Engaging Students in Exploring the Effects of Endocrine Disruptors Through Molecular Storytelling

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BIOME 2025, WIP Session 1

This project is supported by the National Science Foundation - DBI 2018884

Abstract:

Context: A water bottle that is BPA free, a shampoo that is parabens free - we see these labels on products we buy and in various multimedia. We have developed an engaging environmental toxicology lesson to deepen students' understanding of how this class of synthetic and natural chemicals interfere with and disrupt hormonal functions, hence the name Endocrine Disruptor Chemicals (EDCs). The lesson uses a molecular storytelling approach to illustrate the biological mechanisms and real-world consequences of endocrine disruption in molecular detail.

Molecular Case Study: The example that is currently developed focuses on how a specific EDC (called DDT) and how it interferes with the function of the estrogen receptor. Students will learn about the structure and function of estrogen receptors in biology. They will investigate the impact of DDT binding on endocrine function. By combining narrative techniques with scientific inquiry, the lesson engages students in critical thinking about environmental exposures, regulatory challenges, and public health implications.

Modeling to make new case studies: Similarly, a broad range of other EDCs (e.g., BPA, propylparaben), and their impacts on endocrine function can also be examined. Each molecule's story will begin by learning how and why these molecules were created. Students will visualize and describe the chemistry of the EDCs, the biological molecule targeted by them, visualize how the EDC interacts with the target molecules, and explain how the biological functions of the targeted molecule are altered. Through the analysis of molecular models and molecular pathways students gain insight into how environmental toxicologists study molecular-level interactions can that impact ecosystems and human health, ultimately informing personal and societal decision-making. We invite educators to pilot these lessons in their classes, as is or adapt them to meet specific curricular needs. We also welcome collaboration in adding more molecular stories about EDCs to this collection and developing them into open educational resources.

Background: About Endocrine Disruptor Chemicals (EDCs)

- Molecules like DDT (used in mosquito control), BPA (found in plastics), parabens (preservatives, are found in a wide variety of personal care and cosmetic products) and phthalates (also found in plastics) mimic endogenous hormones such as estrogen and testosterone.
- EDCs bind to their receptors to disrupt hormone signaling - e.g., DDT, BPA, and Parabens all bind to estrogen receptors (ERα and ERβ), leading to inappropriate activation.
- Normally estrogen receptors bind to estrogen and travel into the cell nucleus and regulate the activation of specific genes. EDC binding to these receptors can lead to inhibition of specific gene transcription.
- Despite their importance, most biology and toxicology curricula lack molecular-level explanations of EDC action. This results in a conceptual gap in student understanding of how small changes in molecular structure can produce major physiological effects.

Pedagogical Rationale

- This project supports investigative learning where students form hypotheses about molecular interactions, test predictions with models, and reflect on environmental consequences.
- 3D molecular visualization helps students explore structure-function relationships.
  - By manipulating molecular models, students can compare the shape, polarity, and binding interactions of EDCs and natural hormones with their receptors.
  - This approach helps students build mental models of how molecular structure influences biological function.
  - It bridges abstract chemical concepts with tangible biological outcomes, improving spatial cognition which is a critical skill in toxicology. In this educational modules students are prompted to explore how and why molecular shape and chemical properties influence binding to receptors or enzymes.

A Molecular Case Study

Title: Imposter Molecules : How DDT Mimics Estrogen in the Human Body

Hook:

DDT, or dichlorodiphenyltrichloroethane, was first used in the 1940s and became known for its success in reducing malaria cases worldwide. However, long-term environmental and health concerns—such as reproductive and developmental effects—led many countries to restrict its use beginning in the 1970s. While many South American countries have reduced or banned the use of DDT, nations such as Colombia, Brazil, Peru, Venezuela, and Ecuador continue to use it in specific regions to control malaria outbreaks. These efforts follow World Health Organization (WHO) guidelines for indoor residual spraying where alternative methods are less effective.

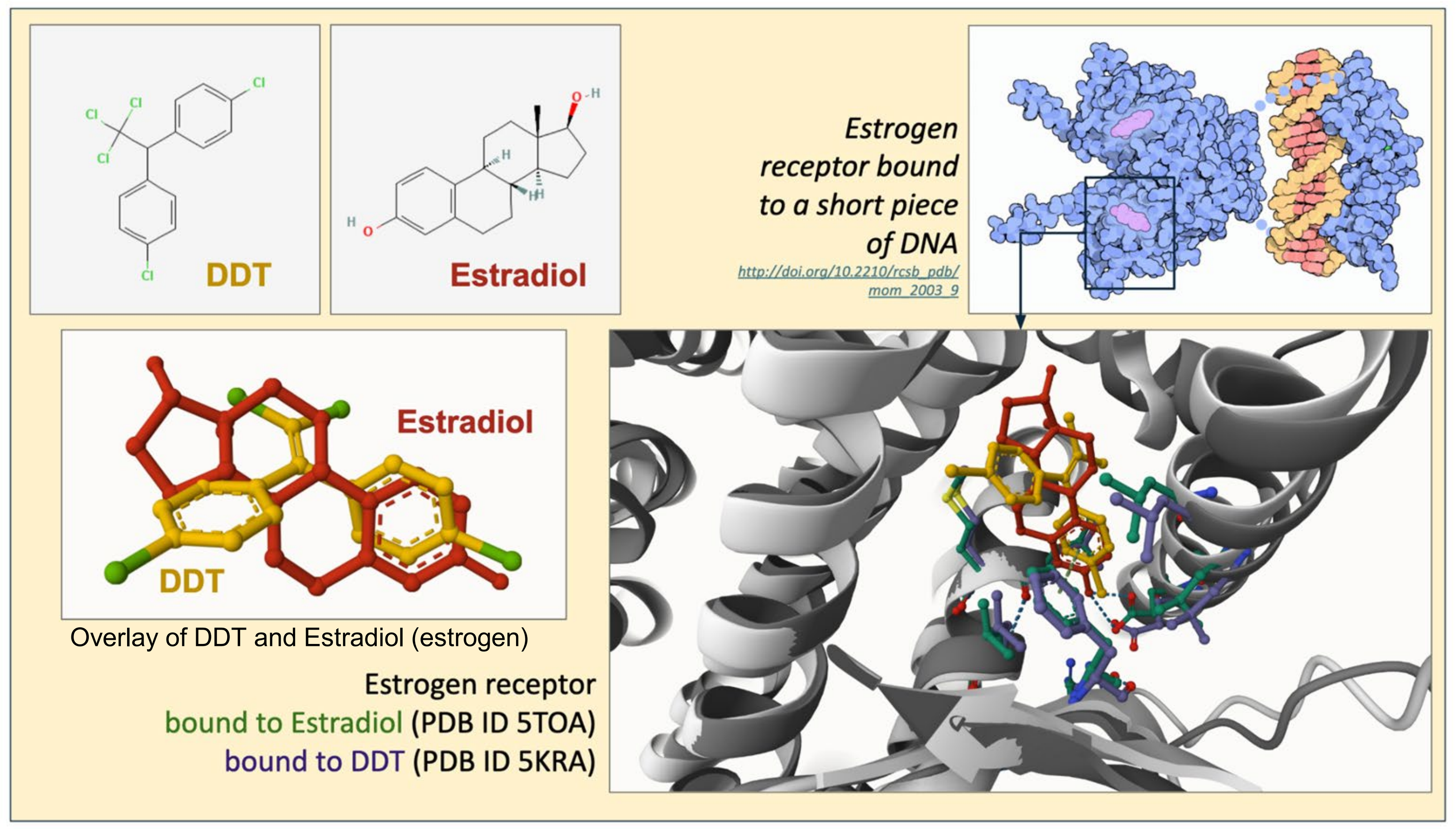
A group of researchers conducted a cross-sectional study on a remote island in Bolivia, where DDT was still being used for malaria control (Arrebola et al., 2016). They studied 200 mother–infant pairs immediately after delivery. The umbilical cord blood serum was collected to measure exposure to two DDT-related chemicals:

- o,p′-DDT (an estrogenic compound)
- p,p′-DDE (an anti-androgenic breakdown product of DDT)

The research found that the levels of p,p′-DDE levels were *negatively associated* with gestational length—i.e., as the levels increased, babies were born earlier. While changes in the o,p′-DDT levels showed *no statistically significant* effect, though previous studies have linked it to reduced birth weights and shorter pregnancies.

Research Question:

Is there a link between prenatal exposure to DDT and negative birth outcomes in South American communities still using the chemical? What type of information is needed to confirm that DDT can cause endocrine disruption?



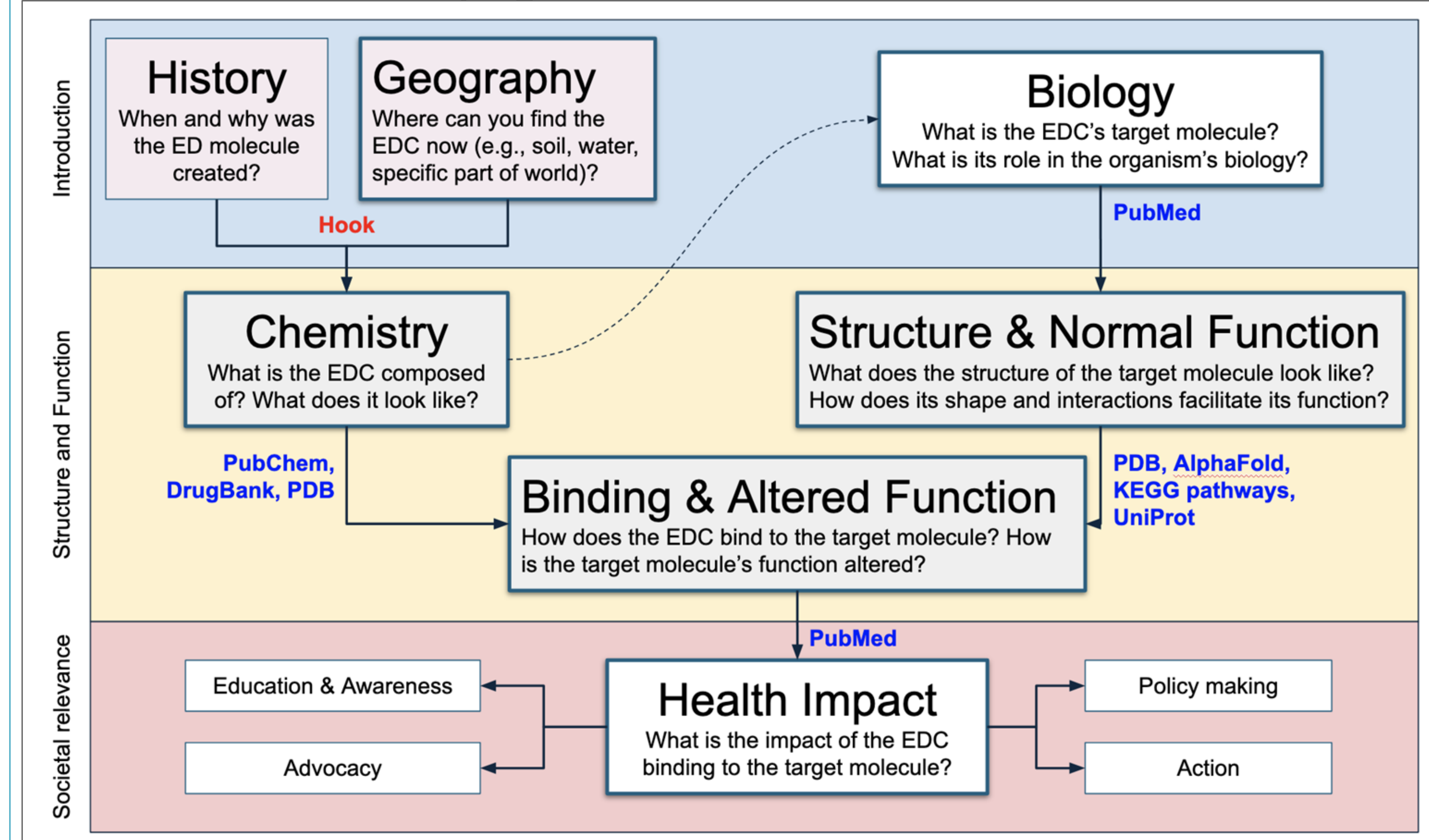
Overlay of DDT and Estradiol (estrogen)

Estrogen receptor
bound to Estradiol (PDB ID 5TOA)
bound to DDT (PDB ID 5KRA)

Learning Outcomes:

- Visualize DDT and estradiol in 2D and 3D.
- Understand the structural basis of hormone-receptor binding.
- Analyze how molecular mimicry allows endocrine-disrupting chemicals to interfere with human hormonal signaling.
- Interpret structure-function relationships using molecular diagrams.
- Compare structural features related to hormone receptor binding.
- Discuss how DDT could mimic estrogen in the human body.
- Predict biological and health outcomes based on structure.

A Framework for Developing More Case Studies



A schematic showing key elements for developing new case studies about EDCs. For any ED molecule, the case study needs 3 sections (as shown in the figure above) - an Introduction section (blue), a structure function exploration section(yellow), and a societal relevance section (red).

Instructional Tools & Strategies

- Case-based learning on real-world topics can engage students in learning about
  - several hormone-altering chemicals (https://www.ewg.org/sites/default/files/2022-08/EWG_Guide_EDC-08.22_C01.pdf)
  - analysis of receptor binding
- This approach integrates core competencies in STEM education - such as
  - data visualization and interpretation,
  - systems thinking, and
  - argumentation based on evidence.
- Activities meet the Vision and Change recommendations for undergraduate biology education and NGSS performance expectations.
  - include peer collaboration,
  - model comparison, and
  - guided reflection, which

An invitation

Use the framework and resources presented above to create new case studies and/or adapt draft case studies to meet the needs of your course/curriculum.

Reach out and email Brian Shmaefsky (Brian.R.Shmaefsky@lonestar.edu) to ask question, develop new case studies or adapt existing ones,

References

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Acknowledgements: Thanks to Molecular CaseNet colleagues and participants of the Fall 2024 and Spring 2025 BioQuest Faculty Mentoring Network members.