engineering Education. 2024; 113: 752-766.

[15] Stegall S, Grushow A, Whitnell R, Hunnicutt S. Evaluating the effectiveness of POGIL-PCL workshops. Chemistry Education Research and Practice. 2016; 17: 407-416.