

# Bioscene

Journal of College Biology Teaching



Volume 32(4)

December 2006

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Journal of College  
Biology Teaching

Volume 32(4)

Dec 2006

ISSN 1539-2422

A Peer-Reviewed Journal of the

Association of College  
and University Biology Educators

Editor:

Stephen S. Daggett  
Avila University

An archive of all publications of the Association of College and University Biology Educators (ACUBE) can be found at <http://acube.org>

Bioscene is normally published in March, May, August and December. Please submit manuscripts by February 1, 2007 for consideration in the next issue.



**Cover image:** Photograph of nesting house sparrows (*Passer domesticus*) feeding their young at Wood's Hole, MA courtesy of Charles Wyttenbach. Identification courtesy of John Rushin.

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# **Bioscene: Journal of College Biology Teaching**

**Volume 32 (4) • December 2006**

*A Publication of the Association for College and University Biology Educators*

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- Articles: Laboratory and field studies that work, course and curriculum development, innovative and workable teaching strategies that include some type of evaluation of the approaches, and approaches to teaching some of the ethical, cultural, and historical impacts of biology.
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- Letters to the Editor: Letters should deal with pedagogical issues facing college and university biology educators

II. Preparation of Articles

Submissions can vary in length, but articles should be between 1500 and 4000 words in length. This includes references, but excludes figures. Authors must number all pages and lines of the document in sequence. This includes the abstract, but not figure or table legends. Concision, clarity, and originality are desirable. A complete submission will consist of the following:

A. Cover letter: All submissions should come with a cover letter indicating that the manuscript is being submitted exclusively to *Bioscene* and why it is appropriate for this journal. Authors may also offer graphics from the article as possible cover art.

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C. Abstract: The first page of the manuscript should contain the title of the manuscript, the names of the authors and institutional addresses, a brief abstract (200 words or less) or important points in the manuscript, and keywords in that order.

D. Manuscript Text: The introduction to the manuscript begins on the second page. No subheading is needed for this section. This supply sufficient background for readers to appreciate the work without referring to previously published references dealing with the subject. Citations should be reports of credible scientific or pedagogical research.

The body follows the introduction. It is recommended that it be broken into sections with appropriate subheadings including Materials and Methods, Results, and Discussion. Some flexibility is permitted here depending upon the type of article being submitted.

Acknowledgment of any financial support or personal contributions should be made at the end of the body in an Acknowledgement section, with financial acknowledgements preceding personal acknowledgements. Disclaimers and endorsements (government, corporate, etc.) will be deleted by the editor.

A variety of writing styles can be used depending upon the type of article. Active voice is encouraged whenever possible. Past tense is recommended for descriptions of events that occurred in the past such as methods, observations, and data collection. Present tense can be used for your conclusions and accepted facts. Because *Bioscene* has readers from a variety of biological specialties, authors should avoid extremely technical language and define all specialized terms. Also, gimmicks such as capitalization, underlining, italics, or boldface are discouraged. All weights and measures should be recorded in the SI (metric) system.

In- text citations should be done in the following manner:

"...rates varied when fruit flies were reared on media of sugar, tomatoes, and grapes" (Jaenike, 1986).

or

" Ulack (1978) presents alternative conceptual schemes for observations made..."

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Multi-authored:

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Books-

BOSSEL, H. 1994. *Modeling and Simulation*. A.K. Peters, London. 504p.

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GLASE, J.C. AND M. ZIMMERMAN. 1991. Population ecology: experiments with Protistans. In Beiwenger, J.M. 1993. *Experiments to Teach Ecology*. Ecological Society of America, Washington, D.C. 170p.

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MCKELVEY, S. 1995. Malthusian Growth Model. Accessed from <http://www.stolaf.edu/people/mckelvey/envision.dir/malthus.html> on 25 Nov 2005.

Note that for references with more than five authors, note the first five authors followed by *et al.*

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Tables should be submitted as individual electronic files. Placement of tables should be indicated within the body of the manuscript. All tables should be accompanied by a descriptive legend using the following format:

TABLE 1. A comparison of student pre-test and post-test scores in a non-majors' biology class.

G. Figures

Figures should be submitted as individual electronic files, either TIFF or BMP. Placement of figures should be indicated within the body of the manuscript. Figures include both graphs and images. All figures should be accompanied by a descriptive legend using the following format:

FIG. 1. Polytene chromosomes of *Drosophila melanogaster*.

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Letters should be brief (400 words or less) and direct. Letters may be edited for length, clarity, and style. Authors must include institution address, contact phone number, and a signature.

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Reviews and informational submissions may be edited for clarity, length, general interest, and timeliness. Guidelines for citations and references are the same for articles described above.

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Article manuscripts may be sent to the current editor either electronically or by hard copy, accompanied by a disc copy. Electronic submissions are preferable. All authors will receive confirmation of the submission within three weeks. Manuscripts should be submitted either as a Microsoft Word or RTF (Rich Text File) to facilitate distribution of the manuscript to reviewers and for revisions. A single-email is required to submit electronically, as the review process is not blind unless requested by an author. If the article has a number of high resolution graphics, separate emails or separate discs mailed to the editor may be required.

If hard copy is sent it must be accompanied by a disc containing the complete submission. Three copies of the manuscript, as well as the original, should be submitted. Standard paper should be used with lines of sections of the manuscripts numbered and enough margin to permit reviewer comments. Two self-addressed stamped envelopes must be included if the authors wish to receive reviews and responses by methods other than email.

#### VI. Editorial Review and Acceptance

All manuscripts will be sent to two anonymous reviewers as coordinated through the Editorial Board.

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- **Novelty:** The manuscript presents new information of interest for college and university biology educators or examines well-known aspects of biology and biology education, such as model organisms or experimental protocols, in a new way.

Once the article has been reviewed, the corresponding author will receive a notification of whether the article has been accepted for publication in *Bioscene*. All notices will be accompanied by suggestions and comments from the reviewers. Acknowledgement of the reviewers' comments and suggestions must be made for resubmission and acceptance. Upon acceptance, the article will appear in *Bioscene* and will be posted on the ACUBE website. The review process can take 4-5 months. Upon final acceptance, the article will appear in *Bioscene* and will be posted on the ACUBE website within six months of publication. Depending upon volume, time from acceptance to publication may take up to a year.

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We are soliciting nominations for four (4) *Bioscene* Editorial Board positions (terms through 2010). Board members provide input in the form of reviews and suggestions concerning the publication of *Bioscene* to the Editor.

Board members are also expected to assist in the solicitation of manuscripts and cover art for *Bioscene*. Board members may be called upon to proofread the final copy of *Bioscene* prior to publication.

**Preference will be given to individuals who regularly attend the annual meeting.** If you are interested in serving a 3-year term on the Editorial Board, please email the editor, Stephen S. Daggett, at [stephen.daggett@avila.edu](mailto:stephen.daggett@avila.edu).

# An Inquiry-Based Laboratory Design for Microbial Ecology

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**Abstract:** There is a collective need to increase the use of inquiry-based instruction at the college level. This paper provides an example of how inquiry was successfully used in the laboratory component of an undergraduate course in microbial ecology. Students were offered a collection of field and laboratory methods to choose from, and they developed a research question that they tested through experimentation. Assessment was accomplished by evaluating authentic scientific meeting style presentations and a lab report in manuscript format. Students enjoyed the inquiry-based format, and the instructors found the experience to be valuable. An example such as this one hopefully will encourage more college faculty to use the inquiry method of instruction in their courses.

**Keywords:** inquiry, microbial ecology, laboratory, active learning, student research

## Introduction

College and university teachers are being encouraged to move away from the use of lecture and cookbook-style laboratories to active learning techniques including Problem-Based Learning, Cooperative Learning, and Inquiry-Based Instruction (Chickering and Gamson 1987; NRC 1996, 2000). Because science is at its core a process and not a list of facts (Schwab 1963), these forms of learning are in line with the cognitive processes that help students to develop as life-long learners (Norman and Schmidt 1992; Svinicki 1998).

Because of the impediments to adopting these strategies such as inadequate preparation of teachers (Supovitz et al. 2000; Colburn 2000; Roehring and Luft 2004), management issues (Colburn 2000; Roehring and Luft 2004), misunderstanding of how inquiry works (Colburn 2000), beliefs about teaching (Roehring and Luft 2004), and the need for change at the level of the classroom and administration (Drayton and Falk 2002), not enough college teachers are adopting Inquiry-Based Instruction (Colburn 2000; Straits and Wilke 2002; McComas 2005). Inquiry can be used successfully, however, as evidenced by its use at the elementary (Wittrock and Barrow 2000), middle school (Songer et al. 2002, 2003), high school (Kashmanian Oates 2002; Zion et al. 2004), and college levels (Mullen et al. 2003; DiPasquale et al. 2003; Sundberg et al. 2005). Inquiry is in use internationally (Abd-El-Khalick et al. 2004; Carber and Reis 2004) as well. Successes such as these should encourage more college teachers to use inquiry in their classrooms and laboratories.

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This paper offers an example of the successful use of inquiry in a laboratory setting. The objectives of this paper are to 1) provide an example of Inquiry-Based learning at the college level, 2) assess student and faculty impressions of the technique, and 3) encourage more college faculty to make use of inquiry in their teaching.

## Course Philosophy

The first offering of BIO 315, Microbial Ecology, at Central Connecticut State University in the fall of 2005 took the form of a course in two halves. The first half focused on the microbes of terrestrial soil environments and the second half focused on microbes in aquatic environments. The soils half was a sincere attempt to use active learning techniques in both the lecture and lab. The lecture portion made use of team-based learning (Michaelsen et al. 2004) and the laboratory portion, which is the basis of this paper, made use of Inquiry-Based Instruction.

We designed the laboratory to encourage students to see the topics through the process of science and to serve as an example of this teaching format for pre-service teachers who were taking the course (9 out of the 16 students who took the course were in the teacher preparation program). The goal was for all students to gain a new appreciation for the way that science is conducted and knowledge is acquired. Additionally, we wanted the pre-service teachers to see that a great deal of content can be learned in the inquiry format and to be less hesitant to use the technique in their own classrooms (Roehring and Luft 2004).

## Course Details

The 16 students who took the course had five weeks to work on their research project after spending the first week taking a walking tour of the forested park near campus that they used for their projects. We gave students a description of five common research techniques from which to choose in conducting their research (Table 1). During the five

weeks of their work, the students were required to come up with a question about soil microbes that interested them, write scientific hypotheses that could be tested using the available techniques, conduct the field and laboratory work, and complete the data analysis. The last week of the soils portion of the lab was used for groups to give a presentation of their work as if they were at a scientific conference.

TABLE 1. Research methodologies provided to students for use in their inquiry-based projects. All requisite materials were available in the lab room.

|  |
|--|
| <p><b>Soil Macrofauna Methods</b></p> <ol style="list-style-type: none"><li>1. Collect soil samples.</li><li>2. Place soil on top of screen in bottom of funnel.</li><li>3. Add 1 cm of ethanol to the bottom of the collection vessel.</li><li>4. Position the funnel on top of the collection vessel with the neck inserted in the collecting vessel and turn on the lights above the funnel.</li><li>5. Allow apparatus to set for a week.</li><li>6. Spread collection onto a petri dish and identify the collection under a dissecting microscope.</li></ol>  |
| <p><b>Bacterial and Fungal Morphospecies</b></p> <ol style="list-style-type: none"><li>1. Mix agar using directions on label. Make glucose agar, R2A agar, and Rose Bengal agar (500 mL is sufficient for 15 – 18 plates).</li><li>2. Autoclave agar and allow to cool a bit</li><li>3. Pour agar into sterile petri dishes and allow to cool.</li><li>4. Collect soil samples.</li><li>5. Weigh 5 g of soil into a 50 mL centrifuge tube and fill to the 50 mL mark with DI water.</li><li>6. Centrifuge at 1500 RPM for 15 minutes.</li><li>7. Remove 5 mL and add those 5 mL to another 50 mL centrifuge tube and fill that tube to the 50 mL mark with DI water.</li><li>8. Centrifuge at 3500 RPM for 10 minutes.</li><li>9. Create a dilution series by pipetting 1 mL from the second centrifugation into a beaker and adding 9 mL of DI water. Repeat this process two more times. This dilution creates concentrations of <math>10^{-1}</math>, <math>10^{-2}</math>, and <math>10^{-3}</math>.</li><li>10. Sterilize an inoculation loop using a flame and inoculate two petri dishes of each medium for each dilution level.</li><li>11. Place petri dishes in 35° C incubator and allow colonies to form.</li><li>12. Assess the communities for morphospecies.</li></ol>  |
| <p><b>Nitrification Rates</b></p> <ol style="list-style-type: none"><li>1. Collect fresh soil sample.</li><li>2. Rebury half of the sample within a Ziploc bag.</li><li>3. Return for the buried sample in two weeks.</li><li>4. Mix 20 g soil with 100 mL 1M potassium sulfate.</li><li>5. Shake every minute or two for 30 minutes.</li><li>6. Filter the liquid through filter paper in a funnel into 100 mL volumetric flask.</li><li>7. Bring to volume with the 1M potassium sulfate.</li><li>8. Dilute to ¼ strength for nitrate analysis.</li><li>9. Create 50 and 100 µg/L <math>\text{NO}_3^-</math> N standards.</li><li>10. For each sample and standard, place 30 mL liquid in a flask and add one packet of the Hach 6 nitrate reagent and stir sample continuously for three minutes.</li><li>11. Allow sample to set for two minutes.</li><li>12. Decant 25 mL of sample into another flask and add one packet of the Hach 3 nitrite reagent. Shake to dissolve.</li><li>13. Allow sample to set for 10 minutes.</li><li>14. Zero Hach DR 2000 spectrophotometer with potassium sulfate at 507 nm.</li><li>15. Read absorbance of untreated, diluted extract in the cuvette.</li><li>16. Transfer the sample to the cuvette and read absorbance.</li><li>17. Subtract the absorbance of the untreated sample from the absorbance of the treated sample to get the corrected absorbance.</li><li>18. Create a regression of absorbance vs. <math>\text{NO}_3^-</math> N of standards.</li><li>19. Use this regression to determine the <math>\text{NO}_3^-</math> N concentrations of your samples.</li></ol> |



TABLE 1  
(Continued)

|  |
|--|
| <p><b>Soil Respiration Assay</b></p> <ol style="list-style-type: none"> <li>1. Collect soil samples.</li> <li>2. Place 10 g soil in the biometer flask and stopper.</li> <li>3. Add 20 mL 2M NaOH to the opposite side of the biometer flask and stopper.</li> <li>4. Incubate for 24 h.</li> <li>5. Unstopper and add 5 mL 1M BaCl<sub>2</sub> to the NaOH and allow precipitation of carbonate to stop.</li> <li>6. Decant NaOH solution into a beaker and add 5 mL thymolphthalein indicator to produce blue coloration.</li> <li>7. Titrate with 2N HCl to the thymolphthalein endpoint (clear).</li> <li>8. CO<sub>2</sub> evolution is equal to <math>(V - B) * NE</math>, where B is HCl needed for a control setup, V is the HCl needed for the soil setup, N = 2 (HCl normality), and E is the equivalent weight (22 for CO<sub>2</sub>). Correct the result to grams of CO<sub>2</sub> evolved per gram of soil per hour.</li> </ol> |
| <p><b>Mychorrhizae Assessment</b></p> <ol style="list-style-type: none"> <li>1. Collect root samples.</li> <li>2. Wash to remove soil particles.</li> <li>3. Trim and fit in the cassettes. Pack loosely.</li> <li>4. Preboil sufficient 10% KOH to cover cassettes, then soak cassettes in KOH for 10 – 20 minutes to clear the roots.</li> <li>5. Wash roots with DI water 5 times.</li> <li>6. Immerse cassettes in 2% HCl for 15 – 20 minutes.</li> <li>7. Preboil sufficient stain solution (trypan blue and acid fuschin should each be used) to cover the cassettes, then soak cassettes for 5 minutes.</li> <li>8. Rinse roots with DI water 5 times.</li> <li>9. Store roots in DI water at 4° C for one week.</li> <li>10. Assess degree of mycorrhizal infection under a microscope.</li> </ol>   |

Students worked in the same three groups that they used for the team-based learning (Michaelsen et al. 2004) that they were experiencing in the lecture portion of the course. As the students worked, the faculty were available for answering any questions that the students had and helped the students to organize materials and techniques. The faculty also provided instruction regarding the methods that the students chose to use if the students had not used a similar method in any previous course. The research projects that students chose included structural and functional comparisons of soil microbes at an increasing distance from a stream, between intact forest and areas that were logged, and beneath invasive species and beneath native species.

This design provided an authentic research experience for the students (McComas 2005), and helped them to appreciate the challenges of conducting the research that professional scientists perform to provide the knowledge that that is incorporated into science textbooks. Along with an authentic research experience, Inquiry-Based Instruction needs to include appropriate and authentic

assessment of student learning (NRC 1996; Straits and Wilke 2002; Colburn 2004; McComas 2005). We accomplished this assessment in two forms. First, student groups gave a scientific presentation describing their questions, hypotheses, methods, and results (Table 2). Second, students individually completed lab reports in the standard scientific format (Table 3). The faculty provided time during lab for students to ask any questions they had about how to present and write in a scientific format. Given that this was a 300 level course, most students had already been exposed to primary literature. Performing these assessment activities required students to act as scientists. (When scientists do research, they present the results of their research at scientific meetings and also submit their work for publication.) In addition, students gave each other peer evaluation grades after the presentations based on group contracts written at the beginning of the lab. A student's average peer evaluation grade (as a percentage) was multiplied by their group's presentation grade to determine the student's grade on the presentation.

TABLE 2. Rubric used for grading the group scientific presentations of the students' research.

|                              |   |  |  |
|------------------------------|---|--|--|
| Title Grade                  | 15 Title is brief but descriptive of the study  | 10 Title is excessively long or does not indicate the subject of the study     | 0 Title is missing   |
| Introduction Grade           | 15 Introduction brings the intelligent, lay-audience up to speed, indicates the importance of the topic studied, and ends with the objectives of the study  | 10 Introduction is lacking in 1 of the required components                     | 5 Introduction is lacking in 2 or more of the required components                        |
| Methods Grade                | 15 Methods section provides a general background of how the study was done  | 10 Methods were minimal and left the audience wondering what was actually done | 0 Methods were absent  |
| Results and Discussion Grade | 15 Results & Discussion gives figures and/or tables to lucidly display the data, oral description fairly interprets the data, provides caution regarding the limitations of the study, and provides direction for future research | 10 Results & Discussion lack 1 or 2 of the required components                 | 5 Results & Discussion lack 3 or more of the required components                         |
| Conclusion Grade             | 15 Conclusion wraps up the findings of the study and offers direction for the future  | 10 Conclusion is lacking in 1 of the required components                       | 5 Conclusion is lacking in both of the required components                               |
| General Grade                | 15 No spelling errors, presentation is easy to follow, and PowerPoint slides are easy to see and understand   | 10 Presentation is lacking in 1 general requirement                            | 5 Presentation is lacking in 2 or more general requirements                              |
|                              | Final Grade (including 10 free points)  |  | Average Peer Evaluation (multiplied by group's grade to calculate student's Final Grade) |

TABLE 3. Rubric used for grading the individual scientific reports of the students' research.

|                           |  |   |   |
|---------------------------|--|---|---|
| Title Grade               | 10 Title is brief but descriptive of the study   | 5 Title is excessively long or does not indicate the subject of the study | 0 <input type="checkbox"/> Title is missing                           |
| Introduction Grade        | 10 Introduction brings the intelligent, lay-reader up to speed, cites background literature, indicates the importance of the topic studied, and ends with the objectives of the study                              | 5 Introduction is lacking in 1 or 2 of the required components            | 0 Introduction is lacking in 3 or more of the required components     |
| Methods Grade             | 10 Methods section details the materials used and the methods employed in enough detail to repeat the study  | 5 Materials <u>or</u> sufficient detail are lacking                       | 0 Materials <u>and</u> sufficient detail are lacking                  |
| Results Grade             | 10 Results section gives figures and/or tables to lucidly display the data, factual representation of the results are given in text format, and interpretation of the data is NOT present.                         | 5 Results lack 1 of the required components                               | 0 Results lack 2 or more of the required components                   |
| Discussion Grade          | 10 Discussion interprets the data fairly, indicates the relevance of the current findings to other literature, provides caution regarding the limitations of the study, and provides direction for future research | 5 Discussion is lacking in 1 or 2 of the required components              | 0 Discussion is lacking in 3 or more of the required components       |
| Literature Citation Grade | 10 Literature citations include at least 5 primary literature sources, are cited accurately, and are referenced in the paper.  | 5 Literature Cited is lacking in 1 of the required components             | 0 Literature Cited is lacking in 2 or more of the required components |
| General Grade             | 10 No spelling errors, all statements are easy to read and understand, and pages are numbered  | 5 Paper is lacking in 1 general requirement                               | 0 Paper is lacking in 2 or more general requirements                  |
|                           | ← Final Grade (including 30 free points)   |   |   |

## Outcomes

The need for information regarding student and faculty perceptions of Inquiry-Based Instruction (Keys and Bryan 2001) encouraged us to conduct a voluntary survey of the students regarding their opinions about the lab. They were asked to comment on class activities that encouraged them to learn, class activities that made learning difficult, and

whether they would have preferred a cookbook style lab in place of the Inquiry-Based lab experience.

Fourteen students completed the voluntary survey. Students wrote that picking an experimental idea for lab, group responsibilities, and group work in general encouraged them to learn. One student wrote that the groups were too large and this made it difficult to learn. Eleven of the students stated that they preferred the Inquiry-Based style of lab and

three indicated that they would have preferred a cookbook style lab. Students wrote that the Inquiry-Based lab was a “great learning experience” and that “predetermined labs can be boring.” Students liked the Inquiry-Based lab because it “allows for independent learning” and noted that they “teach more than the cookbook labs.” One student reported that s/he “enjoyed this course more than any other biology course I’ve had so far (not kidding).” The one complaint that was raised was a need for more time to complete the research. Clearly students were excited about the work and wanted more time to conduct the project. Based upon these comments we are convinced that the students enjoyed the Inquiry-Based experience and appreciated the flexibility and education it provided them.

The experience to be rewarding and informative for the instructors. Students were engaged throughout the experience and were keenly interested in their results. These are the responses that faculty hope to get from their students. The design of the lab required a front-loading of the effort by the faculty. Each method had to be tested before the semester and all requisite materials needed to be acquired and made available by the start of the semester. Once the lab began, however, we were free to concentrate on the process that the students were

### Acknowledgements

The authors thank the Department of Biology at Central Connecticut State University for supporting the use of new teaching techniques and the students of BIO 315 in the fall of 2005 for their work. This project was supported by a Connecticut State University Curriculum Development Grant. We also thank two anonymous reviewers for their helpful comments that improved the manuscript.

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following and encourage them to develop interesting hypotheses and research. This experience is in contrast to formulaic labs, where the faculty must prepare the lab each week and spend time simply making sure that the lab is working. In this inquiry format, students performed problem solving and the faculty could serve as guides (King 1993). Collectively, these experiences were rewarding for both students and faculty as the students took ownership of their projects and worked diligently toward their successful completion.

### Conclusions

This paper serves as an example of the use of inquiry in a college laboratory. It is hoped that the report of successful implementation of Inquiry-Based Instruction in this lab will encourage more college teachers to use Inquiry-Based Instruction since this method is engaging for the students, rewarding for the faculty, and in line with science teaching standards. Students found the experience to be rewarding, educational, and enjoyable. We were encouraged to continue using the technique because of the success in this first offering of the course.

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# Coming to Terms with the Online Instructional Revolution: A Success Story Revealed Through Action Research

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**Abstract:** This paper presents the course of action and outcome of a teacher-based action research project concerning development and evaluation of an online introductory biology course for non-majors. The research took place in a small community college and compared online and traditional instructional formats. A course was developed in an entirely web-centered format. After a semester of instruction, participants were assessed with a 50 item multiple choice test pertaining to content knowledge gained in the course. When their scores were compared with students taught in a traditional classroom format, the scores were essentially identical. The research format may serve as a model for teachers who wish to explore the issue of web-based instruction in their own practice.

**Keywords:** Online biology instruction, web-based teaching, action research

## Introduction

It is very difficult to clearly define *online instruction*. Various monikers such as *distance learning* and *web-centered teaching* are quickly finding their way into our educational lingo. The terms may have different meanings to different teachers. Of course, the essential premise of learning outside of the traditional seat-based classroom is not new. Correspondence courses have been around for decades. What is relatively new, however, is the use of the internet as a primary delivery mechanism for instruction. As early as 1994, DeLoughry predicted that instruction involving online and distance lessons would likely grow very rapidly. Exponential growth, into the millions of students, continues to occur (Kriger, 2001).

Online science instruction probably has its roots in the programmed instruction movement (Melear, 1989; Deutsch, 1992) that first gained significant prominence during the 1970s. Surprisingly little has been written about teaching biology in a web-centered format. Much of what has been written involves the use of internet or multimedia resources as a valuable supplement to primary, traditional instruction (Seng and Mohamad, 2002; Ardac and Akaygun, 2004; Skinner & Hoback, 2004). King and Hildreth (2001) reported that it is, indeed, possible to construct on-line science courses that are compatible to traditional, seat-based science courses. Only a few other writers have explicitly dealt with the issue of teaching biology in an online format in recent professional publications (Collins, 2000; Johnson, 2002). Even though some instructors

have been teaching web-based biology courses for years, the whole issue of on-line biology instruction is certainly a contemporary one. It is our hope that this research report will assist our peers in making quality, informed decisions as they are faced with a revolution in biology instruction. We offer results from one small study on the issue of online biology teaching, as well as details about our methodology that may serve as a model for other classroom teachers.

## Theoretical Framework

Qualitative research methods are highly valued for making sense of the experiences of people and communicating those experiences with a high degree of validity. They differ from traditional, empirically based research methods in that the focus is less on repeatability, large sample sizes and random selection of research subjects (Patton, 1990; Guba, 1995; Denzin and Lincoln, 2000). These are some of the reasons that classroom teachers very often utilize qualitative research designs in educational settings. They are often forced to make do with what is available to them (small classes, limited means of comparison and lack of randomization) as they try to answer their own important research questions. When faced with a dilemma outside of their routine and zone of comfort teachers usually seek practical solutions. One of the best ways to alleviate uncertainty about any situation is by way of action research. Simply put, action research involves a planned, reflective consideration of one's own practice (Reason and Bradbury, 2001).

We suggest that teachers, often without even realizing, routinely engage in action research. They regularly ask questions like “Does this work?” or “How could I improve this unit?” What many teachers often do not do is formalize the process and share findings with their peers or other interested persons. Knowledge gained from a research of one’s own world of action very often has mass appeal to those in similar situations (Jarvis, 1999).

In a formal, academic sense, action research was originated by Kurt Lewin (1947a; 1947b). In all its forms, a few things emerge to characterize the process. The practitioner realizes a problem, issue or question and then formulates a plan of action. The results are carefully reflected upon and may or may not be integrated into the practical knowledge base of the practitioner (i.e. “This worked well, but that didn’t.”). Although the outcomes of action research may have broad appeal, the goal is less about generalizing to other situations and populations than it is about coming up with a pragmatic, workable solution to the original problem faced by the practitioner (Jarvis, 1999; Reason and Bradbury, 2001).

This paper explores and communicates the action research efforts of a community college biology teacher in a small school in the Southeastern United States. The dilemma involved designing a new web-centered freshman biology course. As anyone new to a process such as this could imagine, there were a number of uncertainties, questions and concerns. So, the theoretical framework of action research seemed ideal for gathering information and making an informed decision. Figure 1 presents an overview of our research process involving problem, plan of action and results.

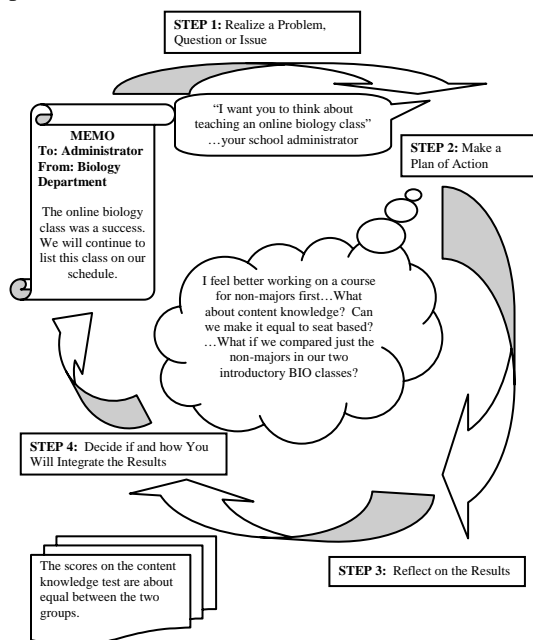


FIG 1. Summary of action research plan and outcome.

## Background of Research

Both the authors are biology teachers in what could be described as a community college or junior college environment. Neither had taught in a distance learning situation at the onset of this project. The first author was recently encouraged to explore the idea of designing and delivering a freshman-level biology course entirely online to benefit distance learning students. Both of the author’s schools have excellent and rapidly growing catalogs of distance learning courses. Most of the courses offered are non-scientific in nature and include such things as history, composition and humanities classes. Within the science departments at both schools, a freshman level chemistry course has successfully been taught with the lecture component online. One school offers some anatomy labs in an on-line format. However, at the time our research project began, the concept of a science course delivered completely online (with no student visits to campus, even for lab) was new to the members of the science department at the school where this research took place. A recent study comparing electronically delivered materials with traditional, text-based delivery found that lab instruction by way of an instructor designed CD-ROM tended to produce lower lab grades among non-majors in biology (Brickman, Ketter and Pereria, 2005). A study such as this clearly has implications to teachers designing a web-centered biology class and lab component.

One goal in developing the new course was to keep it as equitable in content as possible to traditional, seat-based biology classes at the school. A number of pre-made, one-size fits-all computerized course programs and cartridges are quickly finding their way on the market. Many have flashy simulations that while impressive, offer little opportunity for students to practice science. In the words of La Velle (2002) “It just isn’t real.” Several such packages were examined as possible materials for the instructor’s goals and pedagogical style. It was important to the instructor that the students have as many authentic lab opportunities as possible, working with legitimate scientific questions, hands on materials and with living organisms whenever possible. This is consistent with national reform recommendations for teaching college science (Sibert and McInthos, 2001). The instructor ultimately selected a number of simple lab activities that could be done in the students’ homes, as well as activities utilizing library or internet research, to guide and/or supplement the instruction.

The school, where this research took place, has two freshman-level biology course options available to students. One is a two semester sequence, designed for science majors. The other is a

one semester version (Principles of Biology) for non-majors which has not been recently taught at the school. The first semester of the sequence for science majors (General Biology I) is most akin to the non-majors class in terms of content. Because of the small size of the school (and other factors), the course for science majors is taught most often, in multiple sections, and attracts both science majors and non-majors. In fact, non-majors account for the larger percentage of enrollees in the class. Figure 2 compares the essential features of the two courses. Members of the school's science department agreed that the place to begin exploration of web-based learning in biology would be in the course especially designed for non-majors. Due to factors that are beyond the scope of this paper to discuss, classroom sections of the non-majors course have not been offered at the school in some time. While comparing two different courses (majors and non-majors) is not ideal, focusing study on non-majors from both courses seemed to be a viable means of evaluation of the new on-line course.

| General Biology I<br>(designed for science majors)   | Areas of Overlap Between<br>Both Courses   | Principles of Biology<br>(designed for non-science<br>majors)  |
|--|--|--|
| CONTENT  | CONTENT  | CONTENT  |
| <i>A more detailed treatment of all topics.</i>  | Nature of Science<br>Basic Chemistry<br>Cell Biology<br>Metabolism<br>Taxonomy & Classification<br>Genetics<br>Evolution   | <i>A less detailed treatment of all topics.</i><br><br>Ecology   |
| SPECIAL COMMENTS ON<br>LAB   | SPECIAL COMMENTS ON<br>LAB   | SPECIAL COMMENTS ON<br>LAB   |
| <i>Completed in traditional seat-based lab.</i><br><br><i>Students work with earthworms and mealworms. They select their own research question, dependent &amp; independent variables.</i><br><br>Building & Using Taxonomic Keys<br><br>Detailed Taxonomy & Diversity Study of 20 Organisms<br><br>Mitosis<br><br>Meiosis | <b>Introductory Microscopy Lab</b><br><br><b>Guided Inquiry Project</b><br><br><b>Other Labs</b><br><br>Measurement in International System<br><br>How to Use Scientific Literature<br><br>Dietary Analysis<br><br>DNA & Protein Synthesis | <i>Completed with guidance from an approved off campus lab mentor (lab technician, teacher, etc.)</i><br><br><i>Students work with yeast. They select their own research question and independent variables. Dependent variable is assigned.</i><br><br>Writing a Science Autobiography (Icebreaker Activity).<br>Short Taxonomy and Diversity Study of 11 Organisms<br><br>Observation of Mealworms<br><br>Acid-Base Indicator Activity<br><br>Identification of Fat in Foods<br><br>Studying Diffusion<br><br>Modeling Mark & Recapture<br><br>Internet Research on Symbiosis<br><br>Modeling Genetic Crosses With Coin Tosses |

FIG 2. Comparison of both courses with areas of content overlap.

The school's science department and one of the authors (who developed the on-line course) had several concerns about the new venture into online biology instruction. A major concern of the teacher (the first author) was whether a web-based course could be developed that addressed content knowledge (Sibert and McInthos, 2001) as equitably as a traditional seat-based course would. Since the biology course for non-majors had not been offered at the school for some time, there initially appeared to be no way to equitably compare seat-based and on-line instruction. To deal with this methodological complication, the instructor compared the content knowledge objectives that the two courses (the class for science majors in seat-based format and the class for non-majors in online format) had in common. These objectives were compiled into a list. A 50 item multiple choice test, sampling most of the objectives, was generated by the second author (not the teacher of the online course). It was important to initially keep this researcher blinded regarding the nature of this study so as not to influence the choice of questions toward or against the online instructional format. Students in both courses were given copies of the test at the conclusion of the academic term. The test results had no impact on the students' course grades. Completion of the test was entirely voluntary, anonymous and with informed consent. Students were asked to identify the format (seat-based or web-based) in which they studied biology and were asked to list their academic major. All tests were assessed with a pre-made test answer key by one author. The four students in the course for science majors who listed a science or health science related major were eliminated from the study. In this way content knowledge among non science majors could be more effectively compared between the two instructional formats. There were nine active participants in each group.

## Results and Discussion

Interestingly enough, the two highest scores on the exam (94 and 92) were made by students who identified themselves as science majors. Recall that the tests of the science majors were not included in our analysis. Mean test scores and ranges between the two groups of non-science majors are presented in Table 1. With such a small sample size (n = 9 per group) and with no random selection and other methodological complications, no statistical comparison of the data was completed. However, it is obvious that the mean test scores of the seat-based and web-based groups were essentially identical (69.77 vs. 70.00). The range of scores was a bit broader in the online group (36 – 88) than for the

## Methodology

TABLE 1. Comparison of test scores between groups

|   | Principles of Biology<br>(designed for non-science<br>majors)<br><br>Taught Web-based<br>n = 9 | General Biology I<br>(designed for science<br>majors)<br><br>Taught Seat-based<br>n = 9 |
|---|--|---|
| Mean Score on Test (100<br>Point Scale)   | 69.77  | 70.00   |
| Range of Test Scores<br>(100 Point Scale) | 36-88  | 46-88   |

seat-based group (46 – 88). Also, a few more students in the on-line group surpassed a score of 70 on the examination. Figure 3 displays a comparison of individual scores between the two groups.

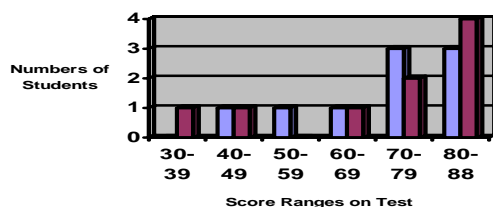


FIG 3. Comparison of individual test scores between groups. Seat-based scores are the lighter bars, while web-based scores are represented by the darker bars.

Remembering that the primary goal of action research is to provide practical and pragmatic information to the researcher (Jarvis, 1999; Reason and Bradbury, 2001), we can state that our concerns about content knowledge of biology in on-line versus traditional instructional formats have been allayed. We believe that we have demonstrated that the non science majors in our study (the primary target population for the new online course offering) are served equally well in both formats in terms of their performance on a summative assessment of content knowledge. With this information, an informed decision was made to continue teaching the web-centered course in the format described above. We were satisfied that, for our non-majors, the web-based format was equitable to the traditional classroom format to which we were accustomed. We certainly do not make a generalized claim to other groups that one format is equal to, inferior to or superior to the other. More research on that point, involving multiple studies with students from various schools, is clearly needed. However, in keeping with one scholarly purpose of action based research, we do

present our findings to our peers. We also offer this paper as a model that may provide assistance to other biology instructors who are new to the world of online education. We hope that our study will assist others in making informed, reflective decisions about their own courses of actions in the growing world of online biology instruction. Continued research regarding the situation described in this paper will be pursued. For example, studies are needed that compare other goals of scientific literacy and mastery (such as inquiry skills) between these alternative instructional formats.

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## Call for Applications -- John Carlock Award

This Award was established to encourage biologists in the early stages of their professional careers to become involved with and excited by the profession of biology teaching. To this end, the Award provides partial support

for graduate students in the field of Biology to attend the Fall Meeting of ACUBE.

**Guidelines:** The applicant must be actively pursuing graduate work in Biology. He/she must have the support of an active member of ACUBE. The Award will help defray the cost of attending the Fall meeting of ACUBE. The recipient of the Award will receive a certificate or plaque that will be presented at the annual banquet; and the Executive Secretary will provide the recipient with letters that might be useful in furthering her/his career in teaching. The recipient is expected to submit a brief report on how he/she benefited by attendance at the meeting. This report will be published in *Bioscene*.

**Application:** Applications, in the form of a letter, can be submitted anytime during the year. The application letter should include a statement indicating how attendance at the ACUBE meeting will further her/his professional growth and be accompanied by a letter of recommendation from a member of ACUBE. Send application information to: Dr. William J. Brett, Department of Life Sciences, Indiana State University, Terre Haute, IN 47809; Phone: 812-237- 2392; FAX: 812-237-4480; Email: [lsbrett@scifac.indstate.edu](mailto:lsbrett@scifac.indstate.edu).

If you wish to contribute to the John Carlock award fund, please send check to: Dr. Tom Davis, ACUBE Executive Secretary, Department of Biology, Loras College, 1450 Alta Vista, Dubuque, IA 52004-0178

# Highlights from the ACUBE 50<sup>TH</sup> Annual Meeting

October 26-28, 2006  
Millikin University  
Decatur, IL



*Honorary Life Members:* Front (l to r)-  
Bill Brett, Ann Larson, Sr. Marion  
Johnson; Back (l to r)-John Jungck,  
Neil Baird, Dick Wilson, Harold  
Wilkinson, Joe Kapler



*New  
members!*



*Even more  
new  
members!*



***Presentation of the Karlock Award***

Pictured: Award recipient, Melanie Anastasio, Bill Brett. Not pictured is Kristy Halverson, who shared this year's award (see column on page 19)

***Audience members engaged in one of the many presentations at this year's meeting.***



***Sponsors and members have several opportunities to interact. Sponsors for this year's meeting were NASCO Biologicals, Midwest Scientific, iWorx/CB Sciences, Inc., Morton Publishing Co., Biohit-Pipettors and Liquid Handling, Mettler/Toledo-The Balance Company, Labcon-Manufacturers of VWR Plasticware, VWR International, Ken-A-Vision Mfg. Co. Inc., McGraw-Hill Publishers, and Bio-Rad Laboratories.***

## ***2006 Carlock Award Recipient Impressions***

As a second year graduate student at University of Missouri-Columbia, I realize that I am very much a newbie in academia and have felt uncertain whether my research will actually be considered worthy and valuable to educators in the science community. My involvement in the ACUBE 50th Annual Meeting has given me hope to continue my pursuits toward redeveloping biology curriculums to include problem based learning activities to help students better learn science concepts. I've found support and encouragement for my interests through the people I encountered, materials and resources made available, and sessions I was fortunate to attend.

I didn't know what to expect from this conference, but I've taken away so many valuable lessons and ideas that I can hardly contain my excitement to incorporate my ideas into the introductory biology courses that I teach. Multiple presentations and posters outlined innovative ideas on how to incorporate research and an interdisciplinary approach toward teaching science. It was challenging to try to decide which presentations I would attend. My only wish was that I could have been able to attend every presentation.

I learned a great deal about the technology available to start incorporating cameras in my labs. While I currently encourage my students to capture images with their digital cameras and draw what they see, these methods are not always reliable. Now I have contact information for new resources and ideas for new ways to implement these materials. Many sessions, offered valuable insights to consider when designing off-campus travel courses, student centered environmental courses, and student lead investigations in introductory biology labs. I was also pleased to find that I am not alone with my

discontentment with undergraduate textbook organization. It's hard to maintain a less can be more approach when nearly every available text keeps increasing its content in inches. With talks such as I found at this conference, there is hope that we may find answers rather than just dealing with the products available.

I particularly enjoyed listening to how David Horn incorporated his research model across courses and extension across years. He has inspired me to try to develop a working research model of my own to incorporate into my biology courses. I had previously been struggling with how I might be able to combine ongoing research at primarily teaching institutions.

I was also very fortunate to be able to attend the BioQuest Workshops at the end of the meeting this year. This is a completely new resource for me and I intend to explore in much greater depth. I am also eager to share what I've learned with my colleagues and professors back home.

It was great to meet and communicate with so many individuals who seem to deeply value teaching undergraduate students. I am so excited to be a part of this wonderful and inspiring organization. I wish to thank everyone who attended the 50th Annual ACUBE Meetings for making this opportunity such a wonderful experience! I hope to see you all again next year in Dubuque, Iowa.

Kristy Halverson  
*Science Education Center  
University of Missouri-Columbia  
Columbia, MO 65211*

# 51<sup>st</sup> Annual ACUBE Meeting

## Learning by Doing: The Integration of Research and Teaching in the Biology Classroom

Oct. 4 -6, 2007

Loras College, Dubuque, Iowa



Area Map, Campus Map and Driving Directions to Loras College available at:  
[www2.loras.edu/college/maps](http://www2.loras.edu/college/maps)

Dubuque does have its own airport served by American Eagle only. Other regional airports include **Cedar Rapids**, 1 hour 20 minute drive from airport to Dubuque, **Moline**, also about one hour and 20 minute drive to Dubuque, **Madison, WI** a 2 hour drive to Dubuque, or **Rockford, IL**, a 2 hour drive to Dubuque.

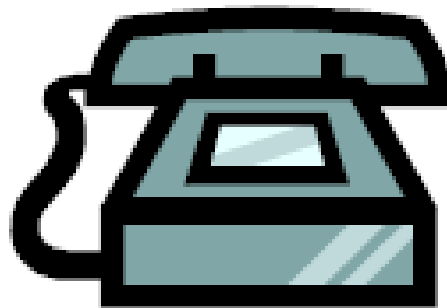
## Housing Preview

### 51<sup>st</sup> Annual ACUBE Fall Meeting

#### *Learning by Doing: The Integration of Research and Teaching in the Biology Classroom*

Loras College  
Dubuque, Iowa

October 4-6, 2007



**Note:** Lodging for ACUBE meeting in Dubuque; each hotel has a block of rooms set aside for our group for Thursday Oct. 4 and Friday Oct. 5, 2007.

#### **Holiday Inn Five Flags – Downtown Dubuque**

450 Main St.

563-556-2000

\$62 +tax per night

**Ask for rooms held for Davis**

#### **Best Western Midway Hotel**

3100 Dodge St.

563- 557-8000

\$65 +tax per night

**Ask for rooms for Loras College Biology  
Teachers**

**Reservations need to be made by Sept. 17, 2007**

#### **Hampton Inn**

3434 Dodge St. (Hy 20 W)

563-690-2005

\$84 = tax per night

**Ask for rooms held for Davis**

#### **Heartland Hotel**

4025 Dodge St. Hy 20 W

563-582-3752

\$55 + tax per night

**Ask for rooms for Loras College Biology  
Teachers**

## Call for Resolutions

The Steering Committee of ACUBE requests that the membership submit resolutions for consideration at the 2006 Annual meeting to the Chair of the Resolutions Committee. Submit proposed resolutions to:

Brenda Moore, Truman State University, Division of Science, MG3062, Kirksville, MO 63501,

Email: [bmoore@truman.edu](mailto:bmoore@truman.edu)

Phone: 660-785-7340

# The Effects of Instructional Approaches on the Improvement of Reasoning in Introductory College Biology: A Quantitative Review of Research

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**Abstract:** The majority of undergraduates lack advanced reasoning patterns, which are necessary for significant achievement in college science courses. The purpose of this paper is to review the studies of various instructional practices in introductory college biology courses that claim to develop reasoning. Most of these were non-traditional, inquiry-based, collaborative approaches that were shown to improve reasoning and scientific attitudes and did not adversely affect content acquisition. The inclusion of writing, direct teaching of formal and informal reasoning models, and length of time of instruction were variables that effected positive gains in reasoning development. How the instructional variables play a role in changing reasoning remains a black box.

**Keywords:** introductory college biology, science education, critical thinking, scientific reasoning

## Introduction

Although college faculty purportedly advocate instructional methods that improve student scientific reasoning skills, only limited research and change in post-secondary science teaching have been documented (Glick, 1994). This can be attributed to a variety of reasons. According to Glick (1994), college faculty are often scientists who are untrained in instructional theory and practice. As a result, these faculty rely on the methods by which they were taught in order to develop a conceptual framework to guide their teaching. This framework is most often a traditional pedagogy, characterized by a rigorous adherence to content transmission and not the development of reasoning skills (Glick, 1994).

Introductory college biology courses tend to have large lecture classes, which often reinforce passive roles for learners. A special challenge exists for faculty to engage students in reasoning in these large classes (Ebert-May et al., 1997). The undergraduate science laboratories also tend to be fact-laden, non-inquiry based, with activities that act in opposition to the development of reasoning skills (Hall and McCurdy, 1990).

The current set-up is due to a fear among college biology educators that content knowledge acquisition would suffer if time were to be dedicated specifically to reasoning skill development during the lecture or laboratory (Sundberg et al., 1994). This has fomented, among science educators, a spirit of antagonism against non-traditional instructional methods that advocate reasoning development.

It is also presumed by these instructors that college students, as adults, should be able to use scientific reasoning strategies independently after reading course materials and listening to lecture presentations (Glick, 1994). When students are unable to do this, according to Glick (1994), blame is simply placed on deficiencies in secondary level preparation.

Unfortunately, as many as fifty percent of first year college students lack the advanced reasoning patterns needed to succeed to college biology, according to Lawson's (1992) review of research on reasoning skills in undergraduates. Perry (1970) and King and Kitchener (1994) found that these entering college students are dualistic (right vs. wrong only) thinkers who are unable to evaluate an argument based on the strength of the evidence. A number of studies of empirical research are cited that outline the deleterious effects of a lack of reasoning ability on achievement in introductory college biology courses (e.g. Lawson, 1992; Lawson, 1980).

In the traditional lecture-based classroom, Piaget (1970) argues, the teacher is the source of all morality and truth, and "from the intellectual point of view...[the student] accepts all affirmations issuing from the teacher as unquestionable..." so that the words are dispensed without the need for student reflection (p.179). Thus, a static, unchanging, and factually based way of knowing is perpetuated. Rogers (1967) denounces this method, declaring that it is the recognition by the learner that knowledge is continually changing that should be the goal of education. Piaget (1970) argues that this traditional method of instruction consolidates the egocentrism

found in childhood by simply replacing "a belief in self with a belief based on authority, instead of leading the way toward the reflection and the critical discussion that help to constitute reason and that can only be developed by cooperation and genuine intellectual exchange" (p. 179) to improve reasoning. Thus, a major purpose for this review is to explore the empirical research on non-traditional instructional methods and their affects on reasoning development in college students in introductory biology to determine the truth of the above claims.

It is important to identify what elements constitute reasoning skill. Most of the recent research on the teaching and classification of reasoning in biology courses incorporate the Piagetian theory of reasoning development (Allen, 1981). This model identifies lower level reasoning (called concrete reasoning) as being limited to merely the describing and ordering of observable phenomena (Allen, 1981; Piaget, 1970). The higher level reasoner (called formal reasoner), in contrast, is characterized by the ability to generate and test alternative explanations when confronted with ambiguity (Allen, 1981). Reasoning is begun by imagining possibilities so that conclusions are drawn using the hypothetico-deductive method (defined as reasoning from a known general principle to the unknown) (Allen, 1981). These reasoners demonstrate the use of formal reasoning patterns, which, for the purpose of this review are defined as the ability to control variables, and use probabilistic, proportional, correlational and combinatorial reasoning (Lawson and Snitgen, 1982). This stage also involves the systematic consideration of alternate hypotheses and evidence to draw conclusions, which for the purpose of this study will be defined as informal reasoning. With such reasoning, individuals possess meta-knowledge and can thus evaluate inconsistencies in their own arguments. Such a reasoner, according to Allen (1981), is an independent thinker and can, for example, develop a workable plan of analysis in a science laboratory given the overall goals and resources of a lengthy procedure.

This development of reasoning is related to the individual's ability to understand the nature and defense of one's own knowledge claims (Allen, 1981). According to Hofer and Pintrich (1997), the area of philosophy that is concerned with the nature and justification of knowing is termed epistemology, and a body of research exists based on how epistemological assumptions influence the development of reasoning. This includes, for the importance of this review, the manner in which individuals come to know and how this influences and is affected by the cognitive processes of thinking and reasoning (Hofer and Pintrich, 1997).

An epistemologically-based, developmental scheme exploring how college students make meaning of their educational experiences was developed by Perry (1970). He was the first to suggest that reasoning in undergraduates was related to epistemologic maturation. During the initial periods of development, according to Perry's model, students view knowledge and produce arguments in a dualistic manner, with right and wrong as absolute and ultimately determined by authority (Hofer and Pintrich, 1997). Thus, in the biology classroom, such individuals expect instructors to distribute information without ambiguities (Allen, 1981).

The progression of student reasoning abilities should continue through a series of stages characterized by more pluralistic views, where knowledge and values are perceived as relative (Perry, 1970). Perry defines these stages by level of student possession of higher level reasoning strategies that employ skills to interpret evidence to form conclusions. Thus, the student at this level accepts the existence of possibly conflicting, multiple viewpoints and evaluates the evidence, internal consistency, and coherence of each perspective to formulate a conclusion (called relativism) (Hofer and Pintrich, 1997).

According to this model of intellectual development, higher levels of reasoning involve student perception of knowledge and values as contextual and relativistic. Thus, in the science classroom, this informal reasoning translates into skills in interpreting data and observations, evaluating equally valid arguments, and drawing conclusions from experiments. Dualistic, lower level reasoners are uncomfortable with the uncertainties involved in interpretation and evaluation of scientific evidence and so decision-making in science becomes an incomprehensible process when the "right answer" is not provided (Allen, 1981). Thus, Perry (1970) contends, instruction should enhance student reasoning to relate scientific evidence with conclusions rather than simply focusing on memorization of those conclusions.

Although Perry's scheme, influenced by Piaget, addresses general thought development, King and Kitchener (1994) point out that some aspects of scientific reasoning are not adequately described by either theorist. Thus, as an extension of Perry's (1970) work, King and Kitchener (1994) propose a model that represents the most recent and extensive work on the development of informal reasoning in college students (Hofer and Pintrich, 1997). The scheme is particularly valuable due to its elaboration of Perry's upper levels of reasoning and will be referred to in classifying the levels of scientific reasoning examined by the authors in the studies reviewed.



King and Kitchener (1994) conducted a fifteen year interview-based study involving the analysis of reasoning in subject responses to ill-structured questions (questions with the possibility of more than one acceptable answer). Through this, King and Kitchener (1994) proposed a seven stage scheme for reasoning development called the

Reflective Judgement model, which focuses on the individual's understanding of the nature of knowledge and the process of reflecting on and justifying that knowledge (Hofer and Pintrich, 1997). Table 1 compares the models of reasoning development described by Piaget (1970), Perry (1970), and King and Kitchener (1994).

TABLE 1. Models of adolescent reasoning in late adolescence and early childhood.

| reasoning level | Perry        | Piaget                       | King and Kitchener |
|-----------------|--------------|------------------------------|--------------------|
| low             | concrete     | dualism                      | pre-reflective     |
| medium          | transitional | multiplicity                 | quasi-reflective   |
| high            | formal       | commitment within relativism | reflective         |

There are three levels within the seven stage model: pre-reflective (stages 1,2, and 3), quasi-reflective (stages 4 and 5), and reflective (stages 6 and 7). In the pre-reflective stages, what is observed or what authority dictates determines truth. As with Perry's dualism, the individual is unable to reflect upon uncertainties in answering an ill-structured question (King and Kitchener, 1994).

During the quasi-reflective levels, there is a growing recognition that the individual cannot know with certainty and that each person is entitled to an opinion. It is during these stages that the belief that knowledge is relative emerges, yet the ability to actively construct arguments and evaluate scientific evidence is absent (King and Kitchener, 1994).

At the reflective stages only, does the role of the knower move from a spectator and receiver of knowledge to an active constructor of meaning. Knowledge is recognized as uncertain and relative so that conclusions made from ill-structured questions include the critical evaluation of different positions. The highest level of reasoning occurs (in science) at this stage when the use of critical inquiry and hypothetical justifications allow for the evaluation and reevaluation of evidence and conclusions for ill-structured questions (Hofer and Pintrich, 1997).

The higher level, reflecting judgement characterizing stages 6 and 7, has been observed in only a tiny fraction of undergraduates interviewed by King and Kitchener (1994), and has appeared consistently only among advanced graduate students (Hofer and Pintrich, 1997). In addition, although it appears that education is positively correlated with reasoning stages, little development actually takes place during the college years, with less than half a stage during the entire four-year undergraduate experience (King and Kitchener, 1994). Thus, studies are needed to investigate what kinds of teaching methods and instructional environments

foster the development of reasoning in college students.

This review will attempt to answer the questions: What instructional methods/environments foster reasoning development? What are the particular instructional variables within the methods that influence reasoning? Does course content achievement suffer when such methods are employed? What other learning variables are influenced by these instructional methods/environments? and, What are the relationships between those variables?

Although each study reviewed operationally defines high level scientific "reasoning" differently, for the purposes of this review, reasoning includes critical thinking and the ability to problem solve and use process skills. Reasoning is also separated into two constructs based on the frameworks presented by Piaget (1970), Perry (1970), and King and Kitchener (1994): formal reasoning which includes control of variables, correlational, probabilistic, proportional, and combinatorial reasoning and informal reasoning, which include the ability to explore nature, raise questions, generate multiple working hypotheses, and evaluate evidence to develop a logical argument (National Science Foundation, 1989).

## Methods

The purpose of this paper is to review the research on instructional approaches that has been concerned with improving reasoning skills in introductory college biology courses. The review of the literature has shown that a very limited amount of empirical research has been done on college biology instruction and even less on the development of reasoning at this level.

The process was begun with a preliminary search of the primary databases: ERIC (Educational Resources Information Center), PsychLit

(Psychological Abstracts), and Dissertation Abstracts. Upon searching these databases for "reasoning" and "college biology", it became alarmingly clear that very few empirical studies were identified (one was found as appropriate). I broadened the search to include synonyms for reasoning such as "critical thinking skills", "logic", "persuasive discourse", and "argumentation", for college, "undergraduate" and for biology, "science". I found few relevant studies, but then searched all of the work done on undergraduate biology in all of the databases.

Through this, I found a few empirical studies, but discovered a review of research by Glick (1994) on "Effective methods for teaching non-majors introductory college biology" which reviewed four studies. I decided to broaden the search by allowing the definition of reasoning to include both formal and informal reasoning. I also included studies using "process skills" as an outcome variable studied, when described by the authors in a way that resembled a form of reasoning as defined by this study.

When searching the bibliographies, most of the citations were opinion-based and non-empirical, speculative discussions of reasoning in science. The studies, which were empirical, often explored the lack of reasoning in first-year college biology students but did not focus on instructional methods to develop that reasoning. I searched the bibliographies of all the studies and found that those, which were even tangentially related were few in number, including a review by Lawson (1992) on non-majors introductory biology. This review provided more related studies and upon a search of the bibliography, found a small number of related studies. The bibliographies acted as a springboard to finding other related work, which finally yielded a total of nine relevant empirical studies.

Personal discussion with Ebert-May, author of "Innovation in large lectures-teaching for active learning," (Ebert-May et al., 1997) reinforced the perception that few studies on reasoning in biology courses existed. As a last attempt, I searched recent science education type journals for studies not yet in the databases, including *Bioscience*, *The Journal of College Science Teaching*, *The Journal of Research in Science Teaching*, *Science and Education*, and *The Journal of Biological Education*. That the search had been completed was indicated when papers alluded to the same sources already identified.

Papers were not selected based on the quality of the study (except publication as a prerequisite) because so few were found. A more complete narrative review should include a comprehensive analysis of study quality in the selection process. However, the studies were selected based on the following criteria:

1. The research subjects were college students enrolled in an introductory undergraduate biology course. Studies including high school students (of which there were many) were eliminated since these subjects are not representative of those who attend college (due to differences in cognitive and intellectual development).
2. The research was empirical in that it addressed a question related to effective instructional methods and evidence to support the conclusions.
3. The written report needed to be available in published journals, Dissertation Abstracts, or through the ERIC and Psychlit databases. Unpublished dissertations and works-in-progress were not included since they are not readily available to instructors hoping to improve their teaching. Also, unpublished work could indicate a lack of quality in the information contained.
4. An outcome variable in selected studies was reasoning. For the purposes of this review, reasoning was classified according to the definition presented in the introductory section and is the major variable examined by this review (shown in Table 1).
5. Studies were each analyzed on the following criteria: claims of the outcomes, validity and reliability of the methodology, types of dependent variables studied, and sample size.

## Results

The following statements can be made with strong support from the empirical research of the studies reviewed, although they are not submitted without contestation. Outcomes for the studies are displayed by Table 1. Several weaknesses were found in some supporting studies and there is not unanimous agreement on all points in this review.

1. Inquiry-based, non-traditional collaborative instruction is more effective than traditional, lecture instruction in developing higher order reasoning skills in introductory college biology courses.
2. The gains in reasoning through inquiry-based, non-traditional collaborative instruction are not achieved at the loss of content acquisition. (Points 1 and 2 will be discussed together since an argument against reasoning development is the suffering of content).
3. Inquiry-based, non-traditional collaborative instruction emphasizing writing to develop reasoning has higher success at developing student reasoning than those methods not emphasizing writing.
4. The direct instruction of formal and informal reasoning leads to gains in those reasoning skill areas.
5. Gender and Major do not appear to interact with instruction to influence reasoning.
6. Enough instructional time is needed to improve reasoning.

7. Developing reasoning skills improves the general intelligence of students.
8. Inquiry-based instruction that improves reasoning also enhances positive scientific attitudes.
9. The BSCS (Biological Sciences Curriculum Study) method of inquiry-based instruction produces no significant gains in reasoning ability.
10. The laboratory is an important part of an introductory biology course since it improves reasoning.

(Figure 1 displays the purported relationships among the variables by the review (dotted lines represent possible relationships to be determined by future studies).

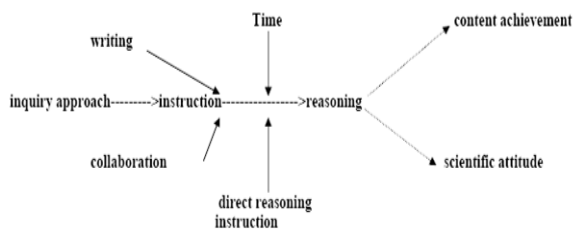


FIG 1. Relationship of variables.

## Discussion

The attempt to change instructional methods in undergraduate biology to include the development of reasoning is not a recent phenomenon. The earliest study found, by Barnard (1942), emphasized the need for students to learn more than just factual content. The reform efforts stimulated by "A Nation at Risk" to improve science reasoning have produced most of the studies on undergraduate biology found in this review (Ebert-May, et al., 1997). No articles were found within the past four years, indicating a need for continued research in this area. All of these include a quantitative, experimental design which employs, as independent variables, instructional methods for increasing student involvement in constructing knowledge to improve reasoning.

All of the studies except those using the unmodified BSCS (Biological Sciences Curriculum Study) method demonstrated an improvement in student posttest reasoning scores in the experimental treatment groups. These seven studies will be presented together first as support for non-traditional instruction. Some used a control to compare their strategies with a traditional, lecture-based method (Barnard, 1942; Tyser and Cerbin, 1991; Haukoos and Penick, 1983; and Ebert-May, et al., 1997).

Barnard (1942) first showed this using a problem solving method of instruction which emphasized student involvement in the collection of

data, forming of generalizations, and evaluation of explanations in science over the lecture method in which students were described as passive acceptors of knowledge in its final form. A pre/posttest quasi-experimental control group design was used with three batteries of tests administered as pretests, mid-semester, and posttests. The problem solving group had higher mid-semester and posttest scores on problem solving through reasoning than the control group. The author assumes equivalence of the groups based on pre-testing and psychological testing and describes the differences in instructional methods in great detail.

However, the results are not convincing due to a number of weaknesses in the study. A modern statistical analysis of Covariance (ANCOVA) should have been done to determine statistical significance of the differences in the pretest/posttest reasoning development of the subjects in the two treatments. A threat to external validity also exists since it is doubtful that the subjects of over fifty years ago resemble modern undergraduates. Additionally, little information is given about the subjects other than heterogeneity in class years, thus again restricting the ability to generalize.

The tests for problem solving through reasoning also had unacceptably low test-retest reliabilities, with reported pretest, mid-semester, and posttests at .67, .53, and .51, respectively. The addition of a mid-semester test also increased the chances of a test-retest effect on achievement as well.

Barnard's (1942) study was also the only study in this review which showed a decrease in content knowledge achievement among the problem solving groups. However, the tests on content also had reportedly low reliabilities (averaged at .43) and the addition of a midsemester test increased the chances for a test-retest effect. Thus, supported by the poor statistical analysis of the data, the threats to external validity, and the low reliability of the test batteries, it can be concluded that little can be learned from this study about improving reasoning in undergraduate biology courses today.

A theme emerging from an analysis of the studies in this review is the use of writing during instruction to develop student reasoning. Tyser and Cerbin (1991), Lawson and Snitgen (1982), Moll and Allen (1982) and Ebert-May, et al. (1997) showed that integrating writing as an expression of reasoning during instruction has a positive impact on student reasoning development.

The use of a "Science News Exercises" instructional method in introductory college biology with a pre/posttest quasi-experimental control group design by Tyser and Cerbin (1991) showed improvement in student reasoning skills. This method represents students with a model for evaluating evidence in popular science articles to

develop a logically persuasive argument. Students guidelines for the direct teaching of reasoning through a three step line-of-reasoning model. This is the only study in the review to directly teach and apply a method for informal reasoning. The model gives simple guidelines for the identification and evaluation of evidence and for then persuasively communicating a developed article.

The "Science News Exercises" group performed statistically significantly better than the traditional lecture group on the objective test for evaluating evidence ( $t=3.46$ ,  $df=1$ ,  $p<.01$ ) and on the lines of reasoning written test ( $X^2=11.93$ ,  $df=1$ ,  $p<.01$ ).

Content achievement was not assessed, but the authors contend that only 200 minutes of lecture time (10% of the lecture course) were used for Science News Exercises. Thus, the concern for a loss of content should be ameliorated according to the authors.

Although Tyser and Cerbin (1991) used statistical analyses (a paired t-test and Chi square) to compare the means, several weaknesses are evident which cast a doubt on the results. First, there is little subject information offered except that 80% are non-majors. This limits generalizability, especially to courses consisting of a high proportion of biology majors. Second, the teachers for control and experimental treatments differed, thus introducing the possibility of confounding variables. Third, the reliability and validity of both the objective and written tests are not offered by the authors. Despite these flaws, the results do show evidence of positive effects of non-traditional instruction emphasizing writing on reasoning development in college students.

A study by Lawson and Snitgen (1982) on the direct teaching of formal reasoning in an inquiry-based course for pre-service elementary teachers also showed positive effects on reasoning development. The course, entitled "Biological Science for the Elementary Teacher" used reasoning modules to facilitate collaboration among students to apply formal reasoning strategies to experimentation. This is the only study in the review to address the direct teaching of formal reasoning. The authors implement Piaget's (1970) suggestion to ground the development of formal reasoning in concrete experiences and social interactions. Their method introduces what is familiar to the student and through collaboration, allows for the student to recognize his/her own faulty reasoning. This creates a mental disequilibrium which is then corrected, according to Piaget (1970).

This Piagetian model was pre- and post-tested using a quasi-experimental design lacking a control group. Using the dependent t-test, the authors report statistically significant pre/posttest increases in formal reasoning for the subjects after taking the

assess 6-7 biweekly scientific articles in terms of course ( $t=9.96$ ,  $df=31$ ,  $p<.001$ ). The Lawson Test for Formal Reasoning was used and verified for face, factorial and construct validity and for reliability according to the authors.

However, the posttest only group scored significantly lower, indicating a possible test-retest effect. In addition, the test for the transfer of reasoning to unfamiliar contexts showed no significant pre/posttest improvement among subjects. Thus, the application of reasoning using this method is not demonstrated. In fact, qualitative analysis of the results indicated that students misapplied reasoning strategies even though they could formally reason. A future study should investigate possible negative effects of this method such as confusing established formal reasoning patterns.

Other qualitative data obtained by this study were particularly illuminating. Some formal reasoners found the course "childish and boring" and others dropped the course citing their desire not to conform to the thinking methods called for by the Reasoning Modules. Although the authors cite positive comments for the course on reasoning development, no qualitative analyses were done to draw definitive conclusions in this respect.

A lack of generalizability to a majors course is also seen since all subjects were non-majors. The absence of a comparative group is a flaw in the research design, as it does not allow for an accounting for a maturation increase over the semester.

Thus, although ostensibly demonstrating positive effects of this writing-based inquiry course, it is not prudent to draw definitive conclusions until the flaws in the study are corrected and it is repeated.

An inquiry method of instruction using video presentations to guide discussions was used by Moll and Allen (1982) to develop reasoning skills in response to ill-structured questions. This course emphasized student writing to create arguments from an analysis of evidence to develop informal reasoning. The method used was described in detail by the authors as stressing student exploration of ideas, interpretations, and various lines of informal reasoning to improve critical thinking skills. These skills are identified as informal reasoning as defined earlier.

A pre/posttest no control group quasi-experimental design was used to show a significantly higher improvement of reasoning skill and content knowledge ( $p<.001$ ) by the experimental group. The gains were not shown to be related to gender or major. The authors also cite qualitative evidence that students appear to reason better after taking the course.

The weaknesses of the study again cast doubt on definitive conclusions. The lack of a

control does not allow for isolation of the effects of reliability is mentioned for the tests, the statistical methods used are not given, the number and description of subjects are omitted, and the types of qualitative methods used are not discussed (e.g. questionnaire and survey).

If this information were given, the study would be particularly interesting because it is the only one to explore the interaction of gender and major with instruction to influence reasoning. In addition, since one section in the study was given more content and scored significantly higher on the content posttest but not on the reasoning posttest than the other groups implies that content alone was not sufficient for improving reasoning.

An inquiry-based study by Lawson (2001) involved 514 non-major introductory college biology students asked to practice formal reasoning strategies using a series of progressively unfamiliar biological inquiry problems. Students were confronted with a scientific problem and asked to use formal reasoning skills to generate hypotheses, set up experiments, predict results, and answer if/then questions about the activity. The lectures infused an if/then analogical reasoning approach in conjunction with the activities. An exemplary activity required students to use formal reasoning strategies to design an experiment to test the variables influencing mealworm behavior in a box. Writing is infused in this design by requiring student written to responses to the activities.

A comparison of the student pre-test and post-test scores on a test of formal reasoning skills indicated that student reasoning improved significantly as a result of the course (dependent  $T = 29.6$ ,  $df = 513$ ,  $p < .001$ ). Test reliability and validity had been established by other studies (e.g. Lawson, 1992). However, Lawson's (2001) design lacked a control group and does not address the effects of the course on content acquisition. The study does not describe the amount of time dedicated to formal reasoning development and how it compares with a traditional non-majors introductory college biology course. A test-retest effect is also not addressed as well as affect effects of the course. Nonetheless, this study offers significant evidence that practicing formal reasoning patterns improves the ability to apply formal reasoning patterns. Possible future studies using this design would improve the study's significance.

The final inquiry-based approach emphasizing writing to develop reasoning skills was conducted by Ebert-May et al. (1997). Care was taken to control variables in instruction in this pre/posttest quasi-experimental control group design. The experimental lectures in non-majors introductory college biology were based on a modified learning cycle (BSCS) model of instruction in which there a high level of student involvement and a risk free

maturation of reasoning over the semester, no atmosphere to facilitate student collaboration in constructing answers to biological questions. The writing assessment included one page papers and group work to answer ill-structured questions. The comparison lectures were traditional and factually based.

Results from an Analysis of Covariance indicated that students in the experimental groups scored significantly higher on process/reasoning questions (identified as informal reasoning for the purposes of this study) on an NABT exam ( $N=283$ ,  $df=3,274$ ,  $p < .05$ ).

Also, in support of the view that such non-traditional inquiry based teaching does not negatively affect content achievement, no significant differences were found between the groups in terms of content questions on the NABT exam. Ebert-May et al. (1997) contend that the amount of material covered in the activity based classroom in the end is equal to material covered in the traditional classroom. Considering the importance of content coverage for student progression to established professional programs (i.e. medicine, dentistry) future studies should replicate such a design, paying particular attention to those standards set forth by pre-professional advisory committees, professional school entrance exams, and professional school admissions.

Qualitative data obtained through random selection of students for interviews and written responses indicated that students were changing the way they viewed the acquisition of knowledge. "Students began questioning the nature of the scientific evidence before them" (p. 606) and "were more likely to apply their understanding of biological concepts to personal, public, and ethical issues than if they had experienced the traditional lecture format" (p.606), showing the development of informal reasoning as defined in this review. A well constructed qualitative analysis such as this can reveal information that quantitative designs cannot. The use of both appropriate questionnaires and interviews in a risk free environment characterize a good qualitative study.

Thus, the research design by Ebert-May et al. (1997) represents the strongest evidence presented so far in support of inquiry based, collaborative instruction as a means of improving reasoning and not weakening content acquisition. It was a mixed method approach, which employed both quantitative and qualitative techniques, which together allow for a broad exploration of the variables. Unlike the previous studies described, this research design includes comparison groups, control of instructional variables (e.g. same lecture notes and instructor), statistical analyses mentioned, a heterogeneous, large

sample size (559 subjects), and an appropriate

There are, however, some unanswered questions remaining with regard to testing (e.g. the reliability and validity of the NABT exam are not given). This is not problematic, if it is assumed that such a national exam has sufficient reliability and validity. However, it is a high school exam and so prior achievement not related to this college course, which is not addressed, could have influenced the results. Also, although the authors mention a Process Skills Instrument to develop reasoning, results on reasoning are only obtained from NABT process questions. In a future study, an exam more appropriately measuring college biology achievement should be implemented. A demonstration of reasoning development other than vague "process skills" should also be used in such a future study as a measure.

The increase in attendance with the experimental groups, possibly due to the daily quizzes, could also have had an impact on increasing reasoning and content performance. Additionally, an interesting future study based on Ausubel's could show the effects of the use of concept mapping to organize the material to make more meaningful connections to improve reasoning. Future studies could isolate the variables within such methods to determine what particularly impacts student reasoning.

The final study supporting the view that inquiry based learning improves student reasoning used a pre/posttest control group quasi-experimental design by Haukoos and Penick (1983). It is the only study in the review that treats the community college level. The effects of a Discovery Classroom Climate (DCC) were compared with a Non-Discovery Classroom Climate (NDCC) in terms of student achievement in biology and the learning of reasoning skills. There were seventy-eight subjects divided into two sections of 10 week long NDCC courses, one section of a 10 week DCC, and one section of a 5-week DCC course.

The classroom climates are described in detail by the authors. In general, the differences were based on the directness of teaching. In the DCC, teaching is indirect, with content dialogued and discovered through ill-structured questioning. Thus, knowledge is constructed by the students as in the other studies shown so far. In contrast, the NDCC was the traditional lecture similar to the comparison methods seen in Bernard (1942) and Ebert-May et al. (1997). An ANCOVA showed that students in the 10 week DCC group scored significantly higher on the reasoning skills exam ( $p < .01$ ) as compared with the other groups. There were no significant differences found between groups in terms of the learning of biological content. Face validity and reliability were

qualitative methodology.

given for the tests measuring reasoning (Science Process Inventory) and achievement (Biology Achievement Test).

Haukoos and Penick (1983) are the only researchers in this review to explore the interaction of time and instruction on reasoning and achievement. Since the 5 week DCC does not show significantly improved reasoning as compared with the 10 week DCC, this implies that enough time must be available to develop reasoning.

Writing is not mentioned by Haukoos and Penick (1983) as a part of instruction and yet positive results on reasoning improvement occurred. Perhaps other variables in their instruction exist to explain the positive effects. This could be explored by future studies. The BSCS method used by Leonard (1983) and Hall and McCurdy (1990) are the only other studies that do not incorporate writing in their instruction and they demonstrate no positive effects on student reasoning. In contrast, Lawson and Snitgen (1982), Tyser and Cerbin (1991), Moll and Allen (1982) and Ebert-May et al. (1997) incorporate writing in their instruction and show the development of reasoning through their methods.

For each of the aforementioned studies in this review, it would be interesting to explore the relative contributions of different variables within the instruction that led to the successful development of reasoning by the authors' methods. For example, although all of the studies employed both collaborative and inquiry methodologies, what were the relative contributions of each these variables to elicit change. If a non-collaborative approach were used, how would the results on reasoning develop change, for example? Also, how would the introduction of a more intimidating, yet non-traditional classroom environment that harms positive attitudes change the results?

This move to isolate instructional variables was attempted, for example, by Lawson and Snitgen (1982) and Tyser and Cerbin (1991), who discovered the positive effects of varying the instruction to include the teaching of how to reason. The other studies assume that improved reasoning patterns emerge as a result of student participation in an inquiry-based instruction. One wonders whether Roger's (1967) fear of routine methodologies can be applied to such direct teaching of reasoning. The student could merely learn the model for reasoning, but not actually be at a more sophisticated level. Evidence for this was seen as described earlier by Lawson and Snitgen (1982), who do not demonstrate the transfer of reasoning improvement to non-familiar topics and an actual decline in reasoning quality.

This raises an important point--is the teaching of reasoning even possible? Students could

be intrinsically locked into a Piagetian developmental predisposed abilities before natural development allows for it may not be possible. It is the contention of this review that instruction can affect reasoning ability, but the evidence given by the six studies favoring this view do not address the mechanism of change in reasoning--it remains a black box. Thus, although empirical results show increases in reasoning levels through the instruction suggested, no specific instructional variables are explained as to why they are causing change.

The improvement of scientific attitudes was explored by Barnard (1942) and Ebert-May et al. (1997). Although the problems in Barnard's (1942) study weaken the conclusions, the inquiry group means showed better scientific attitudes than the comparison group means. The more convincing results emerge from Ebert-May's et al. (1997) study, citing statistically significant increases in self-efficacy for the experimental lecture groups as compared with tradition groups ( $N=283, df=3,274, p<.05$ ). Self-efficacy is defined by the authors as confidence in doing science, analyzing data, and explaining biology to other students. Both studies show increases in reasoning and increases in attitudes, showing possibly a relationship between the two variables. According to Rogers (1967), the effects of attitude improvement on learning is positive. However, from the studies in this review, this cannot be established.

Based on the research describing the successful improvement of reasoning, the fear that non-traditional methods take too much time and detract from content knowledge acquisition should be reduced. Ebert-May et al. (1997) and Haukoos and Penick (1983) cite no loss in content achievement with their experimental groups. Also, Tyser and Cerbin (1991), although not assessing content achievement, contend that lecture time is not significantly impacted since only 200 minutes are used by the "Science News Exercises". Barnard's (1942) study is the only one showing a decline in content achievement with increased reasoning. However, the many extreme weaknesses described earlier may discount these results.

The one study offering information on the improvement of general intelligence through instruction to develop reasoning was by Lawson and Snitgen (1982). Admittedly, intelligence is a vaguely defined construct. It was measured by the authors using the Raven Standard Progressive Matrices test (reliability and validity not mentioned). The pre/posttest differences show statistically significant increases in general intelligence among the experimental subjects ( $t=2.42, df=28, p<.05$ ). Such results indicate further support for the incorporation of reasoning activities in instruction.

stage of reasoning. The ability to change their

The two studies showing no significant subject improvement of reasoning were by Leonard (1983) and Hall and McCurdy (1990). Both used an inquiry oriented Biological Sciences Curriculum Study (BSCS) developed by Leonard (1983) that engaged the student in collaborative activities in the laboratory such as planning and conducting experiments and drawing and evaluating conclusions. The comparison method used by both groups was a traditional laboratory program that was directive and less inquiry oriented. Both used a quasi-experimental control group design and Leonard (1983) found that on a combined content/reasoning posttest, the experimental groups performed significantly better ( $t=3.81, p<.005$ ). Also, in both the experimental and control groups, formal reasoning increased by 15% over the semester, giving support for the importance of laboratories in a time when many are being cut due to economic reasons.

Although Leonard (1983) takes great care to establish equivalence of the treatment groups and states the internal reliability and validity of the tests, the results do not isolate a dependent variable on reasoning--only that content and reasoning are improved together.

Thus, the results by Hall and McCurdy (1990) determine more clearly what the effects are. An ANCOVA on the data show that the BSCS laboratory group scored significantly higher on content achievement,  $F(1,114)=4.07, p<.05$ , but that no significant differences in reasoning ability were found.

The result is surprising insofar as the inquiry-based methods of the other reviewed studies showed improvement in reasoning over the comparison group. In addition, Hall and McCurdy's (1990) research design was strong, with validity and reliability of the tests reported as high, a heterogeneous sample size, equivalence of groups, and appropriate statistical analyses used. Upon closer examination, however, there is a major difference between the other studies and this one--although the BSCS instructional method stresses the evaluation of evidence, raising questions, and generating hypotheses for scientific experimentation (informal reasoning), the pre- and post-test on reasoning assess only formal reasoning. Thus, since the instruction appears to not have matched the assessment, Hall and McCurdy's (1990) results could be misleading.

Thus it can be seen that the studies discussed in this review would allow for stronger conclusions to be drawn if repeated, with their respective weaknesses ameliorated. Also, the many questions that arise when considering the studies more critically, show the gaps in explaining what and how different instructional variables play a role in

changing reasoning. However, it is clear that the successful studies affecting reasoning improvement support use of non-traditional, inquiry-based, collaborative methodologies for the development of student reasoning.

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## ***Book Review***

*A Problems Approach to Introductory Biology*. B. White and M. Mischke. ASM Press, Washington, D.C., U.S.A., 2006, 265 pp., ISBN 1555813720, \$34.95 (U.S.A.).

*A Problems Approach to Introductory Biology* by Brian White and Michelle Mischke is presented as a companion workbook to a college level introductory biology course or an advanced high school course. It is not a stand alone workbook, but requires that some material is introduced by another textbook. Its primary focus is on problem based learning and it provides practice problems which require either pen and paper or the use of computer simulations that are provided on a companion disk. Solutions to the problems are included as a pdf file on the CD-Rom. The computer software can be used on a Mac OSA X system or Windows 98 or higher and requires Java to run but is very easy to use. There are 3 major topic areas covered in this workbook, 1) Genetics, 2) Biochemistry and 3) Molecular Biology.

The Genetics section provides students with a variety of genetics problems, including simple monohybrid crosses, crosses with multiple alleles, sex-linkage, dihybrid crosses and linkage. The problems are presented in a variety of ways, including traditional crosses, human pedigrees, and computer simulations. The computer simulations allow students to perform genetic crosses using a hypothetical insect to generate appropriate offspring and make conclusions based on these crosses. While most of the problems are highly appropriate for an introductory level biology class, there are some problems related to linkage that may be problematic for the beginning biology major.

The biochemistry section uses two computer programs to introduce students into molecular structure. The first program is called Molecular Calculator which can be used to practice drawing the structure of molecules given a structural formula. Once students master the program, they can add functional groups and determine the changes in hydrophobicity introduced by the functional group. This is very useful to allow students to think about how molecules interact with each other in enzymatic reactions. A second program called MolVis allows students to observe a 2-dimensional molecule in 3-dimensions and to manipulate that molecule by rotating it and by zooming in and out on a particular area of the molecule. Atoms in the molecules can be easily identified as well. This computer software is useful to familiarize students with the structure of important biological molecules. Students are asked to draw the molecules, such as sugars and short peptide chains from these 3-dimensional

representations. There are a number of ambiguities that might frustrate some beginning biology students in this effort. The software does not distinguish between single, double or triple bonds and does not identify H bonds associated with the molecules, so beginning students might become frustrated when trying to draw a molecule with a carboxyl group. If students are not paying attention as they rotate the molecules, they can easily become disoriented with the molecule. The program does allow students to view molecules such as lysozyme as three-dimensional images and secondary structures such as beta-pleated sheets and alpha-helices are readily identified in the molecule. There are several nice application problems relating the interaction of molecules in enzymatic reactions. Based on a student's knowledge of covalent, hydrogen and ionic bonds as well as van der Waals interactions, students may design molecules for stronger or weaker interactions and discuss how changes in amino acid sequences could alter enzymatic activity. For some of these problems, it would have been nice to include a table of amino acids. While it is nice to see activities that allow students to view molecules in 3-dimensions and consider the molecular interactions between molecules, some of the problems would be more appropriate in an upper level Cell or Molecular Biology course.

The final section on Molecular Biology allows students to explore the classic experiments by Griffiths, Avery and Hershey and Chase. The problems in this section require students think through the experiments possible models and potential results based on their knowledge of the experiments. There is a section related to DNA replication, transcription and translation and assumes knowledge of promoters, introns and exons and has students predict protein structure from DNA molecule. The Gene Explorer software is a nice demonstration of transcription, intron excision and translation. Students may select a base in the DNA and see the corresponding base in the pre-mRNA transcript and if it is present in the mature mRNA and the coded amino acid in the protein sequence. Students can also manipulate the DNA molecule by inserting, deleting or changing bases into the DNA molecule. The pre-mRNA, mature mRNA and proteins are automatically updated to show the result of these mutations.

This workbook provides a nice set of problem-based learning activities for students to measure their learning and help target their studies. The computer-aided activities showing protein structures and DNA interactions provides a nice visual for students to

begin visualizing molecules. However, whether this book is appropriate for an introductory level course depends upon the depth of your introductory level course. The sections related to Genetics would be a nice supplement to an upper level Genetics course and the Biochemistry section would be an appropriate addition to a Cell Biology course.

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## Editorial

### One Year Later

It has been one year since I became involved in editing ACUBE's journal *Bioscene*. Tim Mulkey and Ethel Stanley did an impressive job at keeping it a professional and informative publication. Since taking over from them, I have gone from a very frustrated novice to a contented veteran. The task of coordinating authors, editors, officers, and printers to produce our journal was daunting. I had only published in it once. Beyond reviewing a few papers and attending editorial board meetings, I had no experience in putting an issue together of this or any other journal.

So what's changed? My perceptions of the journal and our membership have changed. We have an amazing organization. I never realized that until I began work on *Bioscene*. I have received tremendous support from the membership, including excellent suggestions on improving our publication. I am impressed by the articles that are submitted and the thought that people are putting into improving undergraduate education. I intend to implement many of these as my tenure continues.

One of the comments I hear repeatedly is to have more articles about "things that work" in the class and the lab. I am constantly on the lookout for these. However, this is subject to the works submitted for the review pipeline. If you have tried something, no matter how simple, that you feel enhanced your students' learning experiences, write it up and send it to us. While we do not accept everything that comes our way, we will continue to try to be author-friendly, especially if it can help our members improve their teaching.

I had updated the submission guidelines in 2005, but have since re-written these, giving authors and potential reviewers more structure in terms of

what to submit. The new guidelines appear in this issue. Appropriate submissions will still include a variety of article types with the emphasis on "things that work." But reviews of textbooks, websites, and technology are also welcome (very welcome!). The guidelines deal with how to use citations and construct the references section at the conclusion of articles. There will be some consistency to these now, which will allow an article to have a "*Bioscene* look."

Despite our global reach in the internet age, we are still a relatively small group. But I know our members have opinions about what they are experiencing in the classroom. So, I would like to have a "Letters to the Editor" section. On the submissions guidelines, I recommend that letters deal with pedagogical issues facing college and university biology educators. In order to facilitate this, I'll write an editorial for each issue. Perhaps this can be a springboard to further dialogue about issues that educators are facing. If you write a lengthy letter, perhaps we can work it into an issue as a guest editorial. Regardless of what you write about, please write.

Finally, *Bioscene* issues will continue to provide information about our annual meeting. This year's fiftieth annual meeting at Millikin University in Decatur, Illinois was a tremendous success. As always, I took something away from the meeting. I know others did, too. I hope presenters at this year's meeting will submit an article to *Bioscene*. Next year's meeting will be at Loras College in Dubuque, Iowa. I have fond memories of the last time ACUBE met at Loras College, so I'm already excited about next fall. I urge everyone to attend and keep reading *Bioscene*!

Stephen S. Daggett  
*Bioscene* editor

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