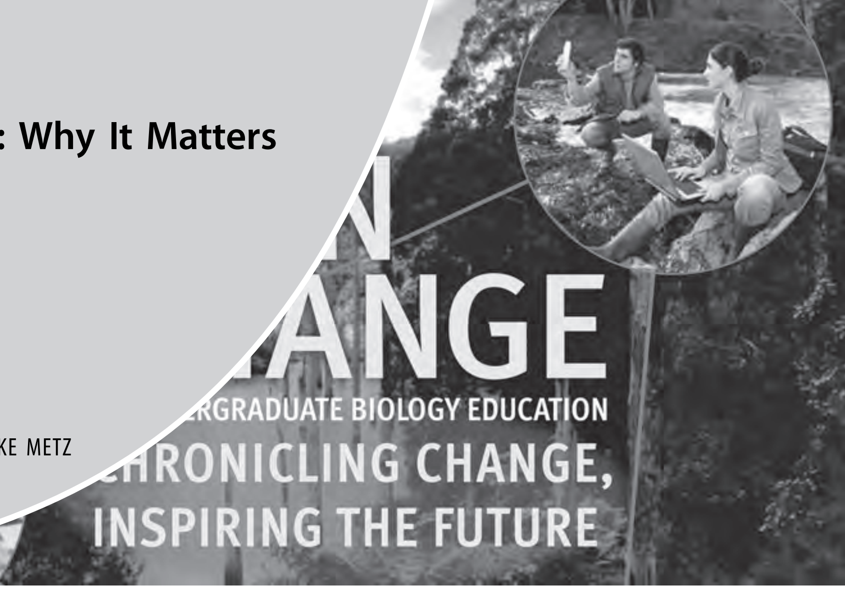
FEATURE ARTICLE

Vision & Change: Why It Matters



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Abstract

The AAAS "Vision and Change" report (2011) has been inspiring undergraduate biology educators nationwide to rethink their educational approach, favoring active-learning strategies to better prepare today's students for a complex, data-rich future. Here, we consider the history of the movement, its place in the greater arena of STEM education, and the reasons why this new approach has never been more critical. We encourage all biology educators to consider becoming agents of change, and we focus on helpful resources and practical suggestions to help ABT readers take the plunge into (or at least get their feet wet in) the welcoming waters of Vision and Change.

Key Words: *Vision and Change; curriculum; undergraduate biology instruction; active learning.*

These past few years, the "Vision and Change" (V&C) movement has spread throughout biology education. The basic tenets are shown in Table 1. V&C endorses an approach to teaching that endows biology students with the career skills they will need and empowers them to contribute to a complex global society. The philosophy behind the change is outlined in the American Association for the Advancement of Science report *Vision and Change in Undergraduate Biology Education: A Call to Action* (AAAS, 2011). Cofunded by the National Science Foundation (NSF), the Howard Hughes Medical Institute, the National Institutes of Health, and the U.S. Department of Agriculture, this free, downloadable report is the culmination of the work of hundreds of faculty, researchers, and students who worked with pedagogy experts and representatives from professional societies and agencies to craft a shared vision of the new biology education of the 21st century.

These past few years, the "Vision and Change" (V&C) movement has spread throughout biology education.

More than just a position paper, the report focuses on changes that will be needed to bring this vision to fruition – it indeed serves as a call to action. Faculty nationwide are being asked to step out from behind their comfort zone (the podium) and to spark student learning by "being a guide on the side, not a sage on the stage." They are being summoned to create unique learning environments that immerse students as active and critically thinking participants in the process of science, preparing them for the grand challenges of today and tomorrow – be they local, national, or international in scope.

V&C has its roots deep in the biology education research of the 19th and 20th centuries. The history of biology education research can be traced back to pragmatists like John Dewey (Dewey, 1916) and William James (James, 1899), who were early proponents of the experiential, real-world-problem-based approach to education (Burns, 2011; DeHaan, 2011; DeBoer, 2014). William James, in his 1899 *Talks to Teachers*, stated that "Any object not interesting in itself may become interesting through becoming associated with an object in which an interest already exists. . . . The difference between an interesting and a tedious teacher consists in little more than the inventiveness by which the one is able to mediate these associations and connections" (quoted in Burns, 2011).

The mandate to make teaching relevant to learners was clear, and a tradition of pedagogy research was established by the 1920s. The argument between lecture-based and experiential approaches to biology learning was already swirling by this time (DeHaan, 2011), although reports were mixed as to the utility of active-learning strategies. To substantiate this trend in forward thinking, journals focused on science pedagogy appeared: *Science Education* was started in 1918, and *The American Biology Teacher* by 1938.

The launch of Sputnik by the Soviet Union in October 1957 became a game changer for American science education. As it beeped ominously overhead, Congress was galvanized into action. Within a year, the NSF allocation for science education

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Table 1. Vision and change tenets of educational practice.

Action Item	Outcome Goals
Integrated curriculum	• Introduce scientific process. • Teach core concepts in the context of engaging real-world problems.
Student-centered learning	• Actively engage students via multiple teaching modalities. • Utilize evidence-based teaching practice based on sound research.
Promote change to campus culture	• Involve students, faculty, and administrators. • Reward research and innovation in teaching. • Support training of biology educators.
Involve the wider community (workforce, nonprofits, etc.)	• Students experience authentic, meaningful engagements with the processes, possibilities, and limitations of science.

was tripled, and the National Defense Education Act was passed to develop better science textbooks (BSCS, 2014).

Great minds were already thinking about how children learned, and how education could work better. Benjamin Bloom and colleagues had just put forward the "taxonomy of educational objectives" as a framework for infusing higher levels of thinking into educational practice (Bloom et al., 1956). Jean Piaget published his theory of cognitive development by 1958 – espousing a *constructivist theory* that children construct their knowledge from experience (Inhelder & Piaget, 1958). Jerome Bruner, in his essay "The Process of Education," advocated for children as active problem solvers capable of tackling complex tasks (Bruner, 1960). Meanwhile, C. P. Snow's influential 1959 "Two Cultures" lecture lamented the separation of scientific and nonscientific competencies among educated people, presciently noting that interdisciplinary thinking would be required to solve the world's most vexing problems (Snow, 1961). With researchers across disciplines calling for more experiential, interdisciplinary approaches to education and inquiry, and with the Cold War fueling a national fervor for better science education, the biology education community was poised to pursue better approaches to education in earnest. Still, a historical glance back makes it clear that change would take time.

The initiative to reform textbooks did get off the ground quickly in the wake of Sputnik. The NSF-funded Biological Sciences Curriculum Study (BSCS) was underway by 1960, focusing on an overhaul of biology curriculum and texts, stressing investigation over lecture and concepts over facts (BSCS, 2014). That project continues to develop inquiry-based curricula to this day. Nonetheless, biology education research itself continued to develop slowly over the next three decades. Joseph Schwab extended constructivist theory to develop a "didactic" theory of education that emphasized student discussion and active learning, pushing inquiry-based strategies in science education for the next 30 years (Schwab, 1962; DeHaan, 2011). Similar movements were afoot in other science disciplines. Physics education research, as an example, solidified into a discipline in the 1970s and has since grown into an integral and respected avenue of physics research (Cummings, 2011).

Another celestial event, the 1985 passage of Halley's Comet, heralded a new era of national studies that furthered the cause of an evidence-based, active approach to biology learning. The evidence for active learning's effectiveness was building. Project 2061 was started by the AAAS in that year as an initiative to ensure science, engineering, and technology literacy for all Americans. The resulting report, *Science for All Americans* (AAAS, 1990), recommended focusing on the "essential ideas and skills having the greatest scientific and educational significance for science literacy," to "teach less in order to teach it better."

Changing educational practice has never been more critical than in this new millennium, but it also has likely never been more difficult. The amount of information "out there" has increased exponentially. Over 300,000 books per year are published in the United States alone (~2 million worldwide; International Publishers Association, 2014), and the number of scientific articles published per year now tops 1 million (Larsen & von Ins, 2010). Moreover, today's generation of children and young adults who are being educated now are inundated with media. It is estimated that more pictures are now taken each day than in the first 100 years of photographic history (TedEd, 2010).

People, and particularly millennials, interact with their friends and family in a way that science fiction authors and futurists might have imagined only a generation ago. They have nearly instantaneous access to information on a scale that is truly mind-boggling. For a new generation to manage and utilize all this information for their own benefit and the benefit of society, they will need a new set of skills. This lived experience is fundamentally different from that of generations before that grew up without the Internet. It will require a mind-shift – from "information centered" to "retrieval centered" – for those of us in education who must prepare our students, and ourselves, for this reality.

Here's a personal example of this shift from the field of medicine, a career desired by many of our undergraduate biology majors. Not so long ago, maybe 10 years or so, one of us (A.M.) had a doctor's visit. It came time to discuss an appropriate medication, and rather than describing the choices, the physician pulled a small booklet out of his pocket. He shook his head and said, "There are now too many medications available. Once upon a time we were expected to have them all memorized, but it is no longer possible. I'd rather look up the information and get it right."

It may have been just a small moment, but it was indicative of something profound. The needed expertise was already shifting – from knowing facts unknowable to others, to knowing what to do with all those facts – how to find them, compare them, and use them to make sound decisions. As the doctor noted, this was not how it used to be; and maybe it wasn't how he was trained. But it was now the skill that he needed to make decisions – some of them life or death. And this shift has happened not just in medicine, but in all fields, including biology.

This "information overload" becomes more pressing every day. We might think of this anecdote and chuckle – who would use a *paper* cheat sheet? Today, it would be a smartphone or an iPad, making even more information accessible (to both doctor and patient alike) with the swipe of a fingertip. The little black book was a paper solution for a digital problem – a solution that did not address the fact that the Internet, perhaps like Sputnik before it, is a game changer. Expertise comes not from *having* information, but in knowing *how to use it*. It is this profound shift in thinking that necessitates that we, the biology educators, endow our students with opportunities to think critically, cross disciplinary boundaries, and develop problem-solving skills – all while working with information on a scale previously unimaginable.

In 1962, Thomas Kuhn described a scientific revolution as a shift in the practice of the (tradition-bound) activity of science (Kuhn, 1962). Revolution in a field comes about because of a shift in *paradigm*, the shared assumptions held by practitioners in the field. The shift is triggered when observed facts don't fit the paradigm, and someone realizes it's time to rethink. Reevaluating a field from a new viewpoint is difficult and time consuming, and Kuhn recognized that such seismic shifts tend to be strongly resisted by the established scientific community.

The current revolution in biology education has come about mostly because one established assumption (that if you tell a student something, they have learned it) did not fit the facts. Once upon a time, a university education was only for the elite few (in 1940, only 6% of men and 4% of women had a college degree; Snyder, 1993), and that premise held up reasonably well for decades. Back in the day, facts were fewer, the student body was not as diverse, access to information was limited, and most jobs did not require a college degree. But as the 20th century rolled into the 21st, educators started to recognize that in a diverse population, not everyone learns the same way (Tomlinson, 2015). They saw that in a media-saturated environment, students were less inclined to focus on lecture for an hour or more at a time, with bored students' "cyberslacking" becoming an increasing problem (Taneja et al., 2015). They realized that the facts were too numerous to be learned, and making sense of large, complex datasets became a skill unto itself (English & Srimaman, 2010). They also were realists. They grasped the new and increasingly complex social, economic, and environmental challenges of the 21st century, and the need for more college graduates with critical-thinking and research skills to solve complex problems. The evidence was mounting, and the revolution was on.

A series of reports in the early 2000s reflected this new national urgency. *How People Learn* (National Research Council [NRC], 2000) espoused educational reform based in cognitive science, which would lead to a deeper understanding of science topics by all. *Bio2010* (NRC, 2003) advocated better preparation for interdisciplinary research careers in biomedical science. *A New Biology for the 21st Century* (NRC, 2009) called for a multidisciplinary, integrated scientific approach to tackle the most pressing global and societal challenges. New national projects were funded; the NSF-funded SENCER (Science Education for New Civic Engagements and Responsibilities) initiative was launched in 1999, crafting curricular elements that teach science in the context of complex, unresolved public issues (Burns, 2011).

It is worth noting that this revolution, this paradigm shift, is now happening across all levels of science (and biology) education. The *Next Generation Science Standards* (NGSS Lead States, 2013) move K–12 students from content regurgitation toward using evidence to support scientific reasoning, and toward solving societal problems (NRC, 2012; NGSS Lead States, 2013; Pruitt, 2014). Advanced Placement (AP) tests underwent sweeping changes starting in 2012 – again away from rote memorization of facts to critical thinking and application of knowledge (Drew, 2011). The Graduate Record Examination (GRE) test was significantly revised in 2011 to emphasize critical thinking, verbal comprehension, and analytical skills over rote memorization. And the American Association of Medical Colleges (AAMC), driven by concerns about the ability of STEM curricula to keep pace with the accelerating rate of scientific discovery (AAMC, 2009) has recently implemented "MCAT 2015" – a medical-school admissions test that emphasizes deep knowledge of critical scientific concepts, scientific reasoning, data analysis, and problem solving (AAMC, 2014). A common thread throughout all of these movements is a shift away from fact acquisition and toward problem solving and critical thinking, thus mimicking V&C.

The evidence continues to grow that the tenets of V&C are necessary for biology education at both the two-year and four-year university levels. Introductory biology is where most students are likely to first encounter experiences with scientific practice at the undergraduate level (Hoskinson et al., 2013). This includes non–science majors for whom a general education biology course may be their last formal encounter with science education. Impacting those students will demand a biology education relevant to their everyday lives.

As it turns out, recruiting a new generation of scientists will demand this as well. Traditional science curricula discourage students, particularly women and minorities, from STEM careers (International Publishers Association, 2014). Nationally, STEM majors represent only 23% of the undergraduate degrees conferred on men, and a mere 9% of those conferred on women. African American, Hispanic, and Native American graduates also continue to be underrepresented in STEM. Increasing both the overall numbers and the diversity of STEM graduates is vital for our strength and competitiveness as a nation, and curricula modeled on V&C principles will be needed to recruit the widest possible pool of talent into the profession.

The good news is that biology education is well positioned to fix these issues, even within the "lecture plus laboratory" structure common to high school and college biology coursework. Lecture periods can be transformed to challenge students to think critically, make connections across disciplines, and work in teams (Kober, 2015). This is already working. A meta-analysis of 225 studies comparing active learning to traditional lecture format in university STEM courses indicates that examination scores improve (6% on average) and student fail less frequently (30% less) when active learning is utilized (Freeman et al., 2014). While 6% may not sound impressive, consider that it represents an average improvement of nearly a full grade, across hundreds of studies. Additionally, 30% fewer failures means that, in a typical, large introductory biology course of 200 students with a typical 20% failure rate, at least a dozen extra students would pass each semester, better understand science, and maybe even switch their major. The impact of such a change, semester after semester, at institution upon institution, would indeed be profound.

The same potential exists on the "laboratory" end. Undergraduate research experience improves actual and student-perceived ability to perform authentic scientific practices, student attitude and outlook on science, and student motivation to pursue a career within science (Hunter et al., 2007; Lopatto, 2007; Russell et al., 2007; Weaver et al., 2008; Jones et al., 2010; Brownell et al., 2014). It also improves academic performance and persistence to a degree, particularly for historically underrepresented students (e.g., Jones et al., 2010). Clearly, research experience is a good thing.

Unfortunately, such authentic research experiences generally take place outside the prescribed curriculum, and relatively few students (and disproportionately fewer underrepresented students – see Bangera & Brownell, 2014) have the opportunity to experience it. For a recent review on challenges and opportunities for individualized undergraduate research experiences (UREs) and course-based research experiences (CUREs), see Linn et al. (2015). But there is opportunity to craft authentic experiences in research within the structure of a classroom laboratory period (e.g., Lopatto et al., 2014; Wiley & Stover, 2014). Indeed, a four-step pedagogical framework used to simplify and streamline development of an authentic research experience has been developed and integrated into two separate undergraduate biology laboratory courses at two different academic institutions (Goedhart & McLaughlin, 2016; McLaughlin & Coyle, 2016). Throughout this framework, instructors act as research chaperones, guiding student scientists through each step while providing constant feedback and environments that allow time for student training in essential techniques, data collection and analysis, self-reflection, mistakes, trouble-shooting, and dialogue over assignments before their final submission for grading (i.e., protocol, notebook, scientific paper, poster, etc.). Importantly, the "four steps" approach scaffolds the scientific process, allowing students who are novices to the scientific process to progressively gain familiarity and comfort in inquiry-based skills. Moreover, this framework can last six weeks to an entire semester, depending on the needs of the students, instructors, or institution. Additionally, mentoring programs between faculty in four-year institutions, and between four-year and two-year institutions, show great promise to expand the availability of undergraduate course-based laboratory research projects with societal impact (Goedhart & McLaughlin, 2015).

The success of any initiative lies in the actions of all of us with "boots on the ground": we, the educators who walk into the classroom every day. Certainly there are challenges: budget cuts coupled with ever-increasing workloads, institutional pressures to "teach to" standardized tests, lack of time and support for professional development, rigid teaching blocks, tenure requirements, service expectations, and/or pushback from higher administrative levels (Addis et al., 2013). Still, change is happening, and a V&C update was recently published to reflect this: *Vision and Change in Undergraduate Biology Education – Chronicling Change, Inspiring the Future* (AAAS, 2015), setting forth specific, numerous, and tested strategies for changing the student experience in undergraduate biology, and providing guidance on evaluation of change strategies. If you have not yet joined this "revolution," what can you do, having realized the *Vision*, to implement the *Change*? Here are some ways to begin:

Start small. It can be daunting to comprehend, let alone implement, a change that seems to demand that you overhaul whole curricula, convince your colleagues to do the same, and – on top of it all – sell it to students who expect to sit there and be "taught." If there's anything that human beings have learned, it's that change starts small and goes slowly. Recall that old Lao Tzu nugget heard at many a graduation: "The journey of a thousand miles begins with a single step." Something as simple as replacing the PowerPoint with an old-fashioned "chalk talk" (whiteboards allowed!), ideally involving students coming up to help problem-solve, can improve student engagement. Or try just one hands-on activity and see where that takes you. A relatively easy example: rather than lecturing on mitosis, make sets of duplicated chromosomes from PVC pipe and spray paint (or pool noodles; Farrar & Barnhart, 2011), have students read about mitosis before class, then take the class outside, break into groups, and have each group design and perform a mitosis skit. Repeat for meiosis. Or try having students make their own videos of the process on iPads (Kamp & Deaton, 2013). Lectures on complex metabolic processes (e.g., protein metabolism) can be morphed into "treasure hunts" where students are given a set of questions that they investigate in groups, using textbooks or websites as resources (Why is ammonia so toxic? How is excess ammonia transported from the tissues? How does the liver deal with excess nitrogen?) We have both successfully used such approaches in the classroom. Engaging activities that make the students question why and how processes occur are remarkably effective at exposing student misconceptions and helping them really "get it" after multiple lectures have already failed. As a bonus, we find it exciting to walk around and help students working in groups reach those "aha moments." It fosters a connectedness with students that is missing in a traditional lecture period.

Don't reinvent the wheel. With so many educators thinking about V&C, there are numerous resources to find activities and approaches you can try in your classroom. Borrow shamelessly. Some of the best resource sites and biology education communities are listed in Table 2. From free, professionally produced and engaging films, case studies, and ready-to-go classroom activities, to biology educator communities that you can tap into, these sites are truly a treasure trove. To tie it all back to V&C, BioCore (a nationally validated tool) can be used to map the core concepts across the subdisciplines and provide a framework for faculty to integrate their own inspiration and expertise into the learning environments they create (http://www.biocore.wisc.edu/). CourseSource (http://www.coursesource.org/) provides online teaching and learning resources that tie together core concepts and learning goals framed from V&C mandates.

Reach out. Making change in a vacuum is hard. It may even be impossible. Finding a mentor, or a like-minded group, can make all the difference. Find colleagues in your institution who are willing to get together and support each other to learn more, or try new activities and innovations. Start a journal club to discuss articles from *ABT* or the freely available online journal *CBE–Life Sciences Education* (http://www.lifescied.org). Or take a free MOOC (massive open online course) together (e.g., "Introduction to Evidence-Based Undergraduate STEM Teaching," recently developed for Coursera: http://coursera.org). Brainstorm ideas. Help each other implement a student-centered activity that will work at your institution. Or break totally out of the box and ask a groomed educator in your own or another institution to mentor you! The American Society of Cell Biology's MALT program matches individuals with experienced teachers to develop effective and engaging teaching practices (http://ascb.org/mentoring-in-active-learning-and-teaching-malt). The PULSE and SENCER projects (see Table 2) also provide

Table 2. Resources for vision and change, active learning, and biology education research.

Resource	Mission/Goals	Offers	URL
Biology Scholars	Empowering biologists to be leaders in science education reform.	Professional development institutes; conference and publishing outlets; professional society networking.	www.biologyscholars.org
BSCS Biological Science Curriculum Study	Transform science teaching and learning to strengthen learning environments and inspire a global community of scientifically literate citizens.	Free and for-purchase teacher resources and instructional materials; online curricula; curriculum development and evaluation.	http://bscs.org
HHMI BioInteractive	Science resources for a flipped, blended, or traditional classroom.	Free virtual labs, short films and lectures, classroom resources, teacher guides.	http://hhmi.org/biointeractive
LifeSciTRC Life Science Teaching Resource Community	Online community for life science educators at all levels, with community and educational resources free and open to educators worldwide.	Over 6700 peer-reviewed teaching resources in K–college, particularly in anatomy, physiology, and cell biology. Most are free.	http://lifescitrc.org
NCCSTS National Center for Case Study Teaching in Science	Promote the development and dissemination of materials and practices for case teaching in the sciences.	Free, peer-reviewed case studies, training workshops, and conferences.	http://sciencecases.lib.buffalo.edu/cs/
PULSE Community Partnership for Undergraduate Life Science Education	Catalyze undergraduate life-sciences departmental transformation, leading to inclusive, student-centered, evidence-based teaching and learning.	Active learning/critical thinking resources. Networking, workshops, visitation teams.	http://pulsecommunity.org
SENCER Science Education for New Civic Engagements and Responsibilities	Engage students in STEM, help students connect STEM learning to other studies, and strengthen students' understanding of science and their capacity for responsible work and citizenship.	Free model courses, classroom resources, webinars. Will also make "house calls."	http://sencer.net

mentorship help; or contact one of the submitting authors in appendix A ("Projects in the Field" section) of the V&C *Chronicling Change* report (AAAS, 2015).

Get administrators on board. Given the stresses faced by educators at all levels, it can be hard to envision substantive change and the risk-taking it entails without having the support of institutional leadership. Help your administrator share in and understand your motivation for curricular change by using an evidence-based approach. Both V&C reports are a great place to start. In particular, the 2015 follow-up report outlines a "Framework for Change," intended to serve as a guide for departments as they work through the V&C recommendations. It includes advice on everything from raising awareness and building the capacity for change to hosting meetings on the goals of V&C, supporting implementation, and assessing results. For more intensive, institution-specific help, the PULSE Community V&C fellows program provides campus visits to facilitate productive conversations and strategic planning for promoting curricular change. The SENCER project will make "house calls" to institutions hoping to rework courses or curricula via local and global issues of civic importance.

Keep what works. It can be surprising how a small switch in approach can make a huge difference, without necessitating a complete overhaul of your fine-tuned lecture. Add a framing question at the beginning and application questions at the end. Teaching a signaling cascade activated by epinephrine? Start with a picture of a moose (or other threatening animal) and ask the students how their bodies would react. Once students have brainstormed some reactions, lead them through the pathway(s) that culminate in these physiologic responses. End the lesson with scenarios. Knowing the pathway, what happens if you give a drug that increases cAMP levels (e.g., caffeine)? A drug that blocks epinephrine receptors (e.g., beta-blocker)? Have students work through the scenarios in groups and come back together to discuss (Whitney et al., 2013). Or preview your Michaelis-Menten lecture with a hands-on enzyme kinetics activity in which a volunteer student plays the enzyme and the class collects data on the "enzyme's" performance (Runge et al., 2006.)

Incorporate research. Whether through whole-class or within-group discussions of scientific literature (e.g., Sato et al., 2014) or authentic research opportunities in a course laboratory, engaging students in scientific practice is key. A short video that showcases instructor and student perspectives on authentic research in the classroom, and faculty development via mentoring, can be found at http://vimeo.com/118326855. The pedagogical framework discussed above, used to transform biology laboratory experiences, is simple and flexible and can be easily adopted for use within the unique infrastructure and resource environments at a variety of institutions and at different levels of biological study (McLaughlin & Coyle, 2016).

The philosopher Alfred North Whitehead once said that "All of western philosophy is but a footnote to Plato." Indeed, the first Western institution of higher learning, Plato's academy, was founded on inquiry – on posing questions, one after another, to get to the truth. Thus, V&C did not drop fully formed from the heavens. It is the culmination of a long history of advocacy for learner-centered approaches that foster critical thinking and connectedness to the world. We educators entered into biology education because we desired to make a difference, to shape and prepare the next generation for the challenges ahead. In 2005, DeHaan envisioned an "impending revolution" – predicting that if widely adopted, active-learning strategies could profoundly impact scientific literacy and research (DeHaan, 2005). V&C is exciting because it is about *change* – and we, the NABT members, have the opportunity to fully engage in the revolution. V&C is the blueprint to help us get this done in the 21st century.

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