INTRODUCTION

In the recent report, Vision and Change in Undergraduate Biology Education: A Call to Action (1), the American Association for the Advancement of Science laid out a blueprint for reforming undergraduate biology education. A key component of the vision is ensuring that all students understand certain core concepts that are necessary for biological literacy, and that they are able to demonstrate a set of core competencies in disciplinary practice. The report draws on a large body of evidence in education research and cognitive science, as well as the input of hundreds of biology faculty, university administrators, researchers, and students. The call to action is embodied in four items: (i) integrating the core concepts and competencies outlined in the report into the curriculum, (ii) focusing on student-centered learning, (iii) promoting widespread engagement in the reform effort at the level of campuses, and (iv) involving the larger biology community. While departments, colleges, and universities work towards implementing systematic reforms, individual faculty can make small changes in the classroom that can have an immediate payoff in terms of concept and competency integration and student-centered learning.

The core concepts and competencies were integrated into every aspect of a first year Inquirers in Biology course at Northeastern University. This course is offered to students majoring in Biology, Biochemistry, and Behavioral Neuroscience who have Advanced Placement credit for General Biology. The class is small (35 students), and is organized largely in a seminar format with no textbook and very minimal lecturing. However, the integration strategies presented here should be applicable to larger classes, as well as classes that are more lecture-focused.


PROCEDURE

In the second week of the semester, after students had completed a few assignments, they were introduced to a conceptual framework of the Big Ideas in Biology. First, the goals of the Vision and Change project were explained, along with the importance of core concepts for understanding biology at all levels—from beginning student to professional scientist, and examples were discussed. Next, each BIB was described briefly, and examples from recent readings were discussed. Students were also given access to text from the AAAS report for fuller descriptions of the core concepts. Finally, students were then given a homework assignment in which they were asked to use a table to analyze each of several recent assignments for evidence of BIBs (see Table 1). The assignments included an article on synthetic biology that all of the students had read, articles from Science magazine that were unique for each student, and a lab scavenger hunt in which each student learned about the research of one of our faculty. After students completed their BIBs analyses, they were asked to give examples during a class discussion. The assignments that students analyzed were intentionally very diverse in order to bring up for discussion a large range of topics in biology and show how they could all be related to the overarching themes present in the BIBs. For example, students noticed in the synthetic biology article that a small error in the synthetic genome had a large effect on the recipient cell and that this was an example of information flow, and that faculty members with very different research interests were all studying evolution in some way.

The following week, I introduced the Skills Used by Biologists. Students were asked to make a SUBs table to analyze components of our course, such as service-learning, as well as the research conducted in the faculty lab that they had explored for evidence of common disciplinary practices (see Table 2). This allowed students to discover for themselves the pedagogical logic behind what they were being asked to do inside and outside of class, and to realize that they were developing useful skills. For example, students realized that while their research projects were obviously...
focused on understanding the process of science, they would also be developing skills in collaboration and communication as they worked with peer evaluators and ultimately presented their research in a poster session.

BIBs and SUBs were highlighted on a regular basis as the semester progressed. For example, as students read news reports about research advances and papers from the primary literature, they were asked to explain the SUBs that were demonstrated in that research. This helped students to focus on both methodological details (e.g., quantitative analysis and modeling), but also the cooperative aspects of the research and its potential societal implications. Ongoing BIBs analysis also helped to make connections across the course.

Towards the latter part of the semester students read an epigenetics research paper. The most obvious concept was Information Flow, but after BIBs analysis, students could connect this topic to those we had covered early in the semester by seeing it as an example of all of the Big Ideas.

BIB and SUB analysis was used regularly for both formative and summative assessments, not only for individual topics, but also to link together topics that students might otherwise see as unrelated. Here is an example of such an assessment on a quiz:

### TABLE 1.
**Example of student Big Ideas analysis.**

<table>
<thead>
<tr>
<th>BIBs</th>
<th>Lab Scavenger Hunt-Professor A’s Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evolution</td>
<td>The model organisms used – lobster and lamprey eel - have evolved to have traits that are best suited to their environment. This is why they are good models for building submarine robots.</td>
</tr>
<tr>
<td>Structure &amp; Function</td>
<td>The shapes of the animals’ bodies allow them to navigate underwater.</td>
</tr>
<tr>
<td>Information</td>
<td>The behavior of the animals is due to functions encoded by their genes. The lab tries to mimic this behavior through new technologies.</td>
</tr>
<tr>
<td>Energy &amp; Pathways</td>
<td>The neural pathways in the model organisms must be understood in order to be able to build robotic versions of the animals.</td>
</tr>
<tr>
<td>Systems</td>
<td>By navigating the ocean, sea lampreys and lobsters are able to find food and survive. In order to do this, they need their various body features that make them good navigators, and they also need the instinct that tells them to perform certain behaviors. The interaction of body plan and behavior is essential and works as a system to enable the animals to survive.</td>
</tr>
</tbody>
</table>

Choose one BIB that was illustrated during our debates 'viruses and the tree of life' and 'definition of a prokaryote'. Succinctly describe how that overarching concept applies to both the appropriateness of the term prokaryote AND the status of viruses.

Students approached this question in various ways. Evolution was the most common BIB, which was not surprising as these topics were covered in the Diversity and Evolution unit and the evolutionary aspects were emphasized. However other BIBs were also chosen. For example, a discussion of how viruses lack certain key structures/functions common to all cells was used to illustrate the Structure/Function BIB, while the way that genes are expressed in eukaryotes and prokaryotes was used to illustrate the Information BIB.

### CONCLUSIONS

Student reactions have been positive and they now readily talk and write about Big Ideas in Biology and Skills Used by Biologists without prompting. In a mid-semester open response evaluation question in which students were
asked to indicate what course component had helped them learn the most up to that point, Big Ideas in Biology was mentioned frequently by students. Furthermore, the formative assessments provided feedback that was very useful in revising the class in real time. For example, it quickly became clear that students equated the systems BIB with ecosystems, or, in some cases, with human organ systems. This forced me to go back to the drawing board to show students that interactions and emergent properties are prevalent at all levels from the subcellular to the biosphere.

Undergraduates, especially first-year students, are novices in the discipline. A large body of cognitive research has shown that novices differ from experts in fundamental ways that go far beyond the amount of knowledge or practical experience accumulated (see How People Learn (2)). A key characteristic of experts that sets them apart from novices is their ability to organize information, and to retrieve and apply it efficiently.

Providing students with the conceptual framework of BIBs can help them to process and organize new information as they acquire it, while the SUBs can show them how practicing biologists approach the discipline in the real world. It takes a little planning to incorporate these concepts and skills into the course syllabus and assessment activities, but implementing this vision can really change your classroom in a positive way.

ACKNOWLEDGMENTS

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REFERENCES