Foundational Concepts in Undergraduate Toxicology – Applying Vision & Change to the Development of Core Competencies and Learning Objectives for an Undergraduate Toxicology Course

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ABSTRACT

In 2011, the National Science Foundation and American Association for the Advancement of Science produced the "Vision and Change Report" (visionandchange.org) which sought to improve education in undergraduate biology for all students by defining Core Concepts: Evolution; Structure and Function; Information Flow, Exchange, and Storage; Pathways and Transformations of Energy and Matter; and Systems. Vision & Change has had a major impact on undergraduate biology education; scientific societies have created and adopted their own Core Concepts for their undergraduate courses and communicated them via peer-reviewed publication. Appointed by the Undergraduate Education Subcommittee and composed of experienced undergraduate educators, the goal of the Learning Objectives Work Group is to implement Vision & Change for undergraduate toxicology and to communicate its findings internally within the Society of Toxicology and externally via collaboration with multidisciplinary organizations including Course Source (coursesource.org), the Life Science Teaching Resource Collection (lifescitrc.org), and peer-reviewed publication. Data were collected and analyzed from more than 20 undergraduate toxicology syllabi from across the United States together with several undergraduate textbooks to quantify themes taught in all toxicology-related courses. A Learning Framework with Five Core Concept themes compatible with Vision & Change was developed: Evolution; Pathways and Transformations of Energy and Matter; Systems Toxicology; Biological Information; and Risk Assessment. Society Learning Goals for these five Core Concepts and Learning Objectives associated with each Society Learning Goal were also created. Publication of this framework alongside those of the other major life science disciplines will facilitate the development and sharing of evidenced-based teaching materials for toxicology educators throughout the world and expand toxicology's impact to a broader audience.

INTRODUCTION

Course Learning Objectives are goals around which a course is organized, defining the demonstrable knowledge and skills that a student should learn having taken the course. Well-crafted Learning Objectives enable consistency in curriculum and enable sharing of content by faculty members from different institutions.

The Learning Objectives Work Group analyzed syllabi submitted by undergraduate educators via the Undergraduate Education Network (UEN) of the SOT and performed an analysis of trends in course content for a variety of undergraduate toxicology courses, including those focused on human health, environment, public health, industrial hygiene, forensics, and pharmacology. Although several courses have specialized content specific to their subdisciplines, consistent themes emerged from the courses that enabled the Work Group to define five principal Core Concepts. This work focuses on the shared themes of the diverse courses within toxicology with a recognition that faculty members will choose specific learning objectives for emphasis, depending on the type of course they are teaching.

In addition to working within the discipline of toxicology, Work Group members investigated course learning objectives that were produced by other scientific societies for their own undergraduate courses or majors. A common thread was their reliance on the National Science Foundation's landmark report entitled, "Vision & Change in Undergraduate Biology Education: A Call to Action", published in 2011. This report has served as the foundation for the development of consistent, interdependent learning objectives in life science. Based on this finding, the Work Group used Vision & Change as the framework for the development of learning objectives for toxicology. The overall goal of this group is to present a uniquely-designed coherent framework of objectives for developing undergraduate toxicology courses within an institution, taking into consideration the foundational sciences that support it.

CORE CONCEPTS FOR UNDERGRADUATE TOXICOLOGY

CORE CONCEPTS IN UNDERGRADUATE TOXICOLOGY

- Evolution – Evolution drives the interplay between toxicants/toxins and xenobiotic defense mechanisms and justifies the use of model organisms.
- Biological Information – Differences in genomes and environmental exposure drive differences in susceptibility and responses to toxicants
- Risk Assessment and Risk Management – Epidemiology and historical events together with science drive regulatory responses to risk to individuals and the environment
- Systems Toxicology – Toxicants affect cellular, organ, individual, and ecological systems
- Pathways and Transformations for Energy and Matter – Interaction of toxicants with organisms are described through paradigms in dose response, ADME, and toxico-/pharmacokinetics

Draft Core Concepts Produced by the Learning Objectives Work Group of the SOT produced in 2017-2018.

Figure 1. The Core Concepts of Undergraduate Toxicology. Core Concepts are the five emergent themes critical to undergraduate coursework in toxicology that emerged from analysis of diverse syllabi of undergraduate toxicology courses.

SAMPLE UNDERLYING CONCEPTS IN FOR THE CORE CONCEPT "EVOLUTION"

	2nd	3rd	4th – Sample Learning Objectives
Model Organisms for Toxicology	Describe features of ideal model systems		• Explain how large numbers of offspring are beneficial for ideal model systems. • Explain how ease of manipulation is important for an ideal model system. • Describe how use of a common model system contributes to reproducibility across laboratories. • Describe how ideal model systems have similarities to humans. • Explain how some model organisms are selected for organ-specific similarity to humans. For example, eyes of rabbits or skin of pigs. • Describe which ideal model organisms have similar xenobiotic metabolism systems to humans. • Explain why cost of maintenance, large number of offspring, and simplicity are characteristics of ideal model systems.
	Describe common model systems, including *Drosophila*, *C. elegans*, mouse, rat, and non-human primate		• Describe which model systems have similar metabolic pathways to humans. 28931683 • Describe the historical importance of each common model system. • Describe the advantages of simple animal model systems compared with cell culture or other *in vitro* approaches. • Describe how genetic similarities between Drosophila and humans make it a valuable model system. 29056683. • Describe how *Drosophila* models metal toxicity in humans 28684721 • Describe the use of *C. elegans* as a model for viral host interactions 28931683 • Discuss the history of the development of *C. elegans* as a model organism 28326696
	Describe how evolution is fundamental to the use of model systems in toxicology		• Describe the relationship between genetic phylogeny and similarity in physiology in terms of model systems for toxicology. • Describe the role of evolution in comparisons of genes across species. • Describe how evolution provides the rationale that animal studies are translatable to humans.
	Describe ethical reasons for using model organisms		• Describe how ethical issues impact the types of experiments that can be performed on humans. • Describe how lack of data in humans supports the use of animals in research. • Describe how reduction, refinement, and replacement (the three R's) ensure the best ethical treatment of animals used in research. • Describe the role of the Institutional Animal Care and Use Committee (IACUC) guides research at local institutions, ensuring the ethical treatment of animals.

Figure 2. Examples of 2nd, 3rd, and 4th level learning objectives for the Core Concept "Evolution". Each of the five principle Core Concepts (1st level learning objectives) is broken down into three additional categories. The 2nd level defines a generic topic, in this example, "Model Organisms for Toxicology". The 3rd level learning objectives define specific abilities that a student should be able to perform upon finishing the course. Finally, the 4th level learning objectives provide specific concepts and case studies that inform the 3rd level. The 4th level objectives are meant to be examples, not a comprehensive list. The entire set of Learning Objectives is available at the hyperlink listed above. We invite commentary on the document by 6/30/18.

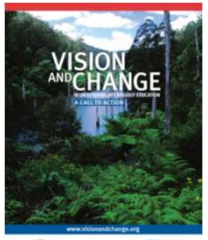

Figure 3. The Vision & Change Report, published in 2011, provided the foundation for change in undergraduate Biology courses. V&C has since spread to other undergraduate courses which can be found at coursesource.org

Introductory Biology

- Evolution – The diversity of life evolved over time by processes of mutation, selection, and genetic change
- Structure and Function – Basic units of structure define the function of all living things
- Information Flow, Exchange, and Storage – The growth and behavior of organisms are activated through the expression of genetic information in context
- Pathways and Transformations of Energy and Matter – Biological systems grow and change by processes based upon chemical transformation pathways and are governed by the laws of thermodynamics
- Systems – Living systems are interconnected and interacting

Produced by the 2011 Vision and Change Committee

Biochemistry and Molecular Biology

- Energy is required and transformed in biological systems
- Macromolecular structure determines function and regulation
- Information storage and flow are dynamic and interactive
- Discovery requires objective measurement, quantitative analysis, and clear communication
- Evolution
- Homeostasis

Produced by the American Society for Biochemistry and Molecular Biology

Figure 4. The format of the Toxicology Core Concepts was based on best practices aligned with Vision & Change. The Core Concepts of undergraduate Introductory Biology "were organized around themes of inquiry in modern biology education. These concepts provide a set of overarching principles that are important throughout the living world, and their use in teaching biology lends meaning to the multitude of facts that a student encounters in any undergraduate biology course." Subsequent to the Vision & Change report, 11 other academic societies have worked to develop Core Concepts for their own disciplines, each building upon the Core Concepts of the previous courses. These learning objectives are hosted at coursesource.org.

SOT Continues to Add Resources for Undergraduate Educators:

- **15 Eminent Toxicologist lectures with associated learning materials**
- **Recorded professional development webinars targeted at undergraduate educators to assist in everything from teaching to professional development**
- **Syllabi and other course materials from around the world**
- **The Undergraduate Educator Network on ToXchange**

All available online at www.toxicology.org/education

PROCESS FOR THE DEVELOPMENT OF LEARNING OBJECTIVES

DRAFT DOCUMENT IS AVAILABLE NOW FOR PEER REVIEW

https://www.toxicology.org/education/docs/SOT-Toxicology-Learning-Objectives.pdf
OR http://bit.ly/2HeRFmf

ANTICIPATED QUESTIONS

➢ What if my Toxicology course does not have Biochemistry and Molecular Biology or Anatomy and Physiology as a prerequisite? *An educator might utilize the Biochemistry and Molecular Biology framework available at coursesource.org to inform the teaching of their Toxicology course, adding material as necessary.*

➢ Is this framework meant to cover every undergraduate Toxicology course? For example, what about Forensic Toxicology or Ecotoxicology? *This framework was designed as the core for all undergraduate Toxicology courses, but an educator might emphasize some topics over others and add material depending on the nature of their course.*

➢ Can I provide some feedback? *Yes, please sign up to act as a peer reviewer. We will contact you shortly after the meeting with instructions for providing feedback.*
www.surveymonkey.com/r/T789ZK3

REFERENCES

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