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Essay

An Active Textbook Converts "Vision and Tweak" to Vision and Change

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Abstract

Multiple reports over more than a century have documented the problems with the way introductory biology has been taught in most colleges and universities. An influential recent report, *Vision and Change in Undergraduate Biology Education*, has called specifically for a major overhaul of the content and mode of delivery for introductory biology. However, when they teach, faculty often replicate the classroom structure they experienced as an undergraduate. In response to calls for change, many faculty placate critics of the status quo by justifying their traditional pedagogical approaches and/or tweaking the content they present. Regrettably, this response has effectively converted the *Vision and Change* reform into "Vision and Tweak." We think that the slow pace of implementing *Vision and Change* reforms also reflects the dearth of structural changes in the foundational element of introductory biology courses, the textbook. We propose that an "active textbook" is essential to achieve the *Vision and Change* goals in introductory biology courses. Our experiences have provided insights that could help others to fully implement *Vision and Change* as intended by the more than five hundred faculty who contributed to this call for reform.

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Materials and Supplemental Materials: Table 1. ICB-Vision and Change core concepts and competencies, Table 2. ICB-Concordance of ICB with Vision and Change, Figure 1. ICB-An active textbook promotes student analysis of data to construct their own knowledge, Figure 2. ICB-Students come to class prepared to discuss the text and Supplemental File S1. ICB-Supporting materials for instructors

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WHAT IS VISION AND CHANGE?

The landmark report, *Vision and Change*, calls for significant overhauls in the gateway course of introductory biology (1). The report is the product of more than five hundred life science faculty convened by the American Association for the Advancement of Science (AAAS), the National Science Foundation (NSF), the National Academy of Sciences, and the Howard Hughes Medical Institute (HHMI). Four years later, despite the consensus origin of *Vision and Change*, the recommended change is happening only in isolated pockets where individuals have invested the significant time and energy needed for full implementation.

A critical obstacle to change is the need to look beyond the classroom itself. For example, "active teaching" as a means to promote change is the subject of many white papers, essays, and studies that focus on what teachers do in the classroom (2 - 8). Such efforts are important but insufficient. To fully realize *Vision and Change*, we must also change what our students do outside of class. To this end, we developed and have used a new textbook (*Integrating Concepts in Biology, ICB*; 9) to enrich student learning (10) and increase student engagement.

Unfortunately, *Vision and Change* did not address textbooks and the important role they play in introductory biology courses (1). As reported in a study by Horsley et al. (11), we have found that students rarely read traditional textbooks, and when they do, their text provides a litany of details that often obscure core concepts, and figures that do not promote core competencies (Table 1). Cognitive psychologists have documented that people learn best when they construct their own knowledge (12,13). Few can absorb and retain long descriptions of facts, mechanisms, and taxonomic groups. Biological knowledge is already too expansive to be mastered by an individual. And, the rapid rate of new discoveries creates an ever-growing gap between what is known in biology and what can be known by a practicing biologist. At least in part because of this growth in knowledge, teachers focus on attempting to deliver this increasing body of information as their major objective.

The *ICB* textbook is the first dramatic attempt to break away from the standard encyclopedic introductory biology tomes that are swelling past an already unsustainable ~1400 pages. In this essay, we share our experiences replacing a traditional textbook with an "active textbook" that asks students to interpret published data so they can answer questions that facilitate the construction of their own knowledge.

NEW MODEL FOR A TEXTBOOK

ICB is radically different from a traditional biology textbook. The most obvious difference is the inclusion of data taken directly from primary literature (Figure 1).

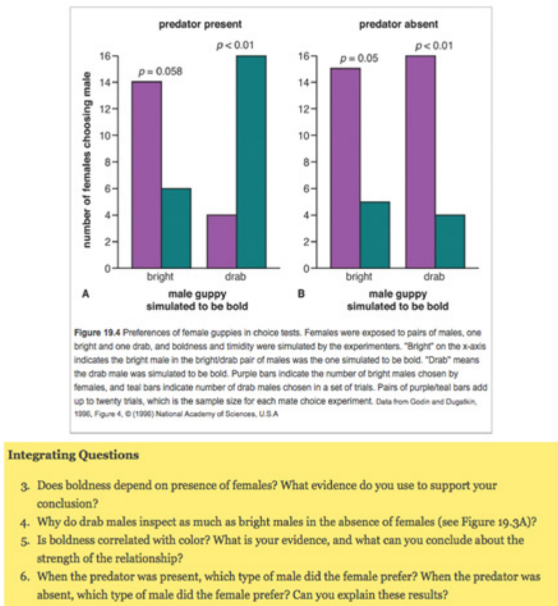

Figure 1. An active textbook facilitates student analysis of data to construct their own knowledge. Screenshot from *ICB* eBook showing data from a research figure addressing the core concept of evolution at the organismal level. The driving question for this section is, "How does selection act on individuals with variable characteristics?" Following the figures are Integrating Questions that help students extract key points from the data as they build a comprehensive understanding.

Figure 1. An active textbook facilitates student analysis of data to construct their own knowledge. Screenshot from *ICB* eBook showing data from a research figure addressing the core concept of evolution at the organismal level. The driving question for this section is, "How does selection act on individuals with variable characteristics?" Following the figures are Integrating Questions that help students extract key points from the data as they build a comprehensive understanding.

These data are the foundation from which students construct their understanding. The Integrating Questions included in the text provide a guided inquiry structure to help students interpret the data as they read the text before class, as well guiding the in-class discussions facilitated by the faculty. The second major difference is that *ICB* encourages science faculty to adopt a humanities approach to learning by focusing on "the text." As in a literature or social science class, the students must read and analyze the text before coming to class, since they know they will be called upon in every class to offer their own interpretation and analysis. In this regard, *ICB* provides the structure for a flipped classroom without the need to produce videos or other flipped multi-media.

IMPROVED LEARNING DYNAMIC

ICB was published in August 2014 and rapidly adopted at six institutions, including Transylvania University (TU), an undergraduate institution in Kentucky with about 1,000 students. A subset of Davidson College (DC) and all TU biology faculty use *ICB* for a two-semester introductory biology sequence that includes laboratory sessions both semesters. Classes are composed of 24 (TU) or 32 (DC) students, most of whom are first year students and interested in a science major and/or a career in health care. Despite slight differences in approach between DC and TU, we believe *ICB* has been very successful in engaging students at both institutions with the material in a way that is much improved over previous iterations of our courses. As a result, TU and DC students have become more sophisticated in how they think about biological ideas. They are making great innovative connections between concepts and have begun to talk more like scientists, as illustrated with quotes from three TU students.

- "Yes, the bar graphs look different, but are they significantly different?"
- "The way the Yucca moths lay eggs on the cactus flowers reminds me of optimal foraging theory... can we use that idea here?"
- "What is an individual? I mean, is a worker bee an individual? Is the hive the individual? I am confused."

At DC, since only some instructors are using *ICB*, we had the opportunity to compare the impact of *ICB* versus a traditional textbook (10). On their own initiatives, DC students compare the two types of courses, prompting an unsolicited email from a DC senior biology major who used *ICB* his first year and who tutored students taking the *ICB* class as well as students taking traditional textbook classes. Here are his comments reproduced anonymously and with permission:

> "The [traditional] class does not allow students to think critically. My friend told me today that she passes her tests by memorizing the page that the test questions come from. This is not science. They are learning what to do to pass a test... They are not being taught to think like a scientist. If the purpose is to teach you to think like a scientist by teaching how to ask interesting questions, approach a problem, process information, and draw conclusions, then I believe [the traditional class] is falling short. If the purpose is to weed out individuals who may actually think critically about interesting biological concepts but lack the motivation or ambition to memorize systems and processes just to pass a test and get a good grade, then this may be the only thing we are accomplishing."

The pre-med advisors at DC and TU agree with this student. The pre-med advisors on both campuses recognized that the data-centered approach of *ICB* provides students with more opportunities to interpret data, solve logic problems, and apply quantitative reasoning. Indeed, the redesigned MCAT emphasizes scientific interpretation and problem solving related to research design and results, as well as data-based and statistical reasoning (14). We believe these competencies are crucial not just for pre-med students, but for all science students and that *ICB* courses provide an excellent foundation (see Table 1 on page 4). For all these reasons, we will continue to encourage more faculty to adopt *ICB* rather than continue to tweak their more traditional courses and use a textbook that does not facilitate students' construction of their own knowledge (10).

The daily reading assignments in our classes hold students accountable for smaller chunks of material per class, compared to assignments from a traditional textbook. The course structure demands students have read and worked with the material before class (Figure 2).

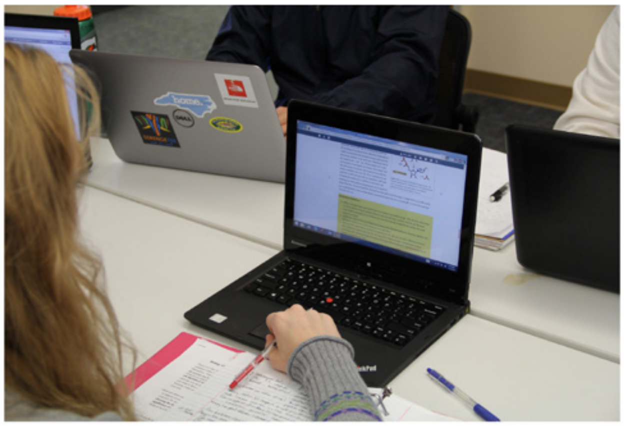

Figure 2. Students come to class prepared to discuss the text. The on-line active textbook changes how students spend their time outside class which generates a different dynamic during class. By building the class around an active textbook, the class is "flipped" because faculty don't present information that students should have read in a traditional textbook but they rarely do.

The Integrating Questions (IQs) focus student reading on the tables, graphs, and figures. By reading the text and answering the IQs, we expect students to determine the research question being asked, how the results are presented, and the conclusions that can be drawn from these results. Furthermore, the IQs help the students perceive the significance of the studies and assimilate the results into the broader biological context. Student pre-class preparation results in an increase in both the quantity and quality of the in-class discussion even if they were unable to fully answer the IQs on their own. We cold-call on every student, which they love and hate simultaneously as indicated in their anonymous course evaluations: "Cold-calling (although uncomfortable at first!) really helped to solidify what I learned from the reading." We note that cold-calling is not the critical determinant of student success; holding them accountable for the reading is. Thus, in large enrollment classes, clicker questions and other strategies could accomplish the same level of accountability. Our students know that they are expected to come to class prepared and so they do. Many students have remarked that studying for exams was much easier for them than in comparable science classes because they had already done all the reading, giving them more time to focus their study on the most difficult material.

IMPROVED TEACHING DYNAMIC

What makes *ICB* different and engaging for the teacher is that it really does make science teaching feel more like a humanities class. By focusing on engaging students with the material through the text, the way we run our classes has changed in a way that we enjoy. Lectures have shifted from a fixed linear narrative to a "choose your own adventure" model driven by the students' questions and comments. It is not uncommon to end class totally surprised by what new ideas or issues we covered in class. Because of this spontaneity, we are more engaged and responsive to the students' learning. It can be unnerving for any faculty member to walk into a classroom knowing that student questions will substantially drive what is discussed in a classroom. However, an *ICB* classroom is similar to a lab meeting where the instructor is still the local content expert, but will not know the answers to all questions, and that is okay. Unanswerable questions provide new opportunities to reexamine the data presented in *ICB*, critique the experimental design, propose new experiments, and speculate based on the available data. In short, students using an active textbook contribute to a new teaching dynamic that helps them become scientists rather than memorizers of terms, mechanisms and phyla.

Often, instructors will raise the fear that the intense emphasis of an *ICB* class on the process of science will decrease the amount of material covered to the point of hurting student preparation for upper level courses. The purported "lack of coverage" may be an illusion. For example, TU faculty covered a large number of diverse concepts, even though they never felt as if they were doing so. In preparation for the final exam, a TU class developed a master list of more than 200 terms that were introduced in class and readings over the semester. The large amount of content did not overwhelm the instructor or the students because the concepts were introduced organically through discussion and interpretation of the data in *ICB*.

Because *ICB* is an "active textbook," teacher preparation for class is completely different from classes taught with a traditional textbook. For example, despite teaching the class multiple times, we have not accumulated lecture notes for the chapters. Prior to class, we re-read the chapter and review the provided PowerPoint slides, which each of us have customized to suit our individual preferences. Sometimes we download the original papers or more recent follow-up studies to enhance class discussions. However, once class begins, we react to student responses to our questions, show them how one idea links to other ideas, and often connect the ideas across biological levels from molecular through ecological systems. Class time seems much more responsive and natural than the highly structured lectures that characterized comparable classes we taught with a traditional textbook. As one author (JDW) noted, "Don't get me wrong, I love my old lectures and thought they were amazingly informative and clever. However, my students were rarely required to think or engage their critical minds in those lectures."

IMPERFECTIONS IN *ICB*

TU faculty had some minor concerns about the book that are worth sharing.

1) The consistent use of the 1990s color scheme of teal, orange, and purple on the graphs make them difficult to discern when printed in black and white. The color scheme was chosen so that color-blind students (7% of American males) could see the differences on the screen. *ICB* deliberately chose a functional color palette over an aesthetic one to maximize

Table 1: ICB-*Vision and Change* core concepts and competencies.

Vision and Change for Introductory Biology	
Core Concepts	**Core Competencies**
Evolution	Process of Science
Structure and Function	Quantitative Reasoning
Information	Modeling and Simulations
Energy and Matter	Integration of Disciplines
Systems Biology	Communication and Collaboration
	Connecting Science to Society

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Table 2: ICB-Concordance of *ICB* with *Vision and Change*.

Vision and Change	*ICB* Active Textbook
Five Core Concepts	Five Big Ideas are conceptually equivalent and covered at five levels of organizational scale
Process of Science	Interpret figures and assess experiments multiple times in each reading assignment
Quantitative Reasoning	Analyze data, assemble evidence, evaluate variance, and determine significance frequently; BioMath Explorations explore specific examples in depth
Modeling and Simulations	BioMath Explorations are interactive vignettes of math concepts that enrich biological knowledge
Integration of Disciplines	Chemistry, mathematics, computer science, psychology and physics applied as needed
Communication and Collaboration	Active classroom methods allow students to discuss data used to construct understanding
Connecting Science to Society	Ethical, Legal, Social Implications readings set core concepts in the context of daily lives

Wagner, J.D., Campbell, A.M., Sly, B.J. and Paradise, C.J. 2015. An Active Textbook Converts "Vision and Tweak" to Vision and Change. *CourceSource.*

access to the data.

2) Although *ICB* helps students distinguish statistically significant differences from just differences, it is not uncommon for a chapter to present bar graphs that lack statistics and then make claims about the bars being different. The figures in *ICB* are reproduced from the original scientific publications. If figures lacked error bars in the scientific publication, they must lack error bars in *ICB* as well. It is striking how some classic papers cited as foundations of our understanding can lack the expected statistical rigor. In all our prior teaching of introductory biology, we had never before experienced students commenting on a lack of statistical rigor they have grown to expect in *ICB*.

3) Two TU students taking both classes during a single semester could see how the knowledge acquired in their molecular/cell class helped them better understand their organismal/ecological systems class. Have these students uncovered a new and more effective way to structure introductory biology - both courses in the same semester? However, most students only take one semester of the two-semester sequence at a time and they may not remember the connections as well. To reduce this limitation, the book provides links between chapters so students can easily click to the other chapter to see how cases from different size scales are integrated.

4) Some of the research examples within chapters seemed forced to fit in one particular core concept (e.g., information) when they could have been placed into other core concepts (e.g., systems biology or evolution; see Table 1 on page 4). However, all five core concepts (i.e., Information, Evolution, Cells, Homeostasis, and Emergent Properties, called Big Ideas in *ICB*) are interrelated so every case could fit under more than one core concept.

5) When a lightning strike knocked out TU's campus internet connection, students were unable to read their textbooks for ~30 hours since the textbook is online and hyperlinked. It was a painful class that day but it also showed us that, under normal conditions, the students were coming to class prepared. There is an app for iPad that downloads the entire book and eliminates the need for connectivity, but most students do not have iPads.

A final limitation is worth addressing separately - only a small fraction of possible research examples are included in *ICB*. Every instructor has his or her favorite specific example that supports a core concept but it would be impossible to present all examples in any book. Rather than a compendium of all popular examples, *ICB* is a model of an active textbook and what can be accomplish by students who use it. *ICB* is a roadmap or template for instructors to help wean themselves of content-heavy lectures or presentations that undermine all the benefits described in this essay. However, because *ICB* is an online-only book, instructors can customize their versions of the textbook by writing new sections or chapters that only their students can see. Therefore, if "the best example ever" is not in *ICB*, instructors can provide the necessary background and data figures to let their students construct their own knowledge using an instructor's favorite examples. The *ICB* authors fully understand how difficult it is to collect research examples and present them in a student-ready format. To nurture the growing community of instructors using *ICB* as a roadmap to fully implementing *Vision and Change*, the *ICB* authors have built an online portal (integratingconcepts.org; see supplement material) where faculty can exchange ideas, pose questions and offer personal experiences to peers they may never meet in person (15). By working together, faculty can avoid tweaking their class and restructure their courses to meet the consensus goals of *Vision and Change*.

CONCLUSIONS

We have found three keys that are essential for full implementation of the *Vision and Change* recommendations. First, student work outside of class needs to be intentionally and effectively structured. If students continue to passively read textbooks, they won't construct their own knowledge and they will not retain the information for upper level courses. Second, students must come to class prepared for classroom activities, which also facilitates studying for exams as the semester progresses. Third, instructors must develop testing methods that reflect the new learning objectives and the work they expect students to do in and out of class. Horsely et al. (11) reported that students typically do not find textbooks helpful, so they rarely read the book. However, if reading the book is a key component of class time and tests, students will use the text to help them construct their own understanding of the material. We have developed a testing method that includes a "data gallery" of figures from *ICB* that requires students to act more like scientists. Instead of just answering questions, students must find the relevant figure from the gallery and explain how their chosen figure provides supporting evidence for their answer. Scientists routinely provide evidence to support their statements and our students are capable of the same behavior. *ICB* instructor resources provide examples of exam questions from every chapter in the book. Duncan (16) found that less than 5% of the figures in a typical textbook contain data. It is no wonder that students using a traditional and passive textbook do not know how to support their answers with data.

In the fall of 2014, two outside reviewers involved in evaluating the national impact of *Vision and Change* visited DC and said that the *ICB* version of introductory biology did "… a very effective job of blurring the distinction between lab and lecture, [because it] has a strong focus on the process of science in both the lecture and lab settings." They continued by saying that *ICB* "offers a highly innovative introductory biology sequence with integration of concepts in a new approach that may be just what the authors of [*Vision and Change*] had in mind. Instead of traditional clustering of topics by level of organization, *ICB* organizes information by [core] concept and then explores how those concepts manifest at different levels of organization."

Changing to a new textbook and teaching approach are not trivial endeavors for either the students or the instructors. Even under the best of circumstances, many people avoid change and fear the unknown. Not surprisingly, our students were initially intimidated by this new approach. However, within three weeks, they had adapted and really enjoyed this new way of learning biology, filling course evaluations with comments overwhelmingly in favor of *ICB*. Similarly, we encountered initial resistance from faculty. Among the faculty from around the country who reviewed *ICB* prior to its publication, the fear of change was the most common reason they gave for not wanting to adopt this new approach. Based on these reviews, several traditional publishers chose not to publish the book, leading the *ICB* authors to self-finance its publication as an eBook through Trunity. Contrary to the maxim "you can't teach an old dog new tricks," we have found that faculty at all stages of their careers can overcome their resistance to change. Novice faculty and full professors alike have adopted this active textbook as a way to align their teaching and students' learning with the *Vision and Change ideals (Table 2 on page 4)*.

SUPPLEMENTAL MATERIALS

- **Supplemental File S1.** ICB-Supporting materials for instructors

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