Cassandra L. Quave *Editor*

Innovative Strategies for Teaching in the Plant Sciences

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ISBN 978-1-4939-0421-1 ISBN 978-1-4939-0422-8 (eBook)
DOI 10.1007/978-1-4939-0422-8
Springer New York Heidelberg Dordrecht London

Library of Congress Control Number: 2014935157

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

This volume is dedicated to the educators that came before us, who introduced generations to this beautiful science called botany. It is also dedicated to those who follow, with the hope that our collective experiences will help them to inspire and instill a love and curiosity for plants in their students.

Preface

In his 1996 paper on the history of problems in botany education, Hershey noted that "As a result of plant neglect, the general public, most precollege teachers, and many college-level biology teachers are generally illiterate about botany." While botany once held a principal role in biology education—even at the high school level—its presence in the curriculum as a core focus topic has been in decline since the early 1900s (Hershey 1996). Moreover, this steady decline in botany education has been compounded by the overall challenges faced in STEM (science, technology, engineering, and mathematics) education. We have reached a critical state in botany education and creative solutions to reinvigorating this field in the classroom are in order.

Awareness of the need for integration of more innovative teaching methods in the biological sciences to boost interest in STEM at large has grown among biology educators since the publishing of the recent landmark document *Vision and Change in Undergraduate Biology Education: A Call to Action* (Brewer and Smith 2011). This document, which was the result of a series of professional meetings and workshops by science educators across the United States (USA), was published by the American Academy for the Advancement of Science (AAAS) and funded by the USA National Science Foundation (NSF). One of the key areas recommended for change included a call for better integration of core concepts and competencies throughout the curriculum and a focus on student-centered learning. Moreover, the document called for engagement of the biology education community in the implementation of the proposed changes.

These changes are of particular importance for the field of botany, which is arguably becoming progressively neglected by educational institutions. This is underscored by recent trends towards the "phasing out" of botany lessons, courses, and even entire botany programs and departments at institutions across the United States. Unfortunately, this may not only result in a critical shortage of new scientists with expertise in this field, but it also comes at a time when trained botanists are most needed to address important emerging issues concerning biodiversity management, biotechnology, food security, and climate change.

Another challenge that we face as botany educators is that for those students who do have access to botany lessons, it can be difficult to cultivate interest in the material. Pedagogical techniques that rely heavily on rote memorization of plant names and characteristics are hardly stimulating to students, and in many cases, they may walk away from a course without ever seeing the “big picture” of why plants matter both to them as individuals and the world at large. In other words, without context, it is incredibly difficult—or even impossible—for students to become engaged with the plant world and make those crucial connections that are necessary for integration of knowledge into their long-term memory. The truth of the matter is that we need to foster student enthusiasm for the plant sciences in order to both encourage the growth of future experts in this field and to cultivate a global community of citizen scientists with an appreciation for and connection to their environment that is mostly plant-based. Ethnobotany, which is the interdisciplinary study of how people interact with plants, can be used to fill in this contextual gap in plant science education by helping students understand their personal and cultural relationship with plants, revealing the practical and persistent value of plants on an individual level.

In 2007, a group of scientists that were developing interdisciplinary undergraduate curricula in ethnobiology met to discuss some common problems encountered in this process. They decided to form the Open Science Network (OSN) to foster both the exchange of ideas and sharing of educational resources. Over the years since it was founded and with the financial support of the NSF, the OSN has brought educators from the natural and social sciences together in a series of workshops with the aim of developing educational standards and compiling resources for teaching initiatives in the field of ethnobiology. One major product of these efforts was the OSN’s report, *Vision and Change for Ethnobiology Education in the USA: Recommended Curriculum Assessment Guidelines* (McClatchey et al. 2013), which was modeled after the AAAS *Vision and Change* document. Like the original V&C document, the OSN report emphasized the need for the inclusion of core concepts and competencies in the curriculum. The idea of using ethnobiology as a tool to bring botany into context for students was highlighted as a means of meeting several of the core competencies listed in V&C, including those concerning the ability to tap into the interdisciplinary nature of science, the ability to communicate and collaborate with other disciplines, and the ability to understand the relationship between science and society. The importance of ethnobiology in the advancement of education in the plant sciences is further developed in a series of case studies in the present volume.

This volume brings together a collection of papers addressing the challenges of botanical education in the twenty-first century, while highlighting novel approaches to engaging students in botanical curricula with the aim of inspiring a new generation of students and instructors. While the approach to education in the plant sciences is explored from varying perspectives, a common focus here is on the innovative ways through which educators can both enrich the plant science content being taught and improve upon student engagement in the study material. Drawing on contributions from scholars from the United States, Europe, and Canada, various teaching methods are demonstrated and both the successes and challenges of different methods are explored. Uniquely to this volume, several chapters describe how core principles from ethnobotany can be used to foster the development of connections between students, their environment, and other cultures around the world.

The 18 chapters included here are organized into five focus areas: (1) defining the needs of educators and students, (2) introducing fundamental skills, (3) connecting students to plants, (4) teaching through field experiences, and (5) integrating technology. These contributions represent a broad spectrum of approaches in botanical education, ranging from community outreach efforts, K-12 education, distance learning, and university programs and courses. Central to the theme of the volume is the concept of creating a sense of connectivity to nature as a tool for capturing student interest in the study material, and helping them to appreciate the critical role that the plant sciences play in everyday life. Perhaps most useful to educators is that many of the contributions also include examples of how a wide range of teaching techniques can be used in plant science education, including authentic learning, student-centered learning, active learning, research-based learning, and mind/brain-based techniques, among others. Ranging from veteran teachers to new faculty, the contributing authors discuss their vision for the future of plant science education and provide concrete examples of how they incorporate local resources and technology into a hands-on approach to teaching and learning in this field.

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Cedric Barrett Baker, Pharm.D., is an ethnopharmacist, food-ethnopharmacognosist and medical botany historian. He holds a Doctor of Pharmacy degree from Mercer University, College of Pharmacy and Health Sciences, where he studied Pharmacognosy with (the late) Dr. Hank Cutler. Dr. Baker has postdoctoral research training from the NIH-ODS and the NIH-NCI Cancer Prevention Division with Dr. John Milner, et al. He has studied ethnobotany and ethnopharmacology at the graduate level with Dr. Dennis McKenna and Kat Harrison at the University of Minnesota-Twin cities. His specialty is in the area of traditional functional/medicinal foods and diets, and their integrative use in traditional dietetics, ethnomedicine, and biomedicine (Southeast Asia/Italy). Dr. Baker was the Sonnedecker Visiting Scholar in the History of Pharmacy for Fall 2009 at the AIHP in the University of Wisconsin School of Pharmacy, Madison. He has several peer-reviewed publications in integrative therapeutics, functional foods, history of pharmacy, and the phytopharmacology of plant foods.

Janelle Marie Baker, M.S., is a Ph.D. student in Anthropology at McGill University. She is a Warren Fellow at the McGill Institute for the Study of Canada, a Vanier Canada Graduate Scholar, and a Canadian Federation of University Women Canadian Home Economics Association Fellow. Her research is on Cree perspectives on wild food contamination in the oil sands region in Canada. This research topic is a response to community's concerns voiced during 6 years of applied work that she did for First Nations doing traditional land use studies and traditional environmental knowledge research and training. She has designed and taught an ethnobotany course for the International Indigenous Studies Program at the University of Calgary, and she continues to tutor for the Anthropology Department at Athabasca University (including an online community-based research methods course that she designed). Ms. Baker has also done ethnoecology research and undergraduate instruction for an NGO in Indonesian Borneo.

Keri Barfield is the Research Programs Manager for the Botanical Research Institute of Texas (BRIT). She has worked in the past on the various international and local research projects at BRIT that included the Andes to Amazon Biodiversity Program and research in New Guinea. She has a background in biology, botany, and ecology. She is a Research Associate with Texas Christian University, where she is currently working with colleagues on phylogeography of two specific pine species. In addition, she has been the project manager for the Open Science Network in Ethnobiology (OSN). The OSN is a collaborative network open to educators and students interested in the exchange of innovative curricula and educational resources that advance the field of ethnobiology. Funded by the National Science Foundation (NSF), the OSN uses open technology to facilitate the exchange of educational techniques, materials, and experiences across institutional and international borders.

Michael Benedict, M.S., received an AAS Degree in Forestry from Paul Smiths College, N.Y., 1976, an AAS Degree in Natural Resources from Haskell Indian Nations University, KS, 1995, a B.S Degree in Systematics and Ecology from the University of Kansas, KS, 1998 and an M.S. Degree in Forestry from the University of Minnesota, MN, 2001. His Master's thesis covered the "Ecology of Black Ash: A study of ring growth and regeneration and its relationship to Native Black Ash Basketmakers." He is a former instructor at the North House Folks School in Grand Marais, Minnesota. He learned basket making from two elders from the Akwesasne Mohawk Nation in the early 1980s, learning both weaving techniques and making basket-making tools. Mr. Benedict is currently working as a Professional Forester in Colorado.

Bradley C. Bennett, Ph.D., is a Professor in the Department of Biological Sciences at Florida International University in Miami, Florida. He earned a B.A. (Biology and Geology/Geography) from Bucknell University, an M.S. (Biology) from Florida Atlantic University, and a Ph.D. (Botany) from the University of North Carolina at Chapel Hill. From 1988 to 1992, he was a postdoctoral fellow and research associate at the New York Botanical Garden's Institute of Economic Botany. He was the 2004-2005 president of the Society for Economic Botany and currently is an associate editor of the journal *Economic Botany*. He is also a member of the American Botanical Council's Advisory Board and serves on NIH's National Center for Complementary and Alternative Medicine Special review panels. His main research focus is neotropical ethnobotany and ethnopharmacology. Dr. Bennett's book *Ethnobotany of the Shuar of Amazonian Ecuador* won the 2006 Mary W. Klinger Book Award from the Society for Economic Botany.

K. W. Bridges, Ph.D., recently retired from the University of Hawai'i at Mānoa. His early academic career started in zoology, with an M.S. degree from the University of Hawai'i. He moved to the broader field of Biology for his Ph.D. degree where he used the then emerging access to computers and computer graphics to study quantitative definitions of leaf shape. He joined the NSF-sponsored Desert Biome study headquartered at Utah State University after graduation. After a few years, he returned to the University of Hawai'i to work with the Island Ecosystems research project and to teach in the Botany Department. His wide academic interests, which generally bringing quantitative techniques into a variety of disciplines, led him to teach and do research in botany, geography, computer science, and tropical agriculture. The major focus of his research has been on systems ecology, marine flowering plants, island ecosystems, and ethnobotany. He was deeply involved in teaching introductory courses through his career and was recognized with the UH Regents Medal for Excellence in Teaching. Dr. Bridges has collaborated with Dr. McClatchey on a number of field studies and innovative educational initiatives.

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Al Kealiʻi Chock, Ph.D., was born and raised in the Territory of Hawai'i. He attributes his interest in Hawaiian culture to his teacher-mother (fourth grade), and botany his high school science teachers. He attended Hannibal-LaGrange College (A.A.), University of Hawai'i at Mānoa (UHM) (B.A., M.S. in Botany), and University of Michigan (AbD). In non-academic situations, nearly all of which involved people and plants, Dr. Chock worked for the U.S. government for 38 years: National Park Service, European Exchange Service, Army & Air Force Exchange Service, U.S. Department of Agriculture (USDA), Environmental Protection Agency (Office of Pesticide Programs) and Food & Agriculture Organization of the United Nations (FAO). He retired in 1992 from the USDA Foreign Service. He began teaching Botany 105 (Economic Plants of Hawai'i and the Pacific) in 1961 and had the course name changed to Ethnobotany in 1964. Since 1992, Dr. Chock has been a UHM Botany adjunct faculty member, where he teaches the Botany 105 Honors section and summer session, and Hawaiian Ethnobotany. He is also a core team member of the Open Science Network in Ethnobiology (OSN). Visit his website at http://www.alchock.info/.

Maria Fadiman, Ph.D., conducts ethnobotanical research (how people use plants) in a global context. She was named one of National Geographic's Emerging Explorers in 2006. In addition to conducting most of her studies in the rainforests of Latin America, she has also researched in Africa, Asia, and Oceania. She currently works on an international cross-cultural study of people's use of plants, and how their utilization can encourage cultural and ecosystem preservation. She completed her undergraduate work at Vassar College, M.A. at Tulane University, and Ph.D. at the University of Texas at Austin. She is an associate professor at Florida Atlantic University in the department of Geosciences.

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Karen C. Hall, Ph.D., grew up with 50 acres of playground in the mountains of North Carolina, and this inspired a lifetime of interest in nature, including the embedded human component. She completed a B.S. in Biology (Western Carolina University), M.S. in Botany, and Ph.D. in Plant Physiology (both at Clemson University). Her dissertation work was focused on knowledge structure and management of medicinal plant practitioners within the Eastern Band of Cherokee Indians in North Carolina. As a living example of this work, she designed and developed the Cherokee Worldview Garden. She is intensely interested in traditional ecological knowledge with specific foci in landscape management, fiber and dye technologies, and sustainable practices. Her childhood played a significant role in a desire to create more people with curiosity and enthusiasm for nature and, thus, she is also an educator. Karen is the former Director of the SC Master Naturalist and Master Gardener programs. Most recently, she moved to Texas to become the Applied Ecologist for the Botanical Research Institute of Texas, where her primary focus is restoration ecology and outreach.

Patricia Harrison, M.Ed., is Vice President, Director of Education, for the Botanical Research Institute of Texas (BRIT), a non-profit research and education organization dedicated to conservation. She has helped guide the growth of the organization and leads its dynamic education program designed to connect people of all ages to nature in ways that build environmental literacy and promote stewardship of our natural resources. She currently is developing an Environmental STEM Innovation Center to engage schools and the public with BRIT's botanical research. Pat is PI for the NSF RCN-UBE Open Science Network for Ethnobiology and contributing editor to the Vision and Change for Ethnobiology. She has authored numerous botany curriculum resources for elementary learners and is a member of the Education Committee for the Society of Economic Botany.

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Kelly Kindscher, Ph.D., is a passionate advocate for native plants and their uses, native landscapes, and wild places. He works at the University of Kansas at the Kansas Biological Survey, where he conducts research throughout Kansas, the Midwest, and the Great Plains and Rocky Mountain states; and in the Environmental

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Will McClatchey, Ph.D., is currently Director of Research, Botanical Research Institute of Texas, Fort Worth, Texas, grew up in the Southwestern USA, and then attended high school and college in the Northwest USA. He earned his B.Sc. degrees in Anthropology and Pharmacy from Oregon State University and then worked as a community and consultant pharmacist for 10 years, during which time he earned an M.S. in Botany and Range Science (Ethnobotany) from Brigham Young University and a Ph.D. in Botany (Evolutionary Biology) from the University of Florida. He has conducted ethnobotanical research in the Southwest Pacific region and SE Asia since 1990. His research focuses on understanding systems function of artificial ecosystems produced by humans, and how management decisions within these systems are impacted by changing environmental conditions. For 15 years he was Professor of Botany at University of Hawai'i, where he developed the world's first B.Sc. in Ethnobotany degree program and has taught thousands of students about Ethnobiology and Conservation Biology. He particularly enjoys working with students in field settings where real research is accomplished.

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Valentina Savo, Ph.D., is an ethnobotanist whose research aims to include a more complex view of the relationships between humans and the environment. Since 2003 she has been working on several different projects spanning from Mediterranean plant ecology, bioclimate, ethnobotany, Traditional Ecological Knowledge (TEK), and plant iconography. She has recently been awarded a postdoctoral fellowship from the Foreign Affairs and International Trade of Canada and has joined the Hakai Network as a Hakai Postdoctoral scholar. Her research explores Coastal First Nations' observations of and adaptations to climate change in British Columbia. Dr. Savo has an excellent track record of publications (in peer-reviewed journals and books) and fellowships with a wide network of international collaborations.

April T. Sawey, Ph.D., is a researcher and environmental educator working with a non-profit conservation organization to promote environmental stewardship through awareness of the crucial role plants play in our daily lives and in the sustainability of our planet. She has experience as a K-16 teacher, academic dean, and administrator, but now applies her skills in the non-formal learning environment. After completing her Bachelor's degree in Biology and her Master's degree in Education, she decided to expand her knowledge of the natural world by choosing a science education doctoral program in which she could focus on environmental science and education. Her research interests include phenomenological approaches to emotional connections in experiential learning, significant life experiences, place-based and mind/brain education. She lives in Fort Worth with her husband Michael and her daughter Alara. They enjoy native plant and vegetable gardening—sometimes in their front yard when their HOA will let them get away with it! Dr. Sawey is a Research and Evaluation Specialist at the Botanical Research Institute of Texas.

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John Richard Stepp, Ph.D., is Associate Professor of Anthropology at the University of Florida. He is occasionally a visiting professor at the University of Gastronomic Sciences in Pollenzo, Italy and Minzu University in Beijing, China. From 2008-2009 he was the Wilder Professor of Botany at the University of Hawai'i. He has conducted ethnobiological research over the last two decades in Central America, Mexico, North America, and Southeast Asia. His research explores persistence, change and variation of traditional ecological knowledge, and ethnobotany. Much of this work has focused on wild food plants and medicinal plants. His work has also focused on patterns in the distribution of biocultural diversity. Other research interests include the anthropology of food, medical anthropology, visual anthropology, GIS and land use change, and human perceptions of climate change. He is the founding editor of the *Journal of Ecological Anthropology*, former editor of *The Journal of Ethnobiology*, and currently senior associate editor of *Economic Botany*, associate editor of the Journal of *Ethnobiology and Ethnomedicine*, and associate editor of the *Journal for the Study of Religion, Nature and Culture*. He is also involved in documentary and ethnographic film production on topics both related and unrelated to his primary research.

Sofia A. Vougioukalou, Ph.D., is a medical ethnobiologist with a background in biology, medical anthropology, and impact evaluation. She is an Honorary Research Associate at the School of Anthropology and Conservation at the

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Gail E. Wagner, Ph.D., is an Associate Professor of Anthropology and associated faculty in the School of the Environment at the University of South Carolina, Columbia. She earned her Master's and Doctorate degrees in Anthropology from Washington University in St. Louis. Dr. Wagner researches the relationships between people and plants, both past and present, in the southeastern United States. Her current paleoethnobotanical projects focus on periods of social transition and changing foodways. She has particularly delved into human relationships with maize (*Zea mays*), beans (*Phaseolus vulgaris*), tobacco (*Nicotiana*), and sumpweed (*Iva annua*). Her ethnobotanical projects focus on biocultural diversity as expressed through botanical knowledge. She heads an archaeological research project tracing the origins and demise of the chiefdom of Cofitachequi in central South Carolina. Dr. Wagner won an award for her teaching of undergraduate students at the University of South Carolina, and has spent many years thinking and publishing on education.

Part I
Defining the Needs of Educators and Students

Chapter 1
Carrying Plant Knowledge Forward in the USA

Patricia Harrison

1.1 Background

At a time when the demand for botanical expertise has been the most critical to addressing threats to biodiversity and the environment, the supply of qualified botanists is shrinking. A study led by the Chicago Botanic Garden in 2010 indicates that botany education has been declining since the early 1900s, resulting in the loss of critical infrastructure needed to support botanical training (Kramer et al. 2010). Herbaria are being disbanded and universities continue to eliminate traditional botany courses as plant science is integrated into multidisciplinary studies (Kramer et al. 2010). Research indicates individuals are not being trained with the skills and knowledge needed to fill essential jobs in science and resource management (Sundberg et al. 2011).

1.1.1 Botanical Training and Economics

From an economic perspective, this decline is indicative of a larger problem with the education system in the USA. For over a century, America's economic strength was built on its scientific capacity for innovation to meet the world's manufacturing and technology needs. The nation was jolted out of complacency when unemployment began to rise as more and more jobs were being moved to other countries due to a workforce unprepared for the jobs that were in demand (Stephens and Richey 2013). The acknowledgment led to a hard look at the public education system that revealed how far the USA lagged behind other countries in math and science scores, a full decade after the National Science Education standards were implemented (NCES 2011). Some alarming aspects of this report include the following statistics and predictions (NMSI 2013):

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C. L. Quave (ed.), *Innovative Strategies for Teaching in the Plant Sciences*,
DOI 10.1007/978-1-4939-0422-8_1, © Springer Science+Business Media New York 2014

- US students recently finished 25th in math and 17th in science in the ranking of 65 countries (NCES 2011).
- Women currently constitute 48 % of the US workforce but hold just 24 % of the US jobs in STEM (science, technology, engineering, and mathematics; Beede 2011).
- Sixty percent of the new jobs that will be open in the twenty-first century will require skills possessed by only 205 of the current workforce. Two-thirds of those jobs will require at least some post-secondary education (NCMS 2000).
- US scientists produced more than 40 % of scientific papers in 1981, but now that number has shrunk to 29 %. The USA is no longer the leader in the field of research as China leads the emerging nations with 1.4 million researchers. For the first time, over half of US patents are being awarded to non-US companies (Ratchford and Blanpied 2010).

In a nation with so many advantages, why has the US education system lost its competitive edge? One of the cultural trends that we are less proud is the outbreak of television reality and game shows that clutter the minds of countless Americans. One such show is called, "Are You Smarter Than a 5th Grader?" in which contestants are asked questions that fifth graders should know. Yet, if one listened to fifth graders speak, mere interpretation of their conversations would likely be challenging. Morphed words and abbreviations used in instant messaging (IM) and texting are becoming part of the language code young people use. This modern phenomenon reveals one of the big issues in our education system. Technology is changing the way our young people think and learn…and communicate. The challenge in education is to adapt to changing students with different learning styles.

In addition, schools are struggling with limited financial and human resources to meet the demands of increased numbers of students they must serve. A high percentage of students enter with language challenges and deficiencies in basic reading and math skills. Most are adept at basic technology skills but are lacking in communication skills and the ability to think critically. The need is for an education system that prepares students for jobs in the twenty-first century, some of which will require skills and technology we cannot imagine (P21 2011).

In an effort to address this growing concern, a plethora of new tools and initiatives have been launched within this decade. The nation is now facing the acknowledgment that to be competitive in the global economy, we need to be preparing students who can "think for a living" and can apply their thinking to complex, real-world problems, using scientific and technological knowledge (Alberts 2013).

In 2009, the White House announced a new campaign for promoting STEM education called "Educate to Innovate" (White House 2009). The administration's goal is to move American students higher to the top in science and math achievement over the next decade. President Obama has identified three overarching priorities for STEM education: (1) increasing STEM literacy so all students can think critically in science, mathematics, engineering and technology; (2) improving the quality of math and science teaching so American students are no longer outperformed by their peers in other nations; and (3) expanding STEM education and career opportunities for underrepresented groups, including women and minorities. Major funding for education has been committed to this initiative through both federal and business partnerships.

The Framework for twenty-first Century Learning focuses on the integration of skills into core academic subjects. It emphasizes the “3 C’s” essential for success in today’s world: critical thinking and problem solving, communication, and collaboration. It recommends integration of these three skills into the teaching of all core subjects, not just science (P21 2011).

The National Research Council has announced the development of *The Next Generation Science Standards* (NGSS) that are being called the “fewer, clearer, and higher standards” (Achieve 2013). These build on literacy and math from a science education perspective. The hope is that new guidelines will focus on not only what it will take to be a successful student, but also what it takes to be a successful employee. They take a firm stand on controversial topics, such as evolution and climate change, as essential to a high-quality science education. To date, 26 states have adopted NGSS for their schools, while some states are rejecting them due to the inclusion of evolution and climate change (Stage et al. 2013).

The trend in education, being reinforced through the new standards, is multidisciplinary learning (Brewer and Smith 2011). At all levels, sciences such as botany are not being taught in isolation but are integrated into multidisciplinary science courses such as environmental science or ethnobotany. Students are being trained as generalists, not specialists (Kramer et al. 2010).

1.2 Challenges in Botanical Education

1.2.1 Obstacles to Teaching in the Plant Sciences

In a local investigation, K-12 educators representing multiple disciplines were surveyed about their botanical knowledge. Results indicate a broad spectrum of interest and aptitude in passing along knowledge to the next generation. Of the educators surveyed, representing multiple disciplines of teaching, there was a direct correlation between a teacher’s interest in the three categories of plants sciences and their knowledge. Yet, on an individual basis, there was no correlation between self-ranking of their plant knowledge and the level of plant science they were teaching. About 57 % of the early childhood educators ranked their knowledge about plants greater than elementary and middle school teachers and their interest in plants greater than elementary teachers. Early childhood teachers also included how plants are used by people in their curriculum more than all other grade levels (Harrison 2013; Fig. 1.1).

When asked about the obstacles for including plants in their curriculum, the majority of respondents indicated that plant studies are not well represented in their state standards, and therefore not in their curriculum framework. The second greatest obstacle was time, i.e., the time to find and incorporate lessons on plants while managing to cover all the necessary objectives during the school year. At the middle school and high school level, some teachers expressed their own lack of knowledge about plants as a hindrance from including it in their curriculum. Others claimed

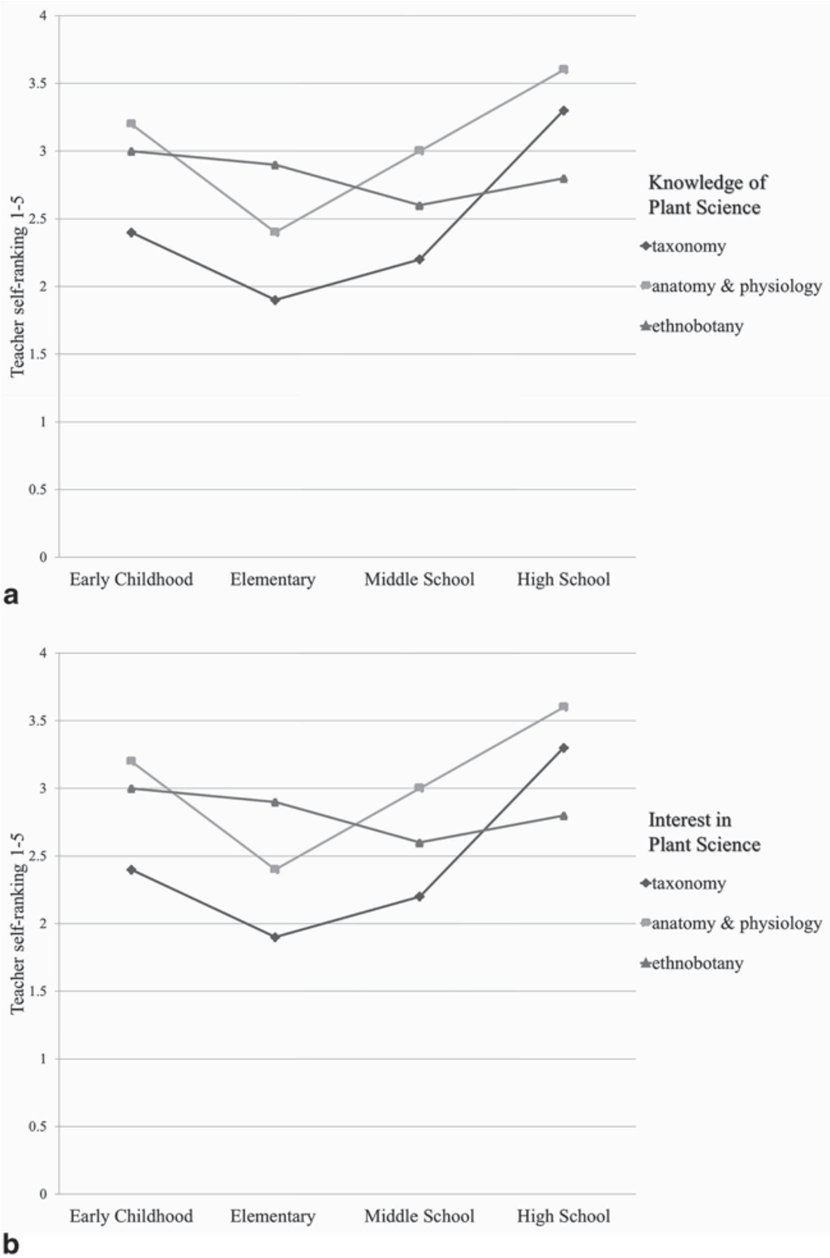

Fig. 1.1 **a** Survey of K-12 educators ranking their knowledge of plant science. **b** Survey of K-12 educators ranking their interest in plant science

they did not have the indoor and outdoor space to give students direct experiences with plants. Although this survey represents a regional study in the Dallas/Fort Worth metroplex, it mirrors a crisis in botanical science education across the USA.

1.2.2 Grand Challenges for Botanical Capacity

In a report on the nation's progress, the National Research Council of the National Academy identified the twenty-first century grand challenges for the US science and land management agenda (NRC 2001). The challenges included (1) managing habitats to sustain biological diversity and ecosystem functioning in a changing climate, (2) maintaining sustainable food production for a growing population with food plants that adapt to a changing environment, (3) understanding the earth's biogeochemical cycles and how they are being disturbed by human activities, (4) predicting climate variability to mitigate future impacts of climate on biodiversity and ecosystem functioning, and (5) expanding sustainable alternatives to fossil fuels through the use of biological systems (Kramer et al. 2010).

A decade later, a comprehensive study led by the Chicago Botanic Garden and Botanic Gardens Conservation International USA, as outlined in a report titled, "Assessing botanical capacity to address grand challenges in the United States," reexamined these challenges in light of declining botanical capacity (Kramer et al. 2010). The purpose of the study was to create a "score card" on the nation's performance on skills needed to meet environmental challenges of the twenty-first century. The report revealed significant changes over the past two decades in the demands placed on botanical education and the resources available to it, including a skilled workforce and financial and management support for research and education. Specifically, it delineated areas requiring botanical expertise as part of a multidisciplinary approach. It concluded that without adequate botanical infrastructure and expertise, our nation's science and land management agenda will increasingly be impaired. The study identified critical gaps in botanical capacity with recommendations to address those gaps (Kramer et al. 2010). Only the education and training components will be addressed here.

1.2.3 Loss of Botanical Degree Programs

The US Department of Education reports that undergraduate degrees in botany are down 50 % and advanced degrees in botany are down 41 % since 1988, when 72 % of the top universities offered advanced degree programs in botany. At the same time, undergraduate degrees in general biology have increased 17 % and advanced degrees have increased by 11 % (NCES 2009, taken from Kramer et al. 2010; Fig. 1.2).

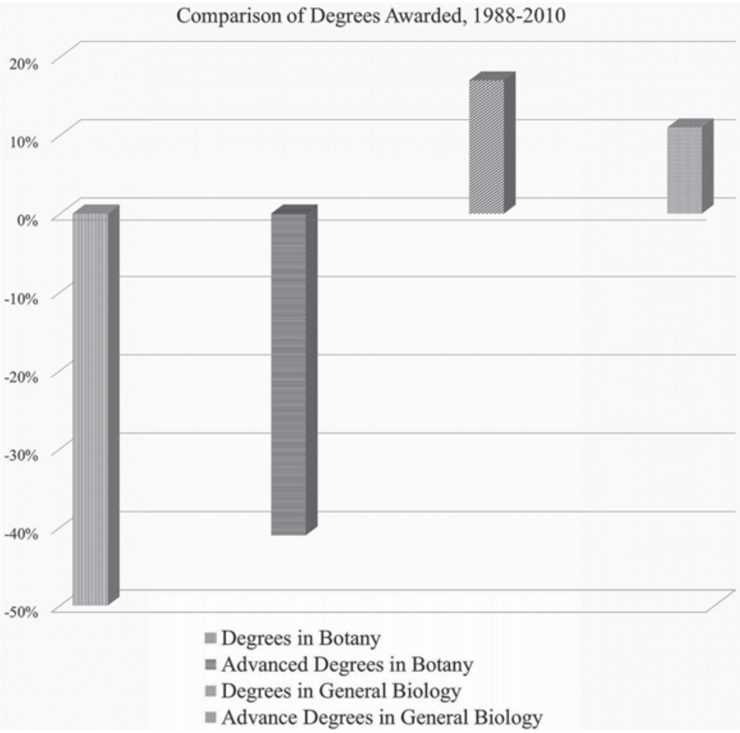

Fig. 1.2 Comparison of botany and biology degrees awarded from 1988 to 2010

1.2.3.1 Decline in Botanical Course Offerings

More than half of these universities have eliminated their botany and related plant science programs. Universities are removing a range of plant science courses, with botany and plant anatomy at the top of the list. Of the 400 faculty surveyed, 40 % responded that plant science courses had been eliminated within the last 5–10 years, and 51 % were not satisfied with the selection of plant science courses offered at their university (Kramer et al. 2010).

1.2.3.2 Preparation for Employment at Federal Agencies

Due to the elimination of botany courses in universities, students considering careers as botanists in federal jobs have difficulty obtaining the training they need to qualify for jobs that, in most cases, require 24 h of college credit courses in botany. To compound the problem, faculty retirement will even further impact courses available within the next decade. Survey respondents indicate that 35 % of all academic respondents and 40 % of all government sector respondents will retire within the next decade (Kramer et al. 2010). There will be a significant need for workforce training and education to fill botanist positions in order to meet the grand challenges.

1.2.4 How Are Universities Preparing Students for a Career Pathway to Fill These Jobs?

The bottom line for the Botanical Capacity Assessment Project is that "Botany is not optional" (Kramer et al. 2010). Yet, the question is how universities will prepare students with the skills necessary to address global challenges? In an article, "Perceptions of Strengths and Deficiencies: Disconnects Between Graduate Students and Prospective Employers" (Sundberg et al. 2011), the data show university students' view of their greatest strengths were in areas that potential employers viewed as their greatest need for improvement. Written communication skills got the lowest ranking among employers (and the highest among students), with ecological skills, field skills, plant identification skills, and botany ranking high as areas that needed the most improvement. The survey shows that skills in problem solving is not where it should be after two decades of a focus on "doing science" to develop critical thinking and problem solving. The concern from this study lies in the fact that employers say that they do not have enough botanically trained staff to meet their current management needs, while at the same time botany departments are being merged into biology departments and plant science courses are not available or are in the process of being phased out. They conclude with the plea for all stakeholders in the education process to "make clear to educational institutions their expectations about graduates" (Sundberg et al. 2011). Universities must prepare students to fill the pipeline for jobs that require trained scientists who have the field skills, communication skills, and critical thinking skills required to implement new strategies for dealing with loss of biodiversity and the threats of climate change on the health and well-being of humans and the environment (Sundberg et al. 2011).

The field of biology has taken steps towards solving this dilemma. In 2009, a call for action for change in biology education sparked a series of stakeholder conversations about the need to ensure that "all students graduate from college with a basic understanding of biology" (Brewer and Smith 2011). From these conversations and professional meetings, a landmark document, the *Vision and Change in Undergraduate Biology Education: A Call to Action,* was published in 2011 by the American Academy for the Advancement of Science (AAAS) and funded by the National Science Foundation (NSF). Authors described the "daunting challenge" in transforming deeply embedded academic traditions of instruction to new strategies that align with what educational research shows about how learning takes place (Brewer and Smith 2011).

Recommendations for "change" are to (1) integrate core concepts and competencies throughout the curriculum, (2) focus on student-centered learning, (3) promote a campus-wide commitment to change, and (4) engage the biology community in the implementation of change. The "call to action" to the biology education community is for all those who teach to "develop a coordinated and sustainable plan for implementing sound principles of teaching and learning to improve the quality of undergraduate biology education nationwide." It stressed that all biologists should be involved since the "stakes are so high" (Brewer and Smith 2011).