Botany Students as Scientists

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Recent criticisms of science education in the United States, along with suggestions on improving science teaching (e.g., Moore, 1990), make it seem that there is not much science nor excitement in most science teaching. However, many professors at public and private universities have long been quietly teaching various biological disciplines, like botany, as if they were the sciences which textbooks and critics suggest they should be. Indeed, Seago (1992) even presented a pedagogical rationale for the role of undergraduate student research, i.e., science, in college courses. Such pedagogy does more than provide students the excitement and discovery of science; the critical thinking it fosters can be integrated not only into a course, but into a student's academic program and life.

Commentaries by well-known journal editors claim that there is a lack of excitement in biological disciplines, a lack of active participation by students in science or the educational processes, a lack of commitment to science by its teachers, and a lack of research by undergraduates (e. g., Goldberg, 1993; Moore, 1993). Such commentaries reveal that some editors may not be aware that many faculty have engaged students in research for years: teaching botany as science.

Nevertheless, it can be argued that students need many courses with traditional lecture/lab approaches with professors giving lectures and presenting ideas and facts, along with standard labs of experiments or observations and even such devices as problem-solving or hands-on-learning. In other words, there is some support for the concept that botany professors teach best when disseminating the fundamentals of essential botanical knowledge that students should know by standard lecture/lab formats. We disagree. If there is anything such as a unit of essential botanical knowledge, it is surely, in large part, that knowledge which derives from current scientific research and literature. In that context, what Moore stated has profound meaning (1986, p. 420): science makes its advances by "studying what is not known rather than what is...known." Further, Seago (1992) argued that students probably generate a better and lasting framework of knowledge when they develop it within the context of science as research and with their own memory and learning systems, not when it is imposed.

Rather than review all the literature on this topic, we will present some of the ways students can participate more actively in coursework and concurrently get the excitement of a science course or program like botany. The arguments for a participatory approach are generally those put forth by Seago (1992): students should be generating and directing research in formal courses. In order for students to understand botany as science, not just the results of botany, it is necessary for them to participate in botany as science. We believe that students learn more botany by addressing research questions during a course.

While there are other elements of formal coursework in which students can actively participate in generating ideas and facts
Table 1. Elements of student participation in botany lecture/lab courses.

<table>
<thead>
<tr>
<th>Research Project</th>
<th>Proposal</th>
<th>1 page: general problem and methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Project</td>
<td>lab and/or field work</td>
</tr>
<tr>
<td></td>
<td>Talk</td>
<td>10-15 min.; in class; like talk at annual meeting</td>
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<tr>
<td></td>
<td>Poster</td>
<td>during class time; paper format; high visibility; location</td>
</tr>
<tr>
<td></td>
<td>Paper</td>
<td>draft and manuscript reviews; literature retrieval; American Journal of Botany format</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Journal Article</th>
<th>Talk</th>
<th>5-10 min. summary of refereed research article</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reviews</td>
<td>Paper</td>
<td>1 page general nature of problem, methods and results, meaning, and relation to course</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Course Subtopics</th>
<th>Talk</th>
<th>15-30 min.; specific course subtopics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratories</td>
<td>Experiments</td>
<td>student-generated work;</td>
</tr>
<tr>
<td></td>
<td>Observations</td>
<td>in conjunction with formal labs</td>
</tr>
<tr>
<td>Examinations</td>
<td>Essay</td>
<td>including work from student talks and labs</td>
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</table>

(Table 1), research should be the most important element of science courses. To generate and direct a research project within the framework of formal courses, a student should produce a research proposal, usually after some discussion with the professor. This proposal should outline the problem, the materials to be used, and the methods to be followed. It may be presented in oral or written form, or both. The proposal must be approved before research can be begun.

Lab and/or field research should be conducted within the limitations of the facilities and the course, such as subject matter, credit units, time, supplies, instrumentation, etc.; students can be very imaginative at overcoming limitations. Students should try to overcome problems that invariably arise and that may cause unsatisfactory results. Even long projects that seem to fail can be useful to a student’s understanding of scientific process in the discipline; rather than repeat such a project, the student should analyze the problems carefully for the paper and report what he/she did.

The formal communications of research are, of course, the culmination of science and thus of great importance to students. In many courses, student talks can be presented near the end of a term; talks of 10-15 minutes are presented like research talks at a scientific society’s annual meetings. Students can also present posters in a paper format at a poster session arranged at class time in a location of high visibility, like a union lounge or main foyer of a science building. Talks or posters allow dialogue with others learning about the research projects. If a talk or poster precedes a paper, it can be used by the student to develop a better concept of the project before the paper is completed and submitted. Appendix 1 has project/paper titles for some botany courses.

The research paper should follow standard format as in the American Journal of Botany or other well-known journals: title, author, abstract, introduction, materials and methods, results, discussion, and literature cited. Titles may not be as precisely stated as they should be (see Table 2), because they
Table 2. Selected titles of student research projects in recent botany courses.

**PLANT KINGDOM:**
- Diatoms of the SUNY Oswego campus littoral zone of Lake Ontario.
- Tree identification of a limited section of the SUNY Oswego lakeside.
- The effects of IAA on *Vicia faba* growth.
- Classification and identification of common Basidiomycetes in and around Oswego NY area.
- The effects of cadmium on the proagation of spider plants.
- Collection of northeastern fungi.
- Fall swamp flora identification of a swamp in Oswego County.
- A study of *Ambrosia artemisifolia* pollen.
- Phosphate uptake in *Oedogonium*.
- An evaluation of autotoxic capabilities of *Typha angustifolia*.

**DEVELOPMENTAL PLANT BIOLOGY:**
- The effects of GA3 on *Avens* coleoptile sections.
- Propogation of geranium plants by shoot apical meristem tissue culture.
- The effects of high cadmium levels on the root hair development of *Arabidopsis*.
- The effects of GA3 and IAA on elongation of morning glory hypocotyls.
- Light effects on the germination of light sensitive lettuce seeds and light insensitive lettuce seeds.

**MORPHOLOGY OF NON-VASCULAR PLANTS:**
- A study of algae in Glimmerglass Pond.
- An investigation of the microstructure and macrostructure of *Ustilago zeae*.
- Fungi of New York's coniferous forests.
- Algal sexual reproduction.
- Different algae in Lake Ontario in the fall of 1986.

**PLANT ANATOMY AND MORPHOLOGY:**
- Geotropism in roots.
- Investigations on the chilling stress effects on *Phaseolus vulgaris*.
- Water conditions in relation to plant stem anatomy and physical appearance.
- Wood identification.
- Leaf anatomy of *Aloe barbadensis* and the significance of the inner bundle sheath parenchyma.

**CYTO-HISTO-TECHNIQUES:**
- A study of the stem of *Tradescantia* sp. plants.
- A comparison of conifer needles using *Pinus strobus* and *Picea glauca*.
- Structural differences in the mesocarp of different varieties of *Pyrus malus*.
- Oil gland comparisons in *Citrus sinensis*.
- An observation of calcium oxalate crystals in *Diffenbachia*.

**PROBLEMS IN BIOLOGY: PLANTS AND ACID RAIN:**
- Acidic effects on cattail bud and root growth.
- Acid rain effects on root hairs of radishes.
- Acid deposition effects on carbohydrate mobility during germination of pea seeds.
- Decreased growth of balsam fir in the uplands and wetlands of the Adirondack Mountains, NY.
- Effects of acidic precipitation on the structure of chloroplasts and concentrations of B-carotene in *Spinacia oleracea* over given time intervals.
are sometimes not submitted when student manuscripts are reviewed and proofed. The abstract must be a paragraph with a succinct statement of the problem and the results. The introduction must contain a clear, concise statement of the research problem, question, hypothesis, or however the student presents the nature of the research pursued. Background, especially for advanced undergraduates or graduate students, may help lead to the statement of the problem.

The materials and methods section must completely describe and list the organisms, supplies, techniques, procedures, instruments, sampling methods, and any statistical techniques employed. This descriptive section is hard for many students because they are accustomed to having had this section written for them in lab manuals. In the results section, students present their findings. At the undergraduate level, it is helpful to keep students from interweaving discussion into results so that they can focus on their own findings, observations, and data. Tables, graphs, drawings, photographs, and verbal descriptions are all important features of the results.

In the discussion section, the students should analyze whether or not their findings are properly based upon the problem posed and the materials and methods used. Then, they should make a comparison to the work of others from the literature; the amount of literature discussed may vary greatly with the level of the course. Botanical literature is cited in the various sections, especially the discussion, and needs to be referenced completely in a literature cited section which follows the rules for authors of the selected style; we recommend the practice in the *American Journal of Botany*. Referral to botanical literature is a very important feature of the research.

Students entering basic botany courses may have had very little exposure to library use and may, in fact, think of acceptable library research as using an encyclopedia and the *Reader's Guide to Periodical Literature*. Good literature retrieval, however, is critical. Most libraries are equipped with indices to the technical literature. These indices are found in hard-copy or book format, in databases stored on CD-ROM within the library itself, or in databases at remote locations that can be accessed "on-line" over telephone or data cables at most institutions. *Biological Abstracts* and *Science Citation Index* are among many such indices that students will find invaluable. There are also sources, such as *Biosis*, which allows access to many remote databases. Interlibrary loans may also be necessary and helpful in retrieving literature.

If professors also have students present short, narrowly prescribed topics or design labs (experimental or observational), students must prepare more deeply for one or more areas of the course and become more integrally involved in the course and its teaching. Thus, we can enhance a student's acquisition of knowledge, including the essential botanical knowledge of the discipline.

We think that having students read and report on refereed research articles from current scientific journals of the campus library is pedagogically sound and exciting. Students can present short, 5-10 minute talks in class and/or submit short, often one page summaries of recent research articles from current journals; these can cover any aspect or subtopic of a course's subject matter. The students should present a brief account of the objective of the research problem, the general methods used and results obtained, the overall meaning of the research, and the relation of the research in the article to the subject matter of the course.

Scientific literature conveys some of the excitement that cannot be done effectively and timely in texts. As soon as students start delving into the abstract or introduction to a paper, they are reading current science, seeing what scientists think is important today, and learning what scientists think is essential knowledge. Even if the articles are
difficult to read and understand, students often get the gist of them, and suddenly the scientific world is so much larger and more interesting. Scrutinizing the works of modern scientists is a wonderful learning device and an important complement to the conduct of research. The authors of such works can serve as models for the student.

Incorporating material from the various student presentations into examinations deepens the participation of students in formal botany courses and heightened their attention to the work of others. We find this easier to do with essay-type examinations that permit students to explore the relation between student contributions and teacher expectations.

We recognize that there are many effective pedagogical methods in college education, but the use of undergraduate student research and participatory learning in courses can only enhance student interest in and understanding of science. Science requires that students participate in their own acquisition of knowledge and experience the excitement and the processes of science, especially through research and the scientific literature. Involvement of students in research and research communications produces essential botanical knowledge and must receive a high-

Literature Cited


