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A Vision for Change in Bioscience Education: Building on Knowledge from the Past

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A Vision for Change in Bioscience Education: Building on Knowledge from the Past

Running title: Building on Knowledge from the Past

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In Purdue's College of Science, Samuel Postlethwait (spostlw8@mac.com) is a botanist and Emeritus Professor from the Dept. of Biological Sciences, Trevor Anderson (ander333@purdue.edu) is a biochemist and education researcher who investigates Visualization in Biochemistry Education (VIBE) in the Dept. of Chemistry, and Nancy Pelaez (npelaez@purdue.edu) is a physiologist from the Dept. of Biological Sciences who co-authored several research reports on the nature of Science Faculty with Education Specialties (SFES). Postlethwait studied how best to individualize student learning while linking lab to lecture in large classes of students from diverse educational backgrounds. As PIs of the Assessment of Competence in Experimental Design in Biology (ACED Bio) Network project (NSF/BIO RCN-UBE Award 1346567), Anderson and Pelaez are bringing together research scientists and biology education specialists to define what students should know and how to teach about biological experimentation.

ABSTRACT

High quality undergraduate education is central to the success of all life scientists. Several major bioscience educational issues are the targets of much debate, research, funding, publications, and reports (e.g. *Vision and Change*). Surprisingly, these issues are considered by modern bioscience instructors as unresolved despite historical reports that claim the contrary. Here we illustrate with evidence how, more than 50 years ago, Sam Postlethwait successfully instituted strategies to address several issues in plant biology education with his audio-tutorials. These strategies succeeded in individualizing instruction of students with diverse educational backgrounds in large classes, incorporating authentic and active learning, integrating lab and lecture to teach about research, developing science competencies, and advancing curriculum and faculty change informed by empirical data. We contend that modern educators could greatly benefit by building on the historical advancements of the past, to ensure they do not waste their efforts re-inventing the wheel.

Introduction and Historical Background

In 2011, the *Vision and Change* report highlighted the need for students to learn about biology as a research science, including the methods and competencies by which advances are made in the life sciences (Brewer and Smith 2011). These ideas are not new. Articles published in the 1950's were already calling for similar improvements in the teaching of the biosciences (Behnke 1957, Tippo 1957), at a time when many botany instructors were among the first to incorporate discovery, problem-solving, and the scientific method, into their courses (Hatch 1951, Davidson 1957). Indeed Miller (1955) reported that 31 Botany courses at major US research institutions included a laboratory component, with seven of these teaching the scientific method as a main objective. For example, Mason (1952) advocated teaching the scientific method, Pettit (1953) provided a guide for how to do this, while Phillips (1957) recommended scholarships to engage students with research starting in their sophomore year.

Dr. Samuel N. Postlethwait, now a 96-year old retired botany professor from Purdue's Department of Biological Sciences, earned a PhD in Botany from the University of Iowa in 1949. His immense contributions to teaching were recognized with many awards, including the *Helping Students Learn Award* from The Purdue Alumni Association in 1983 and the first *Charles Edwin Bessey Teaching Award* from the Botanical Society of America in 1989. As a scientist and education researcher in the 1950's, a problem that interested Sam was how best to deal with large classes of Botany students who were also very diverse in terms of their intellectual preparedness, prior conceptual knowledge and desired learning outcomes, given

that only around 1-4 percent of Botany students actually chose to make Botany their career. Once Sam understood the problem, which was not unlike modern issues of student diversity in introductory biology courses (Brewer and Smith 2011), he proceeded to identify and develop strategies to address the obstacles - the things that made it difficult for students with different needs and backgrounds to learn what they needed to know about botany.

In this paper we describe eight major strategies that Sam used, more than 50 years ago, to successfully address several issues that surprisingly still remain targets of much debate, funding, and modern bioscience education publication. We support our discussions with evidence from Sam and analysis of his and other published resources. We end by illustrating how his innovative strategies from the past could be usefully and easily applied by modern-day instructors to inform and resolve many of the present-day issues they encounter in bioscience education. We also suggest reasons why it is that bioscience instructors keep “reinventing the wheel” in their classrooms, rather than building on the achievements of the past, and offer ways that this problem might be overcome.

1. Individualize and make instruction interactive in large classes of students with diverse educational backgrounds.

In 1961, Sam was teaching a Botany course at Purdue with an enrollment of 380, a situation not uncommon in present-day freshman classes. Although the issue of how to teach large enrollment classes is a major focus of debate in bioscience education today (Brewer and Smith 2011), there has been little or no attempt to

build on how instructors of the past addressed such issues. Instead, most instructors have reverted to the use of massive online multiple choice homework systems (of which MOOC is one of the latest), which come with many well-documented learning problems (Schönborn and Anderson 2008). Recently, “Flipped” teaching (Smith et al. 2005, Preszler 2009), and educational multimedia such as the Khan Academy (<http://www.khanacademy.org/>) and Paul Andersen's Bozeman.com science video collections have become a growing modern trend in which students learn by watching video lectures outside of class time. However, although affording students the opportunity to work individually, none of these systems are designed to be interactive or to integrate lecture with lab to teach students research competencies like Sam did. Sam’s audio-tutorial approach was not automated instruction for large classes, like many modern, multiple choice question-driven courses. Instead, Sam’s strategy was to use multimedia and tutorials to involve the student in every step of the process, with questions and scaffolds to help the student find answers to questions and solve problems, rather than merely delivering information that students had to memorize.

Since Sam’s stated reason for teaching was to “help ALL students learn and be successful,” he recruited peer leaders (See part 2 below) to lead small group discussions, he developed multimedia for “audio-tutorials” (part 3), and he set up learning centers (part 4), with the main goal of individualizing and making instruction interactive so that he could continue to develop students’ key competencies (part 6) in addition to their knowledge of principles and concepts, despite his large classes. The core competencies he expected as learning outcomes

were clearly defined. He integrated lab with lecture (part 5), and he gave students authentic research experiences (part 7) in his undergraduate course. These strategies remain relevant to address pressing challenges for all bioscience faculty members who teach undergraduates today.

2. Use peer leaders in small group workshops.

Sam recruited peer leaders to moderate discussion among students in small groups to help communicate certain information more efficiently, leaving lecture time to focus on key concepts and principles and how these integrate with laboratory work and demonstrations. The peer leaders conducted weekly Teach About Botany (TAB) discussion sessions with the hundreds of enrolled students broken up into small groups of about a dozen students. The focus was not just on what students should learn. Sam thought deeply about what students should be able to do with their knowledge. His strategy was to encourage students to develop their competence (part 6) through “hands-on” activities, after which they were required to write and present oral reports to the TAB group where peers and a peer leader gave feedback to advance the discoveries. This strategy mirrors our modern approach to peer-lead team learning (Gafney and Varma-Nelson 2008, Mauser et al. 2011). As an indicator of success, although Sam’s “new” Botany course was developed for 380 students, his course was subsequently and successfully expanded with the help of Dr. Robert Hurst to a single Zoology and Botany course with a registration of up to 1,800 students per year (Postlethwait and Hurst 1972). Despite

the enormous class size, his peer-led small group strategy continued to function efficiently and effectively in promoting student learning and research competencies.

3. Develop multimedia to engage students in more active learning.

When Sam redesigned his Botany course he especially focused on the things that made Botany difficult in order to help students overcome such difficulties. With a tape recorder, he told stories about plant processes with background observations and questions to encourage individual students to think about mechanisms that regulate plant functions (Figure 1). By asking students to observe and describe before they were asked to generate and interpret data, Sam was providing a meaningful context for understanding plant functions.

[INSERT FIGURE 1 ABOUT HERE]

Audio-visual staff assisted Sam in compiling his first audio-tutorial lessons. These were lectures on tape (Figure 1), which at first relied on audio and printed material as the sole medium of communication. Soon, towards better integrating lab and theory, tangible items such as germinating seeds and live plants were added for teaching students about experimentation. Later, film loops were provided to demonstrate how to investigate difficult-to-illustrate phenomena, such as with time-lapse photography, or where real collection of data would have required advanced technical skill or the use of expensive or dangerous equipment (Postlethwait & Novak 1967).

Sam also developed plastic and Styrofoam models, a key innovation in line with modern attempts to use visual material in teaching (Treagust and Tsui 2013).

He used styrofoam models to illustrate key features of glucose molecules (Postlethwait and Stearns 1957), and he designed plastic models to help illustrate abstract concepts that were too small to be seen such as vascular tissue in plants (Postlethwait et al. 1953). All his media were aimed at fostering a more active, hands-on approach by students to learning about bioscience.

4. Develop learning centers where students can interact with course resources and peer leaders outside lecture periods.

Sam constructed 22 booths like those illustrated in Figure 2 so that for hundreds of students, he just needed 22 copies of material for the booths - 22 pictures, or mimeographed copies, audiotapes, or movies, and later film loops and videos were used. This constituted a significant cost saving, an issue that remains relevant today.

[INSERT FIGURE 2 ABOUT HERE]

Sam's lab was set up as illustrated in Figure 3 with the booths to one side (see right of picture) and other more openly-designed laboratory benches where larger equipment such as spectrophotometers and microscopes could be used for his various learning activities. He designed methods to get everyone actively engaged through home study activities to provide the versatility and variability necessary for a diverse group of students. He achieved this through independent study sessions with audio-tutorial lessons, and by asking students to write down their thoughts at weekly general assembly sessions.

[INSERT FIGURE 3 ABOUT HERE]

With the continued progress in communication devices, a learning center today should not look like Sam's audio-tutorial system, but, like Sam's model, a modern learning system could use technology to permit students to engage in activities to develop their visualization and research competencies (Parts 5 and 6) as defined by the education literature.

5. Integrate lab and lecture to teach students about how scientists do science.

Sam's approach to teaching was to be like a scientist—define the problem first and then structure the instruction activities to fit the problem, instead of using the same procedure for every subject and student. This is in line with the modern idea of “scientific teaching”, something that has been the source of much support by current bioscience educators, funders and many publications (Anderson et al. 2011). Indeed, the fundamentals of this “new” idea were already deployed more than 50 years ago!

In 1874 when Purdue first opened its doors to students, a botanist decided to have two lectures and a separate lab per week. This arrangement had not changed by 1955 when Miller reported that most undergraduate Botany courses involved separate lectures and labs. In most cases there was a disconnect between the concepts learned in lecture and what was applied in lab, a problem that still persists today in many biology courses. To promote the integration of lecture and lab, Sam designed an instructional approach that required students to identify a problem first and then look for sources of information that relate (or don't relate) to the problem, before formulating a conclusion that each student would defend in an oral

presentation to their TAB group. Furthermore, when current research was presented at a weekly general assembly, students would have to write their own summary of the week's topic. This would include a question to be addressed, the sources of information that were brought to bear, a summary of what they had learned from the assembly, and how the work presented related to their own life. Sam's goal was to develop students who understood the relevance of their subject, could link key concepts to laboratory activities, and coordinate explanations in Botany with scientific evidence, goals that are still being addressed today and which he effectively addressed decades ago through audio-tutorials, laboratory exercises, small TAB group discussions, and writing assignments for weekly general assemblies.

Late in his career, someone suggested to Sam that he was "reinventing the wheel" by applying the scientific method to the study of teaching because in 1911, Clements (1923) was already studying science teaching methods. But Sam was well aware of these earlier studies and had built on these ideas from the past by incorporating them into his innovations to teach students about how to do research projects. His approach was informed by a book by Woodhull (1918), *Teaching of Science* (See Fig. 4), which outlined how to teach science as a research endeavor.

[INSERT FIGURE 4 ABOUT HERE]

Sam built his innovations on a foundation of early writings from great theorists (Wells et al. 1973, Postlethwait 1980). Given that earlier professors like Clements (1923), Woodhull (1918), and others (Del Giorno 1969) were advocates for teaching science through research (as illustrated in Figure 4), it is worth

considering today why more concerted effort has not focused on teaching biology as a research endeavor. In particular, Sam believed that the future of bioscience education would be promising if the nature of science itself became the driver of improved approaches to teaching activities, which, in turn, would improve instruction.

6. Define and specifically teach and assess students' learning about core competencies as an integrated part of a course - don't just focus on science concepts and principles.

Stakeholders greatly appreciated Sam's ongoing efforts to help the students develop science competencies. He believed that scientific thinking would be useful to his students, so he developed practical situations in an open learning center to help them improve their scientific competencies (Postlethwait 1980). Table 1 compares examples of the learning objectives focused on by Sam in his courses with those advocated by both the *Vision and Change* document (Brewer and Smith 2011) and other recent work (Schönborn and Anderson 2009, Anderson et al. 2013). Clearly Sam's learning objectives align well with the more recent work, which begs the question of why 50 years later academic institutions continue to reinvent the wheel instead of implementing the important innovations of the past. For Sam, the goals and objectives were always clearly stated so that both student and professor knew what they were and when the student had achieved them. Students knew that they had to master key competencies in order to get high grades in course assessments.

[INSERT TABLE 1 ABOUT HERE]

7. Give students course-based undergraduate research experience (CURE).

According to Sam, to learn botany, students needed to engage more closely with the botanical world, to have a more *authentic research experience*, much like many bioscience educators have been advocating (Del Giorno 1969, Elliott et al. 2010) and in line with a recent focus on course-based undergraduate research experience (CURE) (Auchincloss et al. 2014). Towards this goal, Sam gave students opportunities to use equipment like spectrophotometers and to do things like experiments to investigate competition, sunlight, soil and shade. In those days textbooks had a few black and white drawings but were mostly dominated by text. These were abandoned when Sam gave his class access to the “real stuff”, with lab manuals and anything he could find for a needed illustration about what it means to do research.

Below we present 3 selected examples (Exercises 1-3) that illustrate Sam’s approach to teaching students about the process of science. In this regard, it is important to note how key the *Vision and Change* competencies and learning objectives 1-16 from Table 1 are to the performance of the tasks in these exercises.

Exercise 1: Minicourse on Water Relations in Plants.

In this instructional sequence, the student was first introduced to the problem of water regulation with three plants of the same type, set up in the study area as illustrated in Figure 5.

[INSERT FIGURE 5 ABOUT HERE]

An audiotape recording asks students to compare the three plants and to consider why one does not appear to be very healthy (VC1). The students are asked about the moisture in the bell jar, where it comes from, and to investigate what they think the cause might be (VC4). The process of transpiration is explored and explained with a series of investigations to investigate environmental and structural features that affect the rate of transpiration. In this experiment students were required to use Sam's objectives 1, 3, 5, 8, 9 and the VC competences 1, 3, 4, 5, and 6 listed in Table 1.

Exercise 2: Water flux in plants

After being given a brief summary of theories of water movement in plants and the function of stoma and guard cells, students test the idea that water moves from an area of higher concentration to areas of lower concentration, and that continuous evaporation at the leaf-air interface is a force that helps to "pull" more water from the leaf, from the stem, and eventually from the roots up through the plant as a continuous column (VC3). Students consider why plants lose water, how they lose it, and how they replace what is lost with an experiment (VC1) that requires five days where the first four days data is already collected. From this data they construct line graphs and interpret the results to see that water is lost by plants over time and that we can measure the extent of water loss (VC2). Students are then challenged to find ways to vary light intensities, air movement, and temperature (VC4) and to design a table to record their data from a transpiration experiment. Experimental results show that all three factors have a direct effect on transpiration. Students are

encouraged to discuss with their TAB group (VC5) the experiment they designed, the data collected, and what experimental procedure was most useful. In this exercise, students were required to use Sam's objectives 3, 5, 8, 12, 14, 16 and the VC competencies 1, 2, 3, 4, and 5 listed in Table 1.

Exercise 3: Light in Plant Growth and Development

Although the above mentioned experiments lacked the statistical replication and random assignment of subjects to treatment groups, necessary to help students understand patterns of responses that are detectable in spite of variation in the biological world, Sam still saw to the statistical needs of his students. A minicourse on Light in Plant Growth and Development gave him reason to have a statistician talk at the general assembly about how to statistically handle their data (VC2). Students were challenged to consider how light (VC4) affects plant growth. As seen in Figure 6 and Table 2, fifty seeds were placed in Petri dishes exposed to variable light conditions.

[INSERT FIGURE 6 ABOUT HERE]

For seeds like these, students were asked to analyze sample data (Table 2) to explain the effect of different wavelengths of light on seed germination.

[INSERT TABLE 2 ABOUT HERE]

From this data, it is apparent that germination of these lettuce seeds is promoted by light and inhibited by dark (VC2). More specifically, certain wavelengths of light are effective at promoting germination while others are ineffective (VC3). Red

wavelengths of light stimulate growth similar to white light, so the red wavelength is very effective and is most likely the wavelength of light most responsible for the germination of these lettuce seeds. The far-red wavelength was more inhibitory than darkness, the green wavelength was about equal to darkness, and the blue wavelength slightly stimulated growth (VC5). To understand the relationship between wavelength of light and the germination of these lettuce seeds, students were required to use Sam's objectives 1, 3, 4, 5, 7, 8, 12, 14, 16 and the VC competences 1, 2, 3, 4 and 5 listed in Table 1.

8. Establish and cultivate a learning community that favors constructive faculty and curriculum development

During the 1950's, Sam was instrumental in supporting several science faculty members with both science and education qualifications, including Drs. Joseph D. Novak in biology and James Dudley Herron in chemistry, in their efforts to improve science education at Purdue University (Gilbert et al. 2002). Indeed, this is some of the earliest evidence of what has recently been termed Science Faculty with Education Specialties (SFES) (Bush et al. 2006, 2008, 2011, 2013). Sam also benefited from interactions with Novak and Herron who, in line with the modern tenets of the Scholarship of Teaching and Learning (SoTL), helped him realize the importance of using published educational research to inform his teaching and to investigate the effectiveness of his own teaching innovations. In addition, several doctoral dissertations (Jane Butler Kahle, 1971, among others) and nearly thirty postdoctoral associates (including Anton Lawson who was *Postdoctoral Research*

Associate and Instructor of Science in the Elementary School at Purdue from 1973-74) as well as visiting scholars sponsored by UNSECO, the Fulbright Commission, the Johnson Foundation, Lilly Foundation, and Biological Sciences Curriculum Study, influenced Sam to make adjustments in his thinking and instructional design. One challenge for open learning centers was that some students had difficulty with self-discipline, but Sam gave the responsibility for self-improvement to the students by placing them in charge of advancing their own competency for doing science. This is in line with the modern approach of getting students to take responsibility for their own learning. As a result, the learning center became much more than just a formal arrangement of booths and tape recorders in a room that was open from 7:30 am to 10:30 pm. By providing a system for students to interact with resources, teachers, tutors, and peers who helped teach each other to examine experimental evidence, the situation for Botany education at Purdue became worthy of the name, "learning center." It clearly mirrored the modern-day concept of a *learning community* (Gafney and Varma-Nelson 2008, Mauser et al. 2011, Preszler 2009).

As Sam monitored learning progress, to find out what could be done better to make more students successful, he met weekly with the graduate student TAs and about 30 undergraduate peer leaders, selected because they had previously taken and mastered the course material. The graduate students and peer leaders of Teach About Botany (TAB) sessions helped to design new integrated quiz questions that changed every year so that a student would not know what material would be presented to them for an interview quiz. With so many members of Sam's learning community contributing, there was never a shortage of ideas on how to advance this

course, which led to ongoing curriculum development. When the peer leaders saw their suggestions being implemented, they got the message that this Botany was their course, and not Sam's course. Sam used a scientific approach in critiquing his own teaching procedures. In line with modern curriculum theory (Anderson and Rogan 2011), his course design and development kept evolving over the years until his retirement in 1984. This presents an example of how nurturing such a sense of ownership could also advance many modern courses (Rogan and Anderson 2011).

Sam's faculty development and dissemination strategies were far ahead of his times. In line with modern curriculum change theory (Rogan and Anderson 2011), he learned how to nurture supporters and champions of his cause while diplomatically and tactfully handling and neutralizing any resistance by skeptics and decision makers. This openness to change and learning from others was impressive and certainly gained the respect of many and advanced both curriculum and instructors. Indeed in a modern era where most faculty work in autonomous isolation in teaching their 'own' courses, and are often opposed to any sort of change (Rogan and Anderson 2011), we could learn much from Sam's learning community approach. Sam also quit worrying about 'nay-sayers' when people from other institutions and countries provided external validation of the success of his program.

Conclusions and Implications for Bioscience Teaching

This historical review of methods and strategies for individualized, research-based instruction in large enrollment classes is particularly relevant today given the

ongoing problems of large classes with students who are diverse in terms of their intellectual preparedness. The review is also relevant given the present-day dearth of courses that involve the integration of theory in lectures with learning about research and practical work in the laboratory, the demand for scientific teaching and the massive drive towards the development of student competencies in bioscience education. To support curriculum reform, Sam was faced with what remains a modern challenge: how to measure the effect of teaching techniques on student learning and to demonstrate how a Botany course contributes to learning about biology as a research science. In addition, in founding one of the earliest reported learning communities he was able to foster faculty development and draw on contributions to his courses from a wide range of experts, an approach which is sorely neglected today at universities where individual course autonomy is far more common.

According to Postlethwait and Novak (1967, p. 464), some 47 years ago, "in recent years technological advances in communication devices have provided teachers new dimensions for helping students learn. All too often, however, teachers have seized upon one new vehicle and championed the use of this vehicle without due regard for its limitations for communicating subject matter. One goal of this paper was to emphasize a dimension in teaching-learning that is too often overlooked; we wish to place focus on the fact that all knowledge is learned by individual students and that the acquisition of concepts we wish to teach involves the cognitive development of individual students."

So, why did teaching approaches that Sam had so positively influenced slowly get forgotten? He used great faculty and curricular change strategies, and offered many solutions to freshman botany teaching but, despite this, his innovations were mainly forgotten as the decades proceeded. Others agree there is a need to more effectively share successful teaching strategies (Stagg 2008). Perhaps our failure to learn from past instructional innovations is part of a natural cyclical process of human endeavor that is unavoidable in that new instructors want to impart their own ideas and they feel too busy to learn from the work of the past. Another reason Sam's innovative work is overlooked may be that reading about education is not a priority of faculty members at institutions where an informed approach to teaching carries no value for promotion or a salary raise. Indeed, even Sam earned tenure based on his botany research qualifications, not his education funding and publications. This remains an issue of crucial importance as we move ahead in bioscience education and implement the tenets of *Vision and Change* (Brewer and Smith 2011). As quoted by Sam in his paper (Postlethwait 1978, p. 75), "Nehemiah Grew [the 17th Century English botanist] said, '*Paradoxical as it may seem, there is nothing so constant as change.*' It is true that our world is changing at a phenomenal rate. Wouldn't it be a paradox also if those of us (teachers) who prepare the younger generation to live in a changing world were resistant to change ourselves?"

In conclusion, clearly like any educational change there is always more that can be improved, and Sam certainly didn't successfully address all the issues that persist today regarding the teaching of biology as a research science to freshman undergraduate students. However, his strategies successfully addressed a number

of issues (summarized in Table 3 below) on which modern-day instructors would be well advised to build.

[INSERT TABLE 3 ABOUT HERE]

Our take-home message is that future work should take cognizance of relevant ground-breaking work from earlier times and consider how our collective knowledge might be built on and/or applied to resolve modern issues. Thus literature reviews and their related research studies need to go back further into the history and philosophy of our science to ensure that the same problems don't keep on "rearing their ugly heads," causing us to continually reinvent the wheel.

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Table 1. Comparison between the 6 competencies advocated by *Vision and Change* (V & C) and reasoning competencies with Postlethwait's student learning objectives.

Sam Postlethwait's objectives (referred in the text as s1-16)	Reference to Sam's work	Vision & Change* and reasoning competencies**
1. Identify a problem and work out how to address it with data	Postlethwait, Novak, & Murray (1972) p. 150	VC1, VC6 R-C
2. Draw inferences from video observations (e.g. seed germination during different treatments)	Postlethwait, Novak, & Murray (1972) p. 152	VC1 R-M
3. Use data to explain the effect of physical phenomena (e.g. light of different wavelengths and exposure times) on biological phenomena (e.g. germination) and the expression of various plant characteristics (e.g. growth, etiolation, photoperiodism)	Postlethwait, Novak, & Murray (1972) p. 74	VC1, VC4, VC6 (physics and biology) R-C
4. Cite evidence for the localization of plant functions and characteristics (e.g., receptor site of the photoperiodic stimulus)	Postlethwait & BSCS, (1976), p. 202	VC1, VC3 R-M
5. Cite evidence for the chemical mechanism of various biological responses (e.g. role of phytochromes in the photoperiodic response)	Postlethwait & BSCS, (1976), p. 202	VC1, VC4 R-C
6. Label diagrams representing biological structures and phenomena (e.g. direction of growth, effect of auxin)	Postlethwait & BSCS, (1976), p. 202	VC3, VC4 R-M
7. Be aware of the history of science through understanding classical experiments (e.g. Darwin, Boysen-Jensen)	Postlethwait & BSCS, (1976), p. 203	VC6

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8. Discuss relationships between chemical and physical phenomena (e.g. integration of knowledge: auxins and phototropism)	Postlethwait & BSCS, (1976), p. 203	VC3, VC5 R-C
9. Use diagram, photographs and images to explain the relationship between observable physical effects and chemical interactions (e.g. interactions between auxins and cytokinins)	Postlethwait & BSCS, (1976), p. 203	VC3, VC4 R-M
10. Explain mechanisms of action of biochemicals (e.g. auxins on cells walls)	Postlethwait & BSCS, (1976), p. 203	VC5 R-C
11. Explain the dose-dependence, and concentration effects of various biochemicals in plants (e.g. of auxins)	Postlethwait & BSCS, (1976), p. 203	VC1, VC2, VC3 R-C
12. Interpret graphs of data to do with biological phenomena	Postlethwait & BSCS, (1976), p. 203	VC1, VC2 R-M
13. Describe the reactions of plants to various chemical treatments (e.g. to gibberellic acid)	Postlethwait & BSCS, (1976), p. 203	VC1, VC4 R-C
14. Understand how various processes are regulated	Postlethwait & BSCS, (1976), p. 203	VC3, VC4 R-C
15. Give examples of commercial applications	Postlethwait & BSCS, (1976), p. 203	VC5, VC6 R-C
16. Write a succinct practical report	Postlethwait & BSCS, (1976), p. 203; Postlethwait, Novak, & Murray (1972) p. 149	VC5

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* Key to V & C Competencies: VC1, Disciplinary Practice; VC2, Quantitative Competency; VC3, Modeling; VC4, The Interdisciplinary Nature of Science; VC5, Communication and Collaboration; VC6, Science and Society.

** Key to competencies classified as per the CRM Model of Anderson et al., (2013) and Schönborn & Anderson (2009):

R-M are reasoning abilities with representations and models (e.g. decoding and interpreting representations, drawing representations, using representations to solve problems, visualize data and explain phenomena);

R-C are reasoning abilities with concepts of plant science, experimental and mathematical concepts (e.g. relating and integrating concepts and knowledge, understanding and explaining concepts, and applying knowledge.)

Table 2. Sample data showing the effect of light on seed germination. (Source: Postlethwait & Biological Sciences Curriculum Study, 1976, p. 104)

Treatment	Seeds germinated in light		Seeds germinated in dark			
Total seeds	50	50	50	50		
Variety	Grand Rapids	Great Lakes	Grand Rapids	Great Lakes		
Number Germinated	47	42	18	32		
Percentage germinated	94%	84%	36%	64%		
Grand Rapids lettuce seeds						
	a	b	c	d	e	f
Light conditions	Light	Dark	Blue	Green	Red	Far red
Total seeds	50	50	50	50	50	50
Number Germinated	48	18	26	21	45	0
Percentage germinated	96%	36%	52%	42%	90%	0%

Table 3. Major strategies that modern practitioners can learn from Sam’s achievements to address present-day issues when addressing competencies advocated by *Vision and Change* (VC) (AAAS, 2011).

Sam Postlethwait’s useful innovations	Vision & Change competencies*
I. Organize successful peer assessment.	VC1, VC6
II. Develop lab skills and research competencies.	VC1, VC2
III. Teach students to apply their knowledge.	VC1, VC4, VC6
IV. Teach students to communicate their knowledge.	VC2, VC3, VC5
V. Use a range of physical models and multimedia images to convey difficult to see structures e.g. vascular tissue or abstract concepts like molecules or experiments that are too fast or too slow or too dangerous or too expensive for students to perform on their own.	VC1, VC2, VC3
VI. Individualize instruction in very large classes.	VC1, VC4
VII. Integrate theory from lecture into practical lab activities.	VC1, VC2, VC4
VIII. Form a learning community that supports and nurtures the dissemination of ideas in the community.	VC5, VC6
IX. Strengthen and cultivate positive forces in a system that favors constructive curriculum change and faculty development.	VC1, VC6

- | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| X. Address and weaken negative forces that obstruct and resist faculty and curriculum development. | VC1, VC6 |
| XI. Read the literature to critically analyze, apply and use the theories and work accomplished by science educators and great teachers who develop educational innovations. | VC1, VC6 |

* Key to V & C Competencies: VC1, Disciplinary Practice; VC2, Quantitative Competency; VC3, Modeling; VC4, The Interdisciplinary Nature of Science; VC5, Communication and Collaboration; VC6, Science and Society.

Look at the two plants in your study area. PAUSE. What difference do you notice between them? PAUSE. Although both plants are the same species, one is in flower and the other isn't. Why? Turn to the introductory page in your Study Guide. PAUSE. Notice the changes that occurred as the plants in the illustration passed from light into darkness. PAUSE. Do you see any pattern to the changes? The only differences between the plant pictures are time and the fact that during this time a factor of the environment was manipulated. Since this is a minicourse on the effects of light on growth and development, you have probably guessed that light is the factor that produced the differences shown. How does the plant sense this variation in the environment? Why do some plants bloom in the spring, some in the summertime, and some in the fall? These are some of the questions we will investigate in this minicourse.

Let's begin with the question on Page 1. How does light affect plant growth? PAUSE. On one level you should be able to answer this question simply by comparing a set of light-grown plants with a set of dark-grown plants. In Exercise 1 you can examine seedlings that have been grown under these two conditions. The seedlings are located at the central table for you to observe. Study the plants and make a list of some of the characteristics that seem to be influenced by light.

Figure 1. A tapescript published by Sam shows how he provided background information and posed questions with examples as scaffolds to help students understand effects of light on plant growth and development. (CREDIT: Postlethwait & Biological Sciences Curriculum Study, 1976)

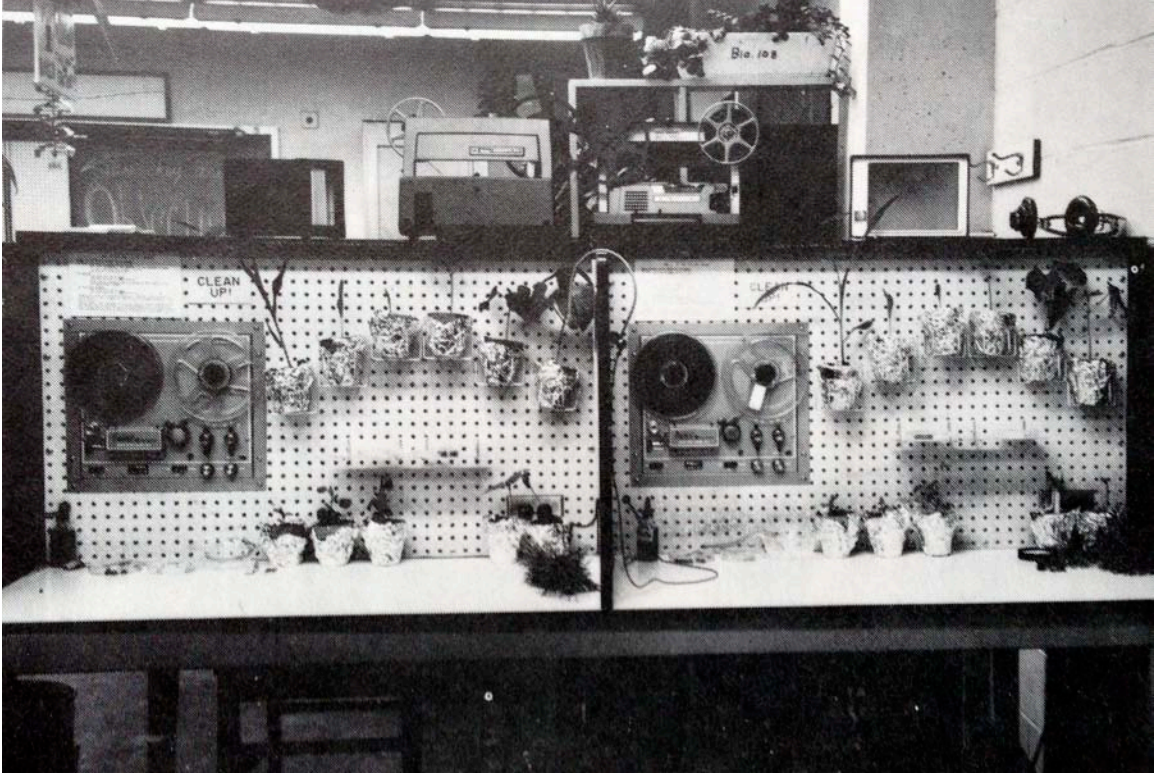


Figure 2. A photograph of a typical booth designed and used by Sam shows various video and laboratory equipment and plant material for experiments. (CREDIT: Postlethwait & Biological Sciences Curriculum Study, 1976, p. ix)



Figure 3. A photograph of students working during one of Sam's laboratory sessions, by Sam. (CREDIT: Postlethwait & Biological Sciences Curriculum Study, 1976, p. x)

THE TEACHING OF SCIENCE

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Figure 4. John Woodhill's textbook from 1918 described how to teach research competencies with methods that provided a basis for those used in Sam's Botany course. (CREDIT: Woodhull, 1918, pp. xiii and xviii)

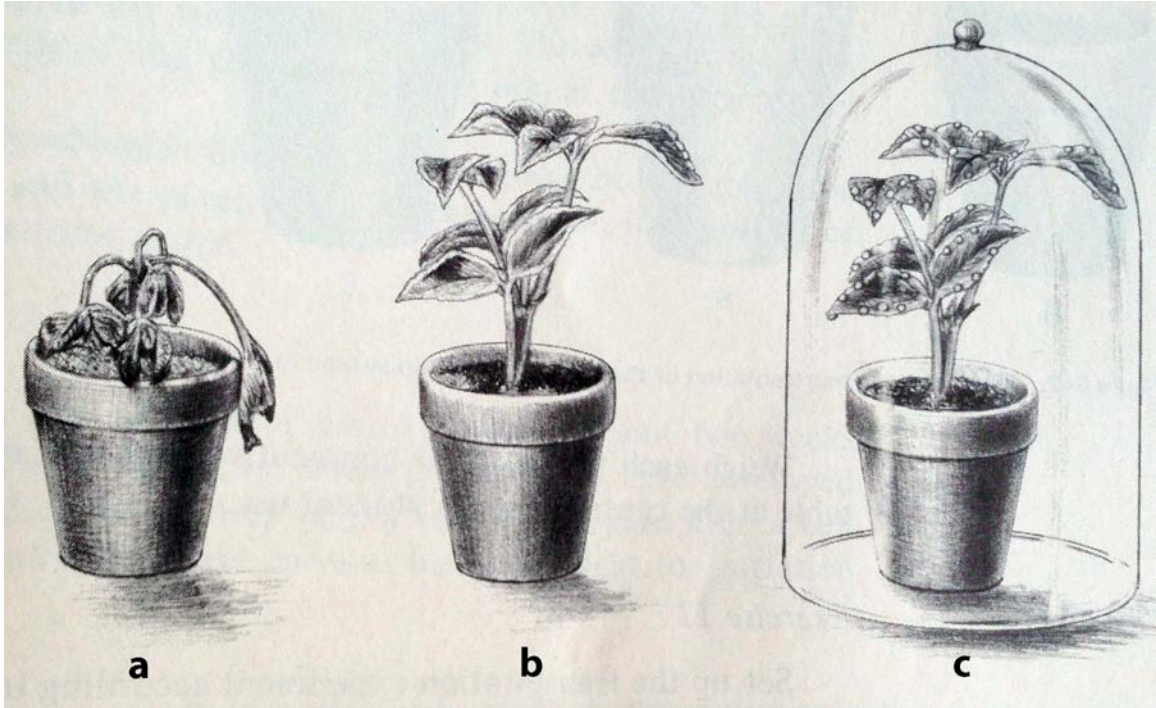


Figure 5. Diagram used to illustrate Sam's experiments on Water Relations in Plants. Plant a is a wilted plant with no water, plant b is a normal healthy plant, and plant c is covered with a bell jar showing droplets. (CREDIT: Postlethwait & Biological Sciences Curriculum Study, 1976, p. 65)



Figure 6. Petri dishes showing the effect of different wavelengths of light on lettuce seed germination. Grand Rapids lettuce seeds were germinated by placing them on moist filter paper and exposing the moist seeds to light at least three days in advance, and then flooding them with ethanol to kill and fix the seeds. Fifty seeds were placed in each of six Petri dishes exposed to the following light conditions: a light, b dark, c blue, d green, e red, f far-red. (CREDIT: Postlethwait & Biological Sciences Curriculum Study, 1976, p. 99-102)