Who Should Change Biology Education: An Analysis of the Final Report on the Vision and Change in Undergraduate Biology Education Conference

Ruhul H. Kuddus
PhD, **Utah Valley University**, 800 University Parkway, Orem UT 840598
Phone: 801-863-6260, Facsimile: 801-863-8460, E-mail: Ruhul.kuddus@uvu.edu

Abstract

Biological sciences have become the frontiers of new discoveries, major tools of solving local and global problems and creators of new employments. The high rate of new discoveries in biological sciences; new advances in cognitive sciences, learning research, computing and informatics; enhanced fusion of biological sciences and other natural sciences; and the requirement of the learners of the digital generation have presented a multitude of challenges to biology teaching and learning. In meeting the challenges and making biology education more effective, the vanguards of biology educations in the United States, namely the National Science Foundation (NSF), the American Association for the Advancement of Science (AAAS), Howard Hughes Medical Institutes (HHMI) and the national Institute of Health (NIH) have organized a series of regional meetings during 2006-2007 and a national conference titled Vision and Change in Undergraduate Biology Education in 2009. The recommendations made by the experts participating in the meetings are summarized in the 2011 Final Report. The Report analysed the challenges quite comprehensively and made many recommendations on the changes needed in new biology education. However, the report placed the responsibilities of changing biology education largely to the biology educators. The present article is a reflection on the Report by a biology educator affiliated with an open enrolment large undergraduate university. The reflection indicates that structural changes though increased human and financial investment and a more concerted effort of the biology educators of high schools and colleges, education administrators, lawmakers, and community organizers are needed for an effective change in undergraduate biology education sought in the report.

Key words: biological sciences, biology teaching and learning, biology education

Introduction

The rapid growth in many fronts of biological sciences and the increased pace of overlapping of other natural sciences, engineering sciences, computation and informatics with biological sciences have presented many challenges in biology teaching and learning, particularly in the undergraduate levels. The challenges prompted the national biology education leadership in the United States to modernize biology education. The National Science Foundation (NSF) initiated a discussion among the biology educators in 2006 and later asked the American Association for the Advancement of Science (AAAS) to further the conversations. In 2007, AAAS with support from Howard Hughes Medical Institute (HHMI) and the National Institute of Health (NIH) initiated a series of regional conversation participated by many biology educators from community colleges to research universities. Using the recommendations of the regional conversations, AAAS and NSF organized the Vision and Change in Undergraduate Biology Education (2009), a national conference attended by over 500 educators from across the United States. I was among the participants of the 2009 conference. I presented a poster (on the role of student research in undergraduate education) and attended as many sessions as possible. Today I hardly recall what contribution I made to the outcomes of the conference. AAAS published the final report on the 2009 conference in 2011 (Vision and Change Final Report 2011). The conference attendants deliberated, among other items, on the following areas: (a) what students should know and be able to do in the set of courses that make up the biology curriculum; (b) innovative pedagogy and the integration of authentic research experiences into individual courses and biology programs overall; (c) assessment; (d) professional development for both the current and future faculty; (d) the kinds of changes that are needed at the institutional level; and (e) tools to facilitate and support change at various (e.g. courses, programs, institutions, etc.) levels.

Many US institutions and professional organizations organize conferences on biology education on a regular basis and many independent researchers, research institutions and professional organizations have prepared many reports on biology teaching and learning. The Vision and Change Conference is essentially the national initiative of the United States on the subject and a confluence of most of the professional organizations and the research leaders as well. The Vision and Change Report analysed most of the research findings and other reports available at the time. For that reasons, the Vision and Change Final Report is a landmark report in reforming biology education in the United States. Since United States is a predominant world leader in biology education and research, the Vision and Change Report could have an international impact.

As a biology teacher of an open-enrolment four-year public university, I strongly felt an urgent need for changes in undergraduate biology education. Since 2004, I have been trying to identify the most pressing problems of undergraduate biology education and implemented experiential methods of teaching and learning. To me, the 2009 conference and the 2011 Report were windfalls. The 2011 Final Report was published both in printed and electronic media but I am unsure how many biology educators studied the report. I circulated the electronic version among my local colleagues and distributed a few copies of the printed version to some of my international colleagues. I studied the Report a few times but I have not assessed the changes I accomplished. AAAS and NSF have planned a national conference (to be held in August 2013) titled 'AAAS Vision and Change in Undergraduate Biology Education: Chronicling the Changes.' The proposed conference most likely will assess the changes proposed in the 2011 Report. The present article reflects on each of the five chapters of the Report and the changes I accomplished in the past four years (2009-2013). Each of the sections of the article summarizes the corresponding chapter of the Report. The final section of the article is my reflection on the Report. The article ends with a number of concluding remarks. The present article is not a substitute of reading the actual Report. The goal of the present article is to propagate the Report so that biology educators may study the Report and debate the issues raised and recommendations made.

I. Biology Education for All Students

This chapter emphasized that new discoveries in biology has been taking place at a breath-taking speed due to the convergence of technological developments in biology and other fields including physical and chemical sciences and in computation and informatics. Progress in computation and informatics have made it possible to study enormous biological data sets. Thus students and teachers of tomorrow's biology must think and contribute beyond the disciplinary boundary. The students and teachers must be competent in the allied disciplines such as chemistry, geology, physics, computer science, engineering and social sciences. Fortunately, most college students take a (three hour 100 level general) biology course. This course offers college biology teachers an opportunity and responsibility to have the general biology students "gain a basic understanding of science as a way to learn the natural world."

The Report indicated that general biology students come with a diverse background and many are non-conventional students. All the students should gain a biology literacy that will make them better-informed citizens. The Report noted that effectively teaching such diverse groups is highly challenging but the educators have some resources available for themselves. For example, National Research Council (NRC) has published resources on cognitive and educational research on student learning (NRC 2000). A lot of new ideas and empirical data on effective (experiential) teaching and learning have been coming forth. The goals of new teaching are student-centred teaching and students developing the ability of critical thinking. The new teaching and learning would be helpful in solving national and global problems ranging from climate change to environmental pollution and food security to preservation of the biodiversity. The Report predicted that the recommendations will not generate an instant change but biology educators who read the Report would continue to work towards instilling functional biological literacy and critical thinking skills to the minds of all students taking general biology.

The 2009 Conference invited 231 undergraduate students (both biology and non-biology majors) and asked for their opinions on biology education. The students spoke highly of biology education, indicating the relevance of biology in everyday life and its importance in discharging ones role as an informed citizen. They also indicated the importance of biology education in global competitiveness, resource utilization and environmental stewardship. More importantly, the students wanted biology education to offer them problem-solving skills and a sound understanding of the scientific methods. In the final section of the chapter, the Report summarized some fifteen reports (published during 1986-2003) on how to improve undergraduate science education.

II. Biological Literacy

The Report stated that keeping an updated undergraduate biology curriculum is highly challenging given the enormity of the new information. Therefore, instead of a content-laden syllabus or a "one size fits all" directive, the Report proposed a series of adaptable core concepts and competencies. Students are intended not only to understand the core concepts but also to apply the knowledge in solving real biology-related problems. Although the new curricula are for the biology major, the core concepts and competencies would provide a 'solid foundation' in all students taking (the introductory) biology course. The five core concepts proposed are (i) evolution; (ii) structure and function; (iii) information flow, exchange and storage; (iv) pathways and transformation of energy and matter, and (v) systems.

The Report mentioned that the theory of evolution by natural selection is the fundamental organizing principle over the entire range of biological phenomena and "it is difficult to imagine teaching biology of any kind without introducing Darwin's profound ideas." The structure and function should be understood from "engineering, models and quantitative analytical data." For examples, the study of anatomy should corroborate the fundamentals of robotics and the study of enzymology should corroborate elements of rational drug design. The students are intended to understand how information is stored and that "all levels of biological organization depend on specific interactions and information transfer." In terms of pathways and transformation of energy and matter, students should understand the laws of thermodynamics and how the laws operate through the cells and the ecosystem. In terms of systems, students should learn how the theories of physical sciences could be used in discovering patterns and in constructing predictive models that elucidate biological processes.

The six core competencies and disciplinary practices listed by the Report are (i) ability to apply the process of science (i.e. students should be able to develop and test hypotheses, design experiments and conduct independent research); (ii) ability to quantitative reasoning (i.e. students should be able to use mathematical knowledge in studying biological systems); (iii) ability to modelling and simulation (i.e. students should be able to use computational algorithm in developing models and use available resources (software) for modelling and simulation); (iv) ability to tap into the interdisciplinary nature of science (i.e. students should be able to develop fluency in non-biology disciplines so that they can be an expert in an area of biology or work in a multidisciplinary team); (v) ability to communicate and collaborate with other disciplines (i.e. students should be able to effectively communicate with experts of non-biology disciplines using verbal, written and visual communication skills); and (vi) ability to understand the relationship between science and society (i.e. students should study case studies or some social science courses so that they can understand the bioethical issues and the effects of science on the society).

The Report advised biology educators to revise the existing biology curricula in the light of the core concept and competencies and initiate a cross-department discussion for a boarder change of the undergraduate curricula. The Report also recommended biology educators to introduce scientific methods early and in all courses, define learning goals around the core concepts and assess students on those goals, make connections between abstract concepts to real-life context, develop life-long learning competencies, discuss fewer concepts but in greater details, stimulate curiosity to natural world and show the passion as a scientist and an educator.

At the end of this section, the Report summarizes the opinions of introductory biology (Biology 101) students about the course. The students wished that the teachers should (i) fully explain the curriculum, preferably through a short seminar; (ii) divide Biology 101 students into three tiers depending on the level of preparation of the students; (iii) reduce the course contents but increase concept-oriented contents; (iv) remove the need of memorization, rather emphasize on problem-solving skills; (v) teach the course as a facilitator of class discussion, and assess student learning using 'essay type' of questions; (vi) be explicit on the learning objectives; (vii) make connection between lecture materials (theoretical aspects) and laboratory exercises; and (vii) make the course more interdisciplinary in nature.

III. Student-centred Undergraduate Biology Education

The Report noted that biology educators have been discussing the need for a new method of teaching for a while because the traditional (lecture-intensive) teaching and traditional assessment methods are outdated and ineffective. However, many biology educators are uncertain about how to connect teaching with learning and how biology education may lead to correct practice of science. Here, for the first time, the Report mentioned that educators are concerned about their students' need for the development of competencies, understanding of the concepts and acquisition of the factual knowledge. The Report supported the recommendations made by Handelsman et al. (2004) on developing a new course or redesigning an existing one. Thus the educators need to decide (i) what students should know and able to do; (ii) the appropriate level of mastery relevant to the level of curriculum; and (iii) what evidence is acceptable for assessing student proficiency.

The Report left it for the biology educators to define student-centred education but it mentioned that student-centred education should be interactive, inquiry-driven, collaborative and relevant. The Report also mentioned that student-centred learning "explicitly addresses learning and how to learn" and causes increased teacher-student and student-student interactions, argumentation, peer-review and feedback. The Report also instructed how to construct course curricula for student-centred learning by providing a good number of acclaimed publications (the items are also included in the References list of the Report).

For student-centred teaching, the Report endorsed 'scientific teaching' proposed earlier by Handelsman et al. (2004). In scientific teaching, educators update courses and curricula based on the evidences that students are "learning the ways of science and developing defined concepts and competencies." The courses should have clear and measurable learning goals and assessment tools to accurately measure how effectively the students are achieving the learning goals. The items to be assessed include "students' mastery of the facts, conceptual understanding, and acquisition of competencies and skills, as well as their attitudes and motivation' as previously suggested (Baldwin et al. 1999, Ebert-May et al. 2003). The assessment tools may include "objective questions, surveys, extended responses, problems, models, projects, (and) laboratory investigations." The student performance data should then be evaluated to learn "what do students understand, what is difficult for them to learn, what motivates the students, (and) how should instructions be modified to better facilitate student learning." The Report recommended frequent assessments and feedback so that student can be continually aware of their own progress and educators understand how students of diverse background add new knowledge to their personal knowledge base.

The Report repeatedly emphasized the alignment of the learning objectives and assessment tools used in a course. If the course emphasizes deep learning but multiple choice questions (MCQ) are used for assessment, the students will not learn the concepts but if the course is fact-based and the assessment method asks for higher-order thinking, then the students will be frustrated and discouraged to take a deeper look at the field. In addition, the assessment method should serve as a data collection tool (for the sake of scientific teaching and making teaching an on-going process of classroom research). The Report suggested that the ease of an assessment method and its ability to correctly evaluate student performance should be examined carefully. The Report noted that the assessment tools that are easier to administer are less effective in student evaluation. The common assessment methods are (i) MCQ and true/false; (ii) models, (iii) concept maps and quantitative responses; (iv) short answers; (v) essays, research papers and reports; and (vi) oral interviews; listed in the order of the level of difficulty and effectiveness in assessment (AAAS 2011). The Report also provided a sizable reference list describing various assessment methods.

The Report proceeded to state that once the course learning objectives and assessment methods are set, effective teaching methods should be implemented. It criticized traditional lecture-intensive method as ineffective and inhibitory to teacher-student and student-student interactions. However, the Report also appreciated that depending excessively on teacher-student and student-student interactions may reduce the coverage of the learning objectives and it may "dumb-down" the course. The Report suggested lecture as one of the many teaching tools. The other methods beside lecture include problem-based learning, case-based learning, model-based learning, peer-led team learning and team-based learning. The Report assembled a number of references describing successful teaching methods implemented in universities across the nation.

The Report described undergraduate research as an essential mean of student-centred learning. The Report promoted that research could be an integral part of any course. The intensity of student research may vary, from literature review to supervised hypothesis-driven independent wet laboratory research. The Report noted that classroom teaching is unable to provide a substitute for traditional student research experience. The Report cited a number of references supporting the point that research experience contributes to lasting student learning. Research opportunities may help students' confidence building, recruit and retain gifted undergraduates to biology research and propel the students to the national research enterprise. The report suggested the incorporation of some research activities in the introductory biology courses. Many universities, according to the Report, have established support system for undergraduate research and the Report recommended incorporation of research as a tool of engaged learning.

The Report summarized five different examples: *(i) Centenary College, Louisiana: A required laboratory research course in genetics for biology major; (ii) City University of New York (CUNY): C.R.E.A.T.E (Consider, read, elucidate hypotheses, analyse and interpret data, think of the next experiment) approach; (iii) National Centre for Science and Civic Engagement (NCSCE): the Science Education for New Civic Engagements and Responsibilities (SENCER) program; (iv) Little Big Horn College, Montana: Community-based participatory research (CBPR) projects; and (v) University of California, Los Angeles (supported by HHMI): The genetic basis of development and pattern formation research project)* that illustrated how research can be successfully incorporated into biology courses and curricula. The above examples indicate that the scope of incorporating research as an integral part of undergraduate biology curriculum is wide and creative. NSF has several programs including Research Experience for Undergraduates or REU (http://www.nsf.gov/crssprgm/reu/) program that offer funding for undergraduate research. A REU site can be either a US or foreign location. Research is a part of undergraduate learning in Britain, Australia and Canada (Healy and Jenkins 2009) and most certainly, many other countries. The Report's proposal of making undergraduate research an integral part of every undergraduate course is a bold new directive. Biology educators of the United States and other nations may reflect on the proposal and its potential impact.

The chapter concludes with the following suggestions to science educators (rephrased), (i) make students active participants in teaching all biology courses; (ii) use lecture and also other innovative teaching methods; (iii) make course active, outcome-oriented, inquiry-driven and relevant; (iv) facilitate student learning within a cooperative context; (v) incorporate research in all biology courses; (vi) integrate multiple assessment tools to track student learning; (vii) assess student learning frequently and give multiple forms of feedback on progress in student learning; and (viii) uses assessment as a data collection tool to improve and enhance (the course and) student learning.

The opinions of the invited undergraduate students on improving teaching and learning are also incorporated in this chapter. The students categorized lecture as frustrating and non-engaging, suggested the use of open-ended questions (in assessment) and creating small learning groups, use of multimedia (not just PowerPoint), and the use of quizzes during and after lecture to assess any possible disconnect. The students suggested inquiry-based and self-designed laboratories that can be messy instead of cookbook type laboratory aided by teaching assistants. The students also liked to have courses requiring reviewing the current and relevant real-world literature and a history/philosophy course in the biology curriculum.

IV. Preparing Campuses for the Challenges

The Report noted that biology educators have been discussing the need for a new method of teaching for a while because the traditional (lecture-intensive) teaching and traditional assessment methods are outdated and ineffective. In this chapter, the report emphasized the need of professional development of biology (and other sciences) educators. Professional development would confer appropriate skills to the science teachers for improved teaching and serving as the catalyst of change. Many universities, according to the Report, have structures for faculty development. Many professional organizations such as American Society for Microbiology (ASM) and American Society of Cell Biology (ASCB) have programs for faculty development. Finally, some national programs such as Project Kaleidoscope (http://www.pkal.org/) and the National Academies Summer Institute (http://www.academiessummerinstitute.org/) have faculty development components.

The Report also emphasized the need of developing the future science faculty. Today's graduate students and post-doctoral scientists, according to the Report, have many opportunities to gain training for effective teaching. For example, NIH has developed Academic Career Development Awards program (http://grants.nih.gov/) in 1999, NSF has developed Graduate STEM fellows in K-12 Education program (http://www.gk12.org/) in 1999 and HHMI has initiated an yearlong program for graduate students and post-doctoral fellows learn 'scientific teaching' (http://www.hhmi.org/).

The Report emphasized a pressing need for change in science education citing that the United States ranks 27th among developed nations in the proportion of college students receiving undergraduate degrees in science or engineering (NAS 2010). It also mentioned that 50% of the students started as biology major in USA relinquish biology as their major by their senior year. Most of the post-doctoral fellows in the United States are foreign nationals and there is a shortage of qualified pre-college science teachers. Although the number of science publication has increased globally by 40%, the same for the American-born scientists has dropped. The women and minorities constitute the majority of the US population but the two groups constitute a small minority of science professionals. The Report urges to pay attention to the above issues for a positive change in biology teaching and learning.

The Report described two institutions (the University of Colorado, Boulder and the University of British Columbia, Vancouver) that have initiated exemplary programs of recruiting and training future science faculties and mentioned that many other universities have a centre of teaching and learning (CTL). The Report advised biology departments to utilize the resources of the CTLs for professional development of the faculty members in order to change biology education. Although the professional development opportunities are expanding, the Report mentioned that many biology educators are uncertain if they should invest time to improve their teaching because their colleagues and administrators may not count the experiences towards their career advancements. Although much improvement is needed, the Report mentioned that administrators of many institutions and professional and discipline-centred journals have started to "judge peer-reviewed publications on discipline-related educational practice and research on a par with those reporting on disciplinary research, judging each on the basis of merit and scholarly impact."

In concluding the chapter, the Report suggested biology educators to undertake the following action items (rephrased), (i) mobilize all stake holders, from students to administrators, towards improving biology education; (ii) support the development of a community of scientists and educators for the advancement of the field and its edification; (iii) demand higher status and rewards for accomplished teaching innovators; (iv) require biology graduate students to engage in teaching; and (v) provide training opportunities to all biology faculty, specially postdoctoral fellows.

Finally the chapter summarized the opinions of the invited undergraduate students on faculty improvement. The students suggested that teachers should (i) be professionally trained (as an apprentice of an expert teacher if necessary); (ii) be given incentives to teach introductory courses; (iii) be aware of and consider student learning expectations and opinions; (iii) more readily available for consultations; (iv) organize internet resources where students could vent their opinions on teacher performance; (v) help students gain more quantitative abilities; (vi) offer more writing courses and consider more student presentations; and (vii) offer opportunities for students to take a variety of courses to 'stressing your mind'' without the risk of hurting their grades.

V. Unity of Purpose: A Call for Action

This chapter is continuation of the Chapter 4 with more emphasis on faculty development for changes in undergraduate biology education. The Report asserted that "faculty need a variety of resources, including ready access to on-going professional development opportunities; better instruments to help gather data on factual, conceptual, and skills-based student learning; and curriculum resources anchored in evidence-based practice and design principles of teaching and learning." The Report cited Anderson et al. (2011) in mentioning that, in addition to resources, "more support is needed at the institutional level, particularly in the form of changes in the faculty reward and support systems." The Report also proposed that undergraduate students should have a role of a collaborator in the process.

The Report also summarized the current resources available for the faculty. The resources include (i) curriculum and teaching materials available in Websites such as BiosciEdNet (BEN, http://www.biosciednet.org/) and HHMI Cool Science (http://www.hhmi.org/coolscience/); (ii) models of interdisciplinary workshops and meetings organized by various professional organizations such as ASM and internet resources such as National Center for Case Study Teaching (http://sciencecases.lib.buffalo.edu/cs/); (iii) assessment tools that can be developed jointly by biology and social science educators and existing tools such as SURE 2 (Lopatto 2008), SALG (Weston et al. 2006) and the Tuning

USA project (http://tuningusa.org/Projects.aspx); (iv) faculty development resources such as HHMI/National Academies Summer Institute (http://www.academiessummerinstitute.org/), the ASMs Biology Scholars Program (http://www.biologyscholars.org/), the SEI program at the University of Colorado at Boulder (http://www.colorado.edu/sei/) and the Minnesota State Colleges and Universities program (http://www.asa.mnscu.edu/facultydevelopment/index.html), and (v) an improved system for rewarding the faculty. The Report conceded that the resources available are not adequate and much has to be added. It praised the roles of many professional societies that are engaged in increasing the resource base. Here the Report, for the first time, mentioned the textbooks indicating that textbooks are convenient packages but use of textbook as the sole teaching tool is harmful.

The Report envisioned a virtual community of biologists for the sweeping changes required in undergraduate biology teaching, in the development of improved curricula, assessment methods and professional development of the faculty. In this line, NSF has created the Research Coordination Networks in Undergraduate Biology Education (RCN-UBE) to make such a community. The Report underscored that such programs needed to be more widely disseminated. Participants of the Vision and Change conference felt the need of the creation of a national clearinghouse of an education toolkit for the biology faculty with components such as best practices and best materials. Resources for the creation and nurturing of the virtual community had already started. The example includes the Evidence net of the Higher Education Academy of UK (http://www.heacademy.ac.uk/evidencenet), Multimedia Educational Resource for Learning and Online Teaching (MERLOT) of the California State University System http://www.merlot.org/merlot/index.htm), BEN of AAAS, and Cool Science of HHMI. The Report urged the biologist community to develop an Internet resource that would search like Google, recommend like Amazon, vet like Consumer Reports, and annotate like Wikipedia.

The Report is the excerpt of the conclusions made by the Vision and Change conference participants. The participants, according to the Report, made a commitment to unify teaching and research, so that the rift between biology teachers and science researchers or biology researchers and science educators can be removed. Since ‘scientific teaching’ and ‘classroom research’ make teaching more evidence-based and classrooms more student-centred, the participants initiated the unification of biology teaching and biology research. The participants imposed the reform on themselves and the science teacher community should join the effort to make teaching more effective. The Report realized the vision which indicates that undergraduate life science education need many changes including the following (i) education should be more active (students should do activities while being taught); (ii) education should be more concept-oriented (not fact-oriented, because biology contents are changing rapidly); (iii) contents (knowledge) and processes (application) should form a unified and not separate learning objectives; (iv) findings of cognitive and learning research should be applied in teaching; (v) active engagement and discovery learning should be applied in all courses but particularly in the introductory courses because those are the only science courses taken by most students and, most importantly (vi) the debate of “depth versus breadth" should be left behind in favour of depth and concepts since biology content is unsettled and too large to pack it in a few courses or even in the entire curriculum.

The chapter and the report closed with the description of the activities of two organizations, the Minnesota Partnerships (http://www.mnscu.edu/) and ASM Conference for Undergraduate Educators (http://www.asmcue.org/), that are highly active in faculty development and changing biology education. The sizable reference list of the Report contained a large number of publications on cognitive and learning research and education policies.

A Vision for Implementing Change

The points discussed in the Report were summarized under the heading 'A Vision for Implementing Change' showing the following action items aimed at ensuring that the vision of the conference becomes an agenda for change. To keep it absolutely straightforward, the action items are presented here unchanged.

1. Integrate Core Concepts and Competencies throughout the Curriculum

- Introduce the scientific process to students early, and integrate it into all undergraduate biology courses.
- Define learning goals so that they focus on teaching students the core concepts, and align assessments so that they assess the students' understanding of these concepts.
- Relate abstract concepts in biology to real-world examples on a regular basis, and make biology content relevant by presenting problems in a real-life context.
- Develop lifelong science-learning competencies.
- Introduce fewer concepts, but present them in greater depth. Less really is more.
- Stimulate the curiosity students have for learning about the natural world.
- Demonstrate both the passion scientists have for their discipline and their delight in sharing their understanding of the world with students.

2. Focus on Student-centred Learning

- Engage students as active participants, not passive recipients, in all undergraduate biology courses.
- Use multiple modes of instruction in addition to the traditional lecture.
- Ensure that undergraduate biology courses are active, outcome oriented, inquiry driven, and relevant.
- Facilitate student learning within a cooperative context.
- Introduce research experiences as an integral component of biology education for all students, regardless of their major.
- Integrate multiple forms of assessment to track student learning.
- Give students on-going, frequent, and multiple forms of feedback on their progress.

- View the assessment of course success as similar to scientific research, centred on the students involved, and apply the assessment data to improve and enhance the learning environment.

3. Promote a Campus wide Commitment to Change

- Mobilize all stakeholders, from students to administrators, to commit to improving the quality of undergraduate biology education.
- Support the development of a true community of scholars dedicated to advancing the life sciences and the science of teaching.
- Advocate for increased status, recognition, and rewards for innovation in teaching, student success, and other educational outcomes.
- Require graduate students on training grants in the biological sciences to participate in training in how to teach biology.
- Provide teaching support and training for all faculty, but especially postdoctoral fellows and early-career faculty, who are in their formative years as teachers.

4. Engage the Biology Community in the Implementation of Change

- Promote more concept-oriented undergraduate biology courses, and help all students learn how to integrate facts into larger conceptual contexts.
- Ensure that all undergraduates have authentic opportunities to experience the processes, nature, and limits of science.
- Provide all biology faculty with access to the teaching and learning research referenced throughout this report, and encourage its application when developing courses.
- Create active-learning environments for all students, even those in first-year biology courses.
- Encourage all biologists to move beyond the “depth versus breadth” debate. Less really is more.

VI. A Reflection on the Report

The Vision and Change Final Report is a milestone in biology education. It is anticipated that all undergraduate biology educators including the participants have studied the report and implemented many changes. Because of various preconceptions and preoccupation, I was unable to fully appreciate the recommendations of the Vision and Change conference till I studied the Report more critically. I still feel that the recommendations should be further debated by a larger group of participants and revised if necessary so that the needed changes can be accomplished in due time. My reflection on the Report presented below is to stimulate such a debate.

The high pace of discoveries in biological sciences seems to be a leading cause for the need of a reform in biology education. The pace of discovery has increased not only in biological sciences but many of the other natural sciences and engineering fields. As the scope of discoveries has increased, the scope of learning has increased as well. Information is now on the fingertips. Biology had been a descriptive subject for long till experts of other natural sciences, mathematics and informatics migrated to biology and traditional biologists embraced those disciplines. A large fraction of biological discoveries made today are in the fields of biochemistry, biophysics, bioengineering, biocomputing and bioinformatics. As much as those are sub-disciplines of biology, biology is a sub-discipline of chemistry, physics, engineering, computing and informatics as well. Therefore, biology needs not to be overwhelmed by the overlapping nature of modern science. For appropriate depth in learning, specific tracks could be established earlier (i.e. high school level) and new hybrid majors can be established.

Many students take biology as the career path because they either dislike other natural sciences and mathematics or they are not good at those. Mastering biochemistry, biophysics, bioengineering, biocomputing and bioinformatics may not be essential for many biology careers. Today, as much as half of the students with biology major relinquish the field before graduation. The biotechnology revolution has not delivered the promised employment boom as it was hyped. The average starting salary for graduates with a biology undergraduate degree is generally lower than that for the graduates with an undergraduate degree in other natural sciences and engineering (Department of Economics, Florida State University 2013). In addition, employment opportunity and job security in some of those areas are better. An increased demand of mastery in natural sciences, mathematics, computation and informatics may improve recruitment and retention but it may repulse many away from the field. Biology curriculum should be accommodative to all students because learning may not be completed at the undergraduate level. As the Report indicated, lifetime learning will continue to prepare the budding biologists for their career paths. Some of the greatest biologists, including Mendel, Wallace and Darwin were not highly competent in all natural sciences in their early life yet they made founding contributions to biology. In the classical age, some polymaths used to study biology. However, progress was accelerated when various disciplines were separated from the conglomerate of 'natural philosophy.'

That general biology is a required course in the US college curricula is a great accomplishment of the US higher education systems. While serving as a US Fulbright Scholar in South Asia, I observed that biology education for 'all students' ends by eighth grade in some countries and by tenth grade in all countries of the region. Thus, in those countries, students in tracks other than biomedical sciences may never have a formal course in biology in their entire adult life. While handling copies of the Vision and Change Final Report, I made appeal to biologists of several universities in the area to work towards including general biology as a required course at least up to the 12th grade level. As the invited undergraduate students opined in the Report, an understanding in biology is essential in solving the major problems our civilization is facing today and biology is the new frontier of expansion of economic activities and employment opportunities. It is difficult to imagine how a nation can accomplish real progress today if a large fraction of its citizenry does not formally study biology during the entire adult life.

The Report clearly established that the general biology course offers the biology educators a great opportunity as well as a great responsibility. In 2009-10, only about 8% of the undergraduate degrees conferred in the United States was in biomedical sciences (NCES 2011). Since general biology (Biology 101) is the only science course of many of the undergraduates, biology educators must instil scientific methods in the mind of the students, as the Report indicated. Equally important for a biology educator is to helping the students conceptualize how biology affects individuals, the communities and the biosphere.

The general biology students come from a diverse background and as the Report mentioned, teaching those students is quite challenging. The Report suggested that the biology educators can make use of the research findings of cognitive and learning research disciplines and may teaching and learning tools available today. The resources could be highly beneficial and even life changing to many biology educators. A good number of the suggested resources are indeed readily and freely available in the Internet. However, the Internet is an ever-expanding, dark and often spooky entity, similar to the outer space. If every biology educators, including the adjunct faculty cannot be invited to the Vision and Change type of discussions or faculty development schools, a bundle of the essential materials (as a hard copy) could be handed over to each biology educator and new and improved bundles should be made available on a regular intervals.

Although the general biology course is a cash cow for most biology departments, generally it is also one of the most neglected courses of the departments. Many of the general biology sections enrol hundreds of students and the adjunct faculty teaches over half of the sections. Irrespective of the educational qualifications and teaching skills, most of the adjunct faculty members earn a nominal remuneration for their services. Changes in this and many areas require financial investment but the Report generally avoided any discussion on new investment.

General biology students from other natural sciences come with a fair understanding of the scientific methods, the physical and chemical sciences and mathematics. Students coming from liberal arts disciplines come with a good communication skill but a smaller repertoire of the physical sciences and mathematics. Perhaps that is why the invited undergraduate students suggested a three-tire general biology course. Yet ‘one size fits all’ is generally the norm in teaching the general biology course. Emphasizing the overlap of modern biology, physical sciences, computation and informatics in the general biology course can be difficult and ineffective because it can be too much for some cohorts and too little for the other. A solution for this problem that conforms to the ‘three-tier’ suggestion of the invited undergraduates is creating general biology course sections such as Biology for Chemists, Biology for Engineers and Biology for Business Majors. Many biology departments have comparable courses such as Physics for Biologists and Computer Science for Biologists.

The Report described the five core concepts and six core competencies of the new undergraduate biology curriculum in sophisticated and literary English. The description could be equally effective if expressed in the language of biology. Biology educators from many countries around the world will inevitably try to learn from the Vision and Change Report. The choice of the core concepts and competencies, to my opinion, is comprehensive and complete. However, a few points can still be made. The Report positioned evolution as the number one core concept and went on to state "it is difficult to imagine teaching biology of any kind without introducing Darwin's profound ideas." In fact, many of the areas of modern biology can be taught without invoking Darwin's ideas. Evolution unquestionably is the central unifying concept of biology, but by choosing "evolution by natural selection" the Report opted a theory over a natural law. All scientific data demonstrate that all genomic entities evolve over time whereas there are many possible processes of evolution including natural selection and random genetic drift. Wallace conceived the theory of natural selection and contributed to its propagation as profoundly as Darwin. Darwin is neither the first nor the last word in evolution or biology and mentioning his name and no other founders of biology in the Report is surprising. Apparently it is a punch thrown at the factions that openly oppose teaching Darwinism in the public schools. There is enough confrontation in biology teaching and the Vision and Change Final Report could have left Darwin alone.

The Vision and Change final report reflects the aspiration of a great nation. The emphasis placed on other physical sciences, highly sophisticated computation and informatics (i.e. modelling and simulation) in the core competencies in the name of biological literacy for 'all students' is ideal. However, it should also have discussed what type faculty and student body the field generally recruits and what investments are needed for the change. The Report has placed the bulk of the responsibility of the change to the shoulder of the undergraduate biology faculty. Of course biology is their field and the biology educators should elevate the field as required but one should consider the capacity of the undergraduate biology educators. For example, a sizable fraction of the US high school graduates lacks adequate preparation to take college level general biology courses (Complete College America 2012) and undergraduate biology faculty has a very limited capacity to change that. Obviously a more concerted structural change is required.

Making "Less really is more" a catch phrase can be problematic. The debate of "depth versus breadth" must be left behind but the catch phrase may be taken out of context. Teaching only a fraction of the curriculum is already a norm in the college level and the catch phrase can embolden some to shrink it further. For example, an evolution enthusiast may finish the semester teaching a general biology course just like Frank McCourt's geometry teacher, preaching Euclid's biography instead of teaching geometry (McCourt 1999). Some of the undergraduate biology courses are part of the professional courses such as nursing and dental hygiene. Introductory microbiology is the only microbiology course these students take as budding professionals. Keeping these students unaware of many of the concepts can be problematic. There should be a prescription of a minimal dose and/or there should be some oversight on how the concept 'Less really is more' is implemented in the classroom.

The Report provided a good summary of the tools of teaching but the formula ultimately appear like 'one size fits all.' When students master the information before coming to the class, lecturing them on the text materials is certainly a waste of time. Unfortunately, many educators in our stratified undergraduate education system have to deal with more fundamental aspects of teaching such as "factual knowledge" and "understanding of the concept" as the Report has mentioned. Without factual knowledge and understanding of the concepts, methods such as active teaching, problem-based learning or game teaching approach can be a waste of time. Anthony Carnevale, director of the Georgetown Centre on Education and the Workforce, pointed out "Our post-secondary system has become highly segregated by class, by race and by ethnicity. It is more and more the case that the four-year college system is whiter and more affluent, [while] the two-year system is browner and blacker and more working class and some poor" (Abdul-Alim 2012). About 50% of the students entering two-year college and about 20% of the students entering four-year college are placed in remedial classes and many of these students never complete the remedial courses and just drop out (Complete College America 2012). Yet, sociologist Brand and her colleagues observed that enrolling at a community college has a modest positive effect on bachelor's degree completion for disadvantaged students who otherwise would not have attended college; these students represent the majority of community college-goers (Brand, Pfeffer and Goldrick-Rab 2012). In such undergraduate institutions, an effective method of content delivery for concept development (through remedial courses) is the first challenge. The Vision and Change participants came from all different types of institutions and the participants seems to be aware of the problem but apparently the body delved the problem superficially. I wonder how much contributions the faculty of the community colleges, junior colleges and open-admission universities made to the Report. How the proposed changes can be successfully implemented in these institutions is not adequately addressed in the Report.

Using teaching tools such as a textbook, intensive lecture and PowerPoint presentations, have become a habit of many biology educators. The Report has discouraged the use of all three. Some new biology educators have abandoned textbooks altogether. In some institutions, a textbook may limit student learning whereas in other institutions, a well-written textbook may serve as the anchor. Undermining textbooks could be counterproductive because it will discourage scholars from taking the painstaking and unrewarding task of writing textbooks. Scholars in the field critically examine and scrutinize the available information before constructing a textbook. In the absence of a good textbook, many students will be forced to rely on the spooky world of the Internet and the words of the teacher who could be a potential demagogue (Rochester 2003).

Chapter 3 of the Report will probably benefit biology educators the most for having a precise description of scientific teaching and the essential link between learning objectives and the assessment tools. Successful educators are quite passionate on their favourite assessment tool. The Report rated the assessment tools placing MCS at the bottom and the oral examination at the top. Many educators would disagree. An adept educator can develop MCS that can be used in assessing student learning at each of the seven levels of Bloom's Taxonomy (UTA 2013). Writing effective MCS is difficult but once the system is developed, evaluation of the answers is extremely easy, fast, accurate and unbiased. MCS is the primary assessment tool of for the majority of the standardized testing organizations. Wring effective MCS requires knowledge, skill and time. In contrast, writing short questions and essay type questions and jotting down questions for oral examinations are much easier but evaluating the answers accurately and objectively is much more challenging. The challenges include difficulties in interpreting student handwriting or accent, comparing the information presented by all the students of the cohort, making and remaking of the answer rubric and taking (or not taking) grammar and syntax into consideration. Every year the College Board hires thousands of biology educators to evaluate the essay-type questions of the AP Biology examination and terminates majority of the evaluators including seasoned educators.

That undergraduate research provides with a lasting learning experience is undisputable. As an undergraduate research mentor, I have observed that beside the 'lasting learning experience,' most students benefit enormously from their research experience in terms of their career advancements. It will be a great change if the Report's suggestion of incorporating 'some elements of research in each biology course, including general biology course,' is embraced by all biology educators.

The Report described the resources available for faculty development quite precisely and mentioned the limitations of the available opportunities. Fulltime tenure-track faculty members are enthusiastic in learning effective pedagogical methods during the first three years of employment. Thereafter, many educators become engaged in many other activities including campus politics, administration, community services, grantsmanship, and entrepreneurship and it may undercut the effort for professional development in terms of effective teaching. The culture of continual pedagogics education (CPE), similar to continual medical education (CME) enforced in the medical professions, could be highly helpful in changing biology teaching and learning. Most for-profit and many non-profit educational institutions now offer on-line courses. Many universities now offer Massive Open Online Courses (MOOC). The conventional universities will soon face significant challenges from online institutions. If the conventional universities fail to prepare students up to the expectations of the students and their employers, the students and their employers will find alternatives. Biology educators should develop a model for CPE to remain relevant, effective and competitive in the changing world of education.

As I mentioned earlier, the Report placed the major responsibility of the changes in the shoulder of the biology educators. On the average, the community college educators teach 18 credit hours and undergraduate university faculty members teach 12 credit hours. Most of the educators are also required to perform some administrate duties, student advising and research. Changing a long-held habit (of using conventional pedagogical methods), mastering the new skills, surviving student and peer-evaluations, adopting the suggested changes and engaged in a perpetual and ever-expanding research project of experimental teaching in the absence of a substantial new incentive can be too much to ask. The biology educators should be held responsible for their personal development but the Report also suggested the educators to become activists, to educate the administrators of the department and the institutions and to demand benefits, recognition and reward. The suggestions are naïve because biology or science educators constitute a small minority in a typical undergraduate institution. Instead, the Report could have proposed establishing an accreditation system for biology (and other science) departments, requiring an environment suitable for student-centred scientific education. Many departments, such as business administration and computer science departments of most undergraduate universities are accredited and such departmental accreditation is independent of the accreditation of the mother institution (the university itself).

Despite my criticism of the Report, the Vision and Change Conference and the Report have profoundly influenced me. I have not changed as much as the Report suggested and I liked to, partly because of my absence for a full one year from regular teaching activities. The following paragraphs summarize some of the changes I was able to accomplish. Since taking part in the Vision and Change conference, I have advocated the importance of the general biology course in home and abroad. I took part in designing assessment tools for general biology learning outcome in my home institution. I have taught a general biology course at least once a year whether I am at my home institution or abroad serving as a visiting scholar. I actively campaigned in the South Asian countries to incorporate general biology in the core curriculum at least up to the 12th grade level.

I have analysed the core concepts and competencies and found them already present in the existing biology curricula of the three institutions I worked for in the last four years. The emphasis given on the items by the Vision and Change Report has served as a necessary reinforcement. I used the core concepts and competencies as a reference while served in the teams of educators that developed the curricula of the Biotechnology BS degree program at the Utah Valley University and the Genetic Engineering and Biotechnology BS degree program of the East West University of Dhaka, Bangladesh and in updating the decade-old course curriculum of the Department of Genetic Engineering and Biotechnology of the University of Dhaka, Dhaka, Bangladesh. I successfully campaigned with my colleagues to incorporate molecular biology into the core curriculum of the Biology BS program at my home institution.

I have implemented scientific teaching in the classroom and observed that student-centred teaching can be ineffective for students lacking adequate factual knowledge of the subject and a clear understanding of the concepts. I developed a new approach that I called the 'micro-questioning' approach (Kuddus et al. 2008) for students' concept development. In micro-questioning approach, the students have to solve a number of MCQ built around each of the learning objectives and in the process the students are expected to develop the concept. The process also makes all the students partners in teaching and learning. I studied the art of developing high quality MCS [UTA 2013, VUCT 2013, Burton et al. 1991). I paid conscious attention (compared to the passive observation of the past) on the learning objectives and the actual student learning and updated the courses based on the observations. Unfortunately, I made no effort of conducting empirical research on this issue but I plan to do that in the future. I have been more enthusiastic in studying the outcomes of the cognitive and learning research outcomes and utilize vetted teaching and learning resources available in the Internet for making my teaching more effective. I used multiple teaching tools including lectures, group activities, animations, (low-level) simulations, quantitative reasoning, research, writing, educational tours, student debate and students attending seminars given by visiting scholars. I paid increased and active attention on frequent assessment and providing rapid feedback on student learning. I have played the role of an activist in terms of making research a part of undergraduate teaching and learning and tried to incorporate some research-like activities in each of the courses I teach.

I have given several presentations in my home and other institutions to propagate the message of the Vision and Change Conference. In the past I served as a resident scholar of the American Society for Microbiology, attended conferences organized by ASMCue and have become a part of the virtual community created by the AMSCue. Yet it appears to me that a few activist biology educators or biology departments will not be able to bring the changes necessary for the Change in undergraduate biology education, rather a more systemic effort will be necessary. Overall, the Vision and Change organizers have placed the future of biology and science education in the right track and hopefully the upcoming conference will accelerate the momentum.

Concluding Remarks

- Biology has been fragmented into microbiology, biotechnology, botany and many other undergraduate programs in the past. To accommodate the recent progresses, biology should be fragmented even further.

- Biology or sub-biology tracks should be established in the high school level so that students develop required depth in their field of study by the time they finish their undergraduate major.

- A more intense incorporation of other physical sciences, mathematics, computing and informatics should be enforced judiciously otherwise more students may abandon biology as a major.

- Biology departments should consider general biology as a primary and essential component and revamp the course in many different ways to satisfy the needs of students of different disciplines.

- General biology course should be taught in such as way that diverse student groups find the course as a mean of improvement of their personal life, a frontier of new discoveries, a mean for developing new products and services and a tool of solving local and global problems.

- Teaching evolution as a central theme of biology should not be confrontational.

- The recommendation “Less really is more” should be applied judiciously without compromising any of the core concepts and competencies.

- The publication and use of good textbooks, either paper or electronic, should not be discouraged.

- Considering MCS inferior and the essay-type questions superior as assessment tools is controversial. Educators should be advised to use the assessment tools that are adequate and the educators are most qualified to utilize them.

- Research should be a required component of undergraduate education and preferably a part of all courses including the general biology course as the Report indicated.

- In addition to motivating biology educators, the biology and science educator leadership should discuss an overall structural change in biology and science education in the pre-college and college levels and the human and financial capital needed for the needed changes.

- Biology educators of the conventional universities should be responsive to the needs of the employers of their students and be aware of the activities of the for-profit and non-profit online educational institutions.

- Biology and science educators should establish an institutionalized method of accumulating continuous pedagogics education (CPE) credits similar to CME credits required for medical professionals for enrichment and relevance.

- Recognized accreditation authorities should certify biology (and other science) departments, similar to business management and computer science departments, independent of the accreditation of the universities, so that the required faculty development and other changes can be enforced.

Acknowledgement

The author is grateful to Dr. Virginia Bayer for examining the manuscript and to AAAS and NSF for the opportunity to attend the Vision and Change in Undergraduate Biology Education Conference 2009. An earlier excerpt of the article was presented at the American Centre, Dhaka, Bangladesh in 2011, while the author was serving as a US Fulbright Scholar in Bangladesh.

References

AAAS (American Association for the Advancement of Science) (2011). Vision and Change in Undergraduate Biology Education: A Call for Change. http://visionandchange.org/ (accessed March 2013).

Abdul-Alim J. (2012). Expert: Stratification Undermines American Higher Education's Capacity for Enabling Social Mobility. Diverse Issue in Higher Education. July 24, 2012. http://diverseeducation.com/article/17239/# (accessed June 2013).

Anderson, W.A., Banerjee, U., Drennan, C.L., Elgin, S.C.R., Epstein, I.R., Handelsman, J., Hatfull, G.F., Losick, R., 0'Dowd, D.K., Olivera, B.M., Strobel, S.A., Walker, G.G., & Warner, I.M. (2011). Changing the culture of science education at research universities. Science, 331, 152-153.

Baldwin, J.D., Ebert-May, D., & Burns, D. (1999). The development of a college biology self-efficacy instrument for non-majors. Science Education, 83, 397–408.

Brand, J.E., Pfeffer, F.T., & Goldrick-Rab, S. (2012). Interpreting Community College Effects in the Presence of Heterogeneity and Complex Counterfactuals. California Center for Population Research, University of California, Los Angeles. http://papers.ccpr.ucla.edu/papers/PWP-CCPR-2012-004/PWP-CCPR-2012-004.pdf (accessed June 2013).

Burton, S.J., Sudweeks, R.R., Merrill, P.F., & Wood, B. (1991). How to Prepare Better Multiple-Choice Test Items: Guidelines for University Faculty. 1991. Brigham Young University Testing Services and The Department of Instructional Science. http://testing.byu.edu/info/handbooks/betteritems.pdf (accessed March 2013).

Complete College America (2012). Remediation: Higher Education's Bridge to Nowhere. www.completecollege.org (accessed June 2013).

Department of Economics, Florida State University (2013). Best undergraduate college degrees by salary, 2010-2011. http://www.coss.fsu.edu/economics/economics/salary (accessed June 2013).

Ebert-May, D, Batzli, J., & Lim, H. (2003). Disciplinary research strategies for assessment of learning. Bioscience, 53, 1221–1228.

Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., Gentile, J., Lauffer, S., Stewart, J., Tilghman, S.M., & Wood, W.B. (2004). Scientific teaching. Science, 304, 521–522.

Healy, M., & Jenkins A. (2009). Developing Undergraduate Research and Inquiry. The Higher Education Academy, York, UK. http://www.heacademy.ac.uk/assets/documents/resources/publications/developingundergraduate_final.pdf (accessed June 2013).

Kuddus, R., Toruno, C., & Khan, A. (2008). Effect of microquestioning approach of teaching biological sciences on student learning and learning strategies. Hawaii International Conference on Education Proceedings, 6, 2272-2289.

Lopatto, D. (2008). Exploring the benefits of undergraduate research: The SURE survey. In R. Taraban and R. L. Blanton, eds., *Creating Effective Undergraduate Research Programs in Science*. New York: Teachers College Press.

McCourt, F. (1999). *Angela's Ashes*. New York, Scribner.

NAS (National Academy of Sciences). (2010). *Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5*. Washington, DC: National Academies Press.

NCES (National Center for Educational Statistics, US Department of Education). http://nces.ed.gov/fastfacts/display.asp?id=37 (Accessed May 2013).

NRC (National Research Council). (2000). *How People Learn: Brain, Mind, Experience, and School*, expanded edition, Washington, DC: National Academies Press.

Rochester, M.J. (2003). Critical demagogues: What happens when ideology and teaching mix. Education Next, 3(4), 77-82.

UTAIAR (University of Texas Austin, Institutional Assessment Resources). (2013). Multiple-choice questions based on Bloom's Taxonomy. http://www.utexas.edu/academic/ctl/assessment/iar/students/plan/method/exams-mchoice-bloom.php (accessed March 2013).

VUCT (Vanderbilt University Center for Teaching). (2013). Preparing to teach. http://cft.vanderbilt.edu/ (accessed March 2013).

Weston, T., Seymour, E., & Thiry, H. (2006). Evaluation of Science Education for New Civic Engagements and Responsibilities (SENCER) Project. http://www.ncsce.net/About/pdfs/SENCER-EvaluationReport.pdf (accessed March 2013).