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Forum

FORUM

Society of Toxicology Develops Learning Framework for Undergraduate Toxicology Courses Following the Vision and Change Core Concepts Model

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ABSTRACT

The Society of Toxicology announces the development of a Learning Framework (https://www.toxicology.org/education/docs/SOT-Toxicology-Learning-Objectives.pdf) for undergraduate toxicology that will facilitate the development and sharing of evidence-based teaching materials for undergraduate toxicology educators throughout the world. This Learning Framework was modeled on the "Vision and Change Report" (www.visionandchange.org), an effort of the National Science Foundation and American Association for the Advancement of Science defining Core Concepts and Core Competencies to inform undergraduate biology course design. Vision and Change (V&C) has gained national acceptance, becoming a foundation for 14 upper-level courses designed by professional life science scientific societies. The undergraduate toxicology Learning Framework includes 5 Core Concepts aligned with V&C that encompass the discipline of toxicology: Evolution; Biological Information, Risk and Risk Management; Systems Toxicology; and Pathways and Transformations for Energy and Matter. Underpinning the Core Concepts are Level 2 Toxicology Concepts, which are broad disciplinary categories, Level 3 Learning Objectives, which address specific learning goals, and Level 4 Example Learning Objectives and Case Studies, which provide examples of how content might be taught. Syllabi from more than 20 undergraduate toxicology courses and several undergraduate toxicology textbooks were surveyed to determine toxicology-related Learning Objectives. From these, undergraduate educators can design courses tailored to their institutional needs by selecting a subset of Learning Objectives. Publication of a Learning Framework for toxicology will enable integration into other disciplines and facilitate the development and sharing of evidenced-based teaching materials for toxicology to educators in allied disciplines. Ultimately this will expand toxicology's impact to a broader audience.

Key words: education; Vision and Change; learning objectives; undergraduate; core concepts; evidence-based teaching practice.

The Society of Toxicology (SOT) has long recognized the importance of undergraduate toxicology education to the toxicology career pipeline. SOT began by sponsoring multiple forums on undergraduate education in toxicology, leading to the establishment of the Undergraduate Education Subcommittee (UGSC) of the Education Committee (reviewed by Barchowsky *et al.*, 2012). In recent years, there have been regular Education-Career Development sessions at the annual meeting that focus on undergraduate education, and include programs on undergraduate research, research-based approaches to teaching effectiveness, and careers for toxicologists at primarily undergraduate institutions. SOT also sponsors numerous activities and awards for undergraduates, including the highly successful Undergraduate Diversity Program and Sunday Undergraduate Education Program.

SOT recently reorganized education activities into 2 committees: the Faculty United for Toxicology Undergraduate Recruitment and Education (FUTURE) and the Education and Career Development Committee (ECDC). FUTURE is tasked with the recruitment, retention, training, and education of undergraduates interested in toxicology, initiating and facilitating programmatic activities for both undergraduate students and educators in the discipline of toxicology. For students, these include the ToxScholar program which recruits guest lecturers to speak at institutions with minimal exposure to toxicology, travel awards for undergraduates to attend the annual meeting, undergraduate internships, and activities at the annual meeting for the undergraduate students. For undergraduate faculty, FUTURE facilitates the Undergraduate Educator Network online community of practice at ToXchange (www.toxicology.org), Research and Professional Development Grants for undergraduate educators, continuing education webinars, maintenance of toxicology teaching resources at the Life Science Teaching Resource Collection (www.lifescitrc.org) and Course Source (www.coursesource.org), and the Eminent Toxicologist lecture series, which provides recorded guest lectures and associated educational materials free of charge online.

Undergraduate toxicology programs remain somewhat rare, however, in part because many undergraduate-focused institutions lack both sufficient faculty and specialized coursework in toxicology to offer a complete undergraduate degree. Fortunately, offering a single undergraduate toxicology course is not beyond the scope of many of these institutions. For example, at many small institutions, toxicology faculty are frequently hired into biology, chemistry, or biochemistry departments. Although they may not initially be hired to teach a toxicology course, these faculty often introduce toxicology-focused topics into their primary courses. As such, discussing acetylcholinesterase inhibition by organophosphates in a biochemistry or neuroscience course offers a way to explore enzyme inhibition or neurotransmitter dysregulation in the context of a large class of neurotoxic compounds to which millions of people are exposed each year. Moreover, new faculty at primarily undergraduate institutions are often encouraged to create electives based on their own area of expertise. This can open the door for toxicology faculty to then create their own stand-alone toxicology course.

Creating new undergraduate toxicology courses is often hampered, however, by the fact that not only are there no previously existing courses on which to build at these institutions, but there are also no other toxicologists with whom the new faculty can interact. In addition, undergraduate toxicology textbooks are often quite different from one another in terms of content, organization, and depth. There is, therefore, a significant need for curricular materials to aid these faculty in the development of effective toxicology courses.

SOT has provided some assistance in this area by developing a resource collection for undergraduate educators (https://www.toxicology.org/education/edu/educators.asp; Accessed Aptil 15, 2019). Syllabi, assignments, and other content from SOT members have been curated and are available to SOT members. Thus, some examples of syllabi from many types of undergraduate toxicology courses (public health, pharmacology, industrial hygiene, environmental science, etc.) are available. Although these resources are certainly beneficial, they do not rise to the level of support offered by the type of Learning Objectives (LOs) promoted by organizations such as the National Science Foundation (NSF) and American Association for the Advancement of Science (AAAS) that are available for other scientific disciplines.

Course LOs are a core set of goals around which a course is organized that also define demonstrable knowledge and skills a student will have learned and mastered at the conclusion of a particular course. Well-crafted LOs for a course at a single institution enable consistency throughout the curriculum when multiple educators are required to teach the same course. Nationally-adopted LOs enable consistency of content at different institutions. They also provide a framework that enables faculty members to build their own course emphasizing peer-reviewed themes and content.

Through both national efforts and those of partner scientific societies, core guiding principles have been created for many life science courses, including undergraduate biology, biochemistry, genetics, and anatomy and physiology. In 2011, "Vision and Change in Undergraduate Biology Education: A Call to Action" was published (Brewer and Smith, 2011). A joint venture of the NSF and the AAAS, this influential report sought to move undergraduate biology courses away from the routine memorization of long lists of facts to an approach that is based on evolving theories of learning that make science more accessible to all learners. The report advocates emphasizing scientific competencies and themes that underlie the process of science and are integrated across multiple disciplines. A major product of this report was the development of Core Concepts and Core Competencies that all students, including nonmajors, should learn from basic undergraduate biology courses. Vision and Change (V&C) defined the Concepts and Competencies that serve as overarching themes for undergraduate biology courses, regardless of the depth to which the courses are taught or whether the course was targeted to biology majors or nonmajors. Core Concepts focus on the fundamental themes that underpin all of biology, and they include concepts such as "Evolution" and "Structure and Function" (Table 1, left column). On the other hand, Core Competencies focus on fundamental *tasks*, such as the "ability to apply the process of science" or the "ability to tap into the interdisciplinary nature of science." V&C has since become a cornerstone of biology education in the United States (Vasaly *et al.*, 2014).

Since V&C was published, similar efforts have been led by scientific societies in their own domains (Austin, 2018). For example, the American Society for Biochemistry and Molecular Biology sponsored the development of Core Concepts for Biochemistry and Molecular Biology (Table 1, center column; (Grover et al, 2019)), and the American Society for Cell Biology sponsored the development of Core Concepts for Cell Biology (Adams et al, 2019). Thus far, Core Concepts have been produced for 14 different undergraduate subjects, and have been

Table 1. Comparison of Core Concepts for Undergraduate Biology, Foundational Concepts for Biochemistry & Molecular Biology, and Core Concepts for Undergraduate Toxicology

Vision and Change Core Concepts for Undergraduate Biology Education — Vision and Change in Undergraduate Life Science Education - A Call to Action	Foundational Concepts for Biochemistry and Molecular Biology—American Society for Biochemistry and Molecular Biology—Working Group for "Biochemistry and Molecular Biology Foundational Concepts"	Core Concepts for Undergraduate Toxicology—Society of Toxicology—Learning Objectives Work Group
Evolution: The diversity of life evolved over time by processes of mutation, selection, and genetic change	"Energy" is required and transformed in biological systems	Evolution: Evolution drives the interplay between toxicants/toxins and xenobiotic defense mechanisms and justifies the use of model organisms
Structure and Function: Basic units of structure define the function of all living things.	"Macromolecular structure" determines function and regulation	Biological Information: Differences in genomes and environmental exposure drive differences in susceptibility and responses to toxicants
Information Flow, Exchange, and Storage: The growth and behavior of organisms are activated through the expression of genetic information in context	"Information storage and flow" are dynamic and interactive	Risk Assessment and Risk Management: Epidemiology and historical events together with science drive regulatory responses to risk to individuals and the environment
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	"Discovery" requires objective measurement, quantitative analysis, and clear communication	Systems Toxicology: Toxicants affect cellular, organ, individual, and ecological systems
System: Living systems are interconnected and interacting	"Evolution & homeostasis"	Pathways and Transformations of Energy and Matter: Interaction of toxicants with organisms is described through paradigms in dose response, Absorption, Distribution, Metabolism, and Excretion (ADME), and toxico-/pharmacokinetics

After Core Concepts in Undergraduate Biology were introduced in the seminal Vision & Change Report of 2011 (left column), scientific societies responded by developing Core Concepts for their own areas of expertise. For example, the American Society for Biochemistry and Molecular Biology developed Foundational Concepts for Biochemistry and Molecular Biology in 2013 (center column). The Learning Objectives Work Group of the Society of Toxicology has drafted Core Concepts for undergraduate toxicology (right column).

published at *CourseSource* (www.coursesource.org), an open access repository for core concepts aligned with V&C and related evidence-based teaching materials to support them.

As the premier scientific society in toxicology, SOT is best-positioned to create a Learning Framework for an undergraduate toxicology course. In addition, it strongly supports SOT's stated strategic objective of "increasing the pipeline of students entering graduate school in toxicology." Thus, in 2017, upon recommendation of the SOT UGSC, the SOT's Education Committee appointed the Learning Objectives Work Group (LOWG) to assess topics taught in undergraduate toxicology courses, and to develop LOs using best-practices within the life science discipline. The committee was composed of educators from a range of institutions, including small liberal arts colleges, regional comprehensive universities, R1 research universities, and the Education Director from the SOT (see the author list). All of the committee members are experienced undergraduate educators and represent expertise across a breadth of different course styles for toxicology. The LOWG gathered and analyzed syllabi submitted by undergraduate educators via the Undergraduate Education Network (UEN) of the SOT, and then performed an analysis of trends in course content for a variety of different undergraduate toxicology courses. These included courses that focused on human health, the environment, public health, industrial hygiene, forensics, pharmacology, biochemistry, and others. Although several courses have specialized content specific to their subdisciplines, consistent themes did emerge.

The LOWG adopted the V&C framework to ensure the broadest possible outreach to nontoxicologist educators, and to align the work with best-practices in biology education. Using both the themes that emerged from the syllabi and the V&C framework, 5 Core Concepts were developed for undergraduate toxicology (Table 1, right column). These Core Concepts build on those from courses that might be likely to serve as prerequisites for an undergraduate toxicology course (including undergraduate biology and biochemistry), and include the following overarching concepts: Evolution, Biological Information, Risk Assessment and Risk Management, Systems Toxicology, and Pathways and Transformations for Energy and Matter.

For undergraduate toxicology, the 5 Core Concepts for toxicology constitute Level 1 of the Learning Framework. Beneath this first level are 3 additional levels (example shown in Table 2). Level 2 Toxicology Concepts are broad categories that include all topics likely to be taught in the entire breadth of undergraduate toxicology course types: human health, pharmacology, environmental, etc. Level 3 consists of LOs that describe content specific to Level 2. Finally, the Level 4 LOs provide examples and case studies of how each Level 3 LO might be taught or presented in a course, and this level includes references to example case studies when possible. It should be noted that Level 4 LOs are simply examples and are not intended to be either prescriptive or comprehensive.

Following the presentation of draft LOs at the 2018 annual SOT meeting, comments and suggestions were obtained from

Table 2. A Level 2 Toxicology Concept, Together With Level 3 Learning Objectives and Level 4 Example Learning Objectives and Case Studies for the Level 1 Core Concept "Evolution"

Level 2: Toxicology Concepts	Level 3: Learning Objectives	Level 4: Learning Objectives—Example Learning Objectives and Case Studies
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 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 3 R's) ensure the best ethical treatment of animals used in research • Describe the role of the Institutional Animal Care and Use Committee (IACUC) in guiding research at local institutions, ensuring the ethical treatment of animals

Level 2 Toxicology Concepts (left column) are broad categories of content. Approximately 150 Level 3 Learning Objectives (LOs) (center column) encompass the breadth of undergraduate toxicology courses, although only a subset is expected to be emphasized in an individual toxicology course. Level 4 LOs and Case Studies (right column), which are not intended to be comprehensive, provide faculty with ideas and potential examples of how to teach the Level 3 LOs.

undergraduate educators, graduate educators and toxicology program directors, Specialty Sections, the UGSC, the Education Committee, and the SOT Council to ensure the broadest possible feedback and outreach. The resulting document is available at the SOT website (https://www.toxicology.org/education/docs/SOT-Toxicology-Learning-Objectives.pdf; Accessed Aptil 15, 2019) and will be published on coursesource.org together with those of the 14 other life science courses.

In order to best use the LOs, undergraduate educators should first familiarize themselves with the V&C movement in undergraduate biology education and evidence-based teaching practices. To build a syllabus from the LOs, the undergraduate educator can then decide the appropriate overall theme or themes of their course and perform backward design (Barber, 2018). For example, the educator may decide that the course will focus on human health. This provides the overall context in which the LOs will be incorporated. Additionally, the educator should also consider the prerequisites for the course, which could provide the faculty member with LOs from other disciplines that could also be incorporated into the course (see, eg, coursesource.org). This latter point may be particularly important if those courses are not prerequisites for a toxicology course at their institution. It would be expected that, in most cases, instructors would utilize all Level 1 Core Concepts, but place differing emphases on the underlying Toxicology Concepts and LOs, depending on the theme of the course. Feedback from other educators familiar with V&C would also be helpful in this process.

We anticipate that the availability of this Learning Framework will significantly facilitate the development of undergraduate toxicology courses at institutions that have perhaps not previously offered them. Doing so will increase the exposure of undergraduate science majors to the field of toxicology, and hopefully augment the number of students seeking graduate or career opportunities in toxicology-related areas. In addition, the adoption of these LOs by undergraduate educators already teaching a course will facilitate the sharing of learning materials aligned with these LOs, allowing educators to enhance and improve their own courses. The partnership between SOT and the educational websites "Life Sciences Teaching Resource Collection" (www.lifescitrc.org) and "CourseSource" (www.coursesource.org) has also been a key in providing the opportunity to spread these resources outward to educators in related fields who may not be affiliated with SOT. In short, the development of these LOs not only enables toxicology to take its place alongside other key disciplines in support of the V&C movement, but also facilitates the spread of toxicology as an undergraduate elective, and promotes excellence in undergraduate toxicology teaching.

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