Tested Studies for Laboratory Teaching
Proceedings of the Association for Biology Laboratory Education
Vol. 33, 251–258, 2012

Using Scientific Process (as Defined by the Inquiry Wheel) To Guide Multi-session Inquiry-based Laboratory Experiences in the Biology Major

Stephanie Fuhr, Kristin Douglas, Jason Koontz, Lori Scott and Dara Wegman-Geedey

Augustana College, Department of Biology, 639 38th St, Rock Island IL 61201 USA
(**stephaniefuhr@augustana.edu; kristindouglas@augustana.edu; jasonkoontz@augustana.edu; loriscott@augustana.edu; darawegman-geedey@augustana.edu**)

As scientists and science instructors, we all appreciate the value of understanding scientific process and the challenges and triumphs inherent in this widely accepted approach to knowledge acquisition and problem-solving. At our workshop, we discussed how our biology department at Augustana College has incorporated knowledge and experience of scientific process developmentally throughout our curriculum. Our department has adopted the **Inquiry Wheel** as a model for scientific process (Harwood, Reiff, and Phillipson, 2002) and is utilizing a variety of exercises in a freshman seminar course, multi-session labs, and a senior inquiry experience to develop inquiry skills in all of our majors.

Keywords: scientific inquiry, scientific process, developmental approach to learning

Introduction

In 2005, faculty members in the department of biology at Augustana College developed a course of action to integrate both inquiry and reflection with intentionality and focus throughout our curriculum in the biology major. When assessing our major, our faculty agreed that inquiry and inquiry-based learning was already present in many of our courses. However, we also agreed that we could improve the transparency of our intentions with respect to scientific inquiry by streamlining our definition and model of scientific inquiry and embedding exercises and assignments throughout our curriculum that would correlate with student developmental stages and learning abilities (Chickering and Reisser, 1993; Perry, 1968). The end product of our discussions in 2005 became our **IRIS** (Integrated Reflection and Inquiry in the Sciences) Program. Our IRIS program has five goals which are summarized in Table 1. It is the intention of this paper to discuss our inquiry goal (Table 1), our chosen definition and model of inquiry (scientific process), our inquiry objectives in the major, and how we are implementing these objectives in the courses throughout our major.

In 1996, the National Research Council (NRC) defined inquiry, knowledge and understanding, and scientific literacy in the book, *National Science Education Standards*. The definition for inquiry is as follows:

> *"Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world."*

We affirm these definitions and have adopted the second *(Inquiry [also] refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world)* as our working definition of inquiry.

Just as it is critical to have agreed upon a definition of inquiry moving forward, it is also important to have agreed upon a model for inquiry as a process. In surveying the literature, we came across the Inquiry Wheel (Fig. 1) as a model for scientific inquiry (Harwood, Reiff, and Phillipson, 2002)

This particular model of scientific inquiry was developed based upon interview data from 52 science faculty members in nine science departments at a large Midwestern research university. Faculty members were asked a series of questions about their own conceptions of scientific inquiry and their descriptions became the basis for Fig.1. The inquiry

© 2012 by Stephanie Fuhr, Kristin Douglas, Jason Koontz, Lori Scott, and Dara Wegman-Geedey

Table 1. IRIS Goals.

Inquiry	**Students will demonstrate their ability to generate questions that lead to scientific inquiry.**
Reflection	Students will reflect on their undergraduate experience and how their transitions and transformations from college student to biologist have changed.
Independent Learning	Students will demonstrate their ability to take responsibility for their own learning.
Information Literacy	Students will demonstrate information literacy in the sciences by performing literature searches, and by reading, interpreting, and evaluating primary literature.
Communication	Students will demonstrate proficiency in formal presentation skills as they present their work in written and/or oral contexts.

Table 2. Behavioral Objectives for IRIS Inquiry Goal

Understand the similarities and differences between the Inquiry Wheel and the traditional scientific method
Learn to recognize the importance of all types of questions in the inquiry process (center of the wheel)
Learn to recognize questions that lead to scientific inquiry
Practice the process of designing or evaluating scientific studies
Practice generating questions that lead to scientific inquiry
Describe the path one follows in finding answers to their scientific inquiry

wheel model appealed to us because it identifies questions as central to the entire process, allows for multiple entry points into the wheel, and authentically emphasizes the non-linear and recursive path that scientific inquiry so often follows. We have found at Augustana that it is important to point out to students that new and revised research questions can emerge from any point in the wheel and that our work within each stage of the wheel often leads us to more questions than answers. Furthermore, emphasizing the critical nature of the actions implied by Investigating the Known and Communicating the Findings allows for students to consider isolated and sometimes technical questions within the broader context of the work of science and society at large.

Inquiry skills must be learned and practiced in different contexts before they become a way of processing information (Hofstein *et al*, 2005). To foster understandings of scientific inquiry, students are introduced to the scientific process in a deliberate, developmentally staged hierarchy through a series of learning objectives (Table 2) embedded in courses throughout our biology major.

In our IRIS curriculum students are introduced to inquiry skills through beginning exercises in a freshman seminar course and our four core courses which are required for every major. Our students currently complete two multi-week lab experiments in our core courses, and we are in the process of developing a third multi-week experiment in a third core course. These labs are designed to mimic scientific process as best as is feasible with limited time and resources. In addition to our core courses, upper level courses are designed to reinforce and build upon inquiry skills developed in earlier courses. Every student in our biology major is required to complete a senior inquiry (SI) course which is designed to be a culminating experience in the major. Student inquiry begins with an investigation of primary literature in their chosen field followed by the generation of a question that leads to independent scientific inquiry. All stages of scientific inquiry modeled by the Inquiry Wheel including communication of findings in a format accepted by the larger scientific community are completed in the SI. We began implementation of our IRIS curriculum in 2008, and the first cohort of students to fully experience the program will graduate in May of 2012.

Figure 1. The Inquiry Wheel, Stages of Scientific Inquiry (Robinson, 2004)

Notes for the Instructor

Beginning Exercises

As a part of our IRIS curriculum we developed a one credit freshman seminar course entitled *BIOL 150: Becoming Biologists* that is required for all biology majors. In this course students engage in a number of exercises and assignments that introduce them to scientific process and thinking and require them to begin identifying and practicing the behaviors articulated in our inquiry objectives (Table 2). Students are asked to compare and contrast the Inquiry Wheel as a model for scientific inquiry and more traditional models they might have experienced in science courses throughout their primary and secondary education (i.e. the Scientific Method). They are also asked to track a student narrative of scientific inquiry through the Inquiry Wheel, as well as a narrative of a professional scientist's work and asked to compare and contrast the pathways taken in each case. In another activity, students practice generating questions that lead to scientific inquiry through observations of empirical evidence provided in the form of maps, pictures, and figures. Students then work in groups through the "idea" part of scientific inquiry by developing a plan for carrying their hypotheses through scientific process. Question-types from multiple stages of the Inquiry Wheel are modeled, and students generate targeted questions of their own as they work through their experimental plans.

Students in BIOL 150 are asked to reflect on the lessons in the course and to discuss the concepts and exercises that they found most useful in their development as a biologist and a learner. Excerpts from these student reflections are powerful affirmations of student learning and development. Below are two student excerpts that demonstrate important gains in student understanding and appreciation for scientific inquiry in the BIOL 150 course:

> "In reflecting upon the various things I have learned throughout this course, this would be an incomplete reflection if I were to leave out the Inquiry Wheel. The most important lesson I learned concerning the Inquiry Wheel was that questions--specifically, asking the right questions--is key to doing any science. Because questions are the central feature to the Inquiry Wheel and are the catalysts for forming testable hypotheses, it is crucial to always be curious and ask complex, yet direct questions about any observed phenomenon. And this practice should not be limited to the sciences, but rather exercised in all areas of academia and learning. For, not only do asking pertinent questions improve critical thinking, it serves as the gateway to exploratory and innovative thinking."

"I have learned that forming and applying questions is especially important to becoming a biologist. I have to admit, I am horrible with forming questions. I never know how to ask them so they make sense and make them something that I can actually successfully investigate. My favorite activity of this class and most useful to me, knowing that I can't form questions, was the group activity that dealt with defining the problem, forming the question, and articulating the expectation. We had to find out what was a possible cause of there being so many bird deaths in certain parts of the science building. We were able to take everything that we had learned from the inquiry wheel and apply it to real life situations. We had to form questions and apply them to the situation to find possible causes for why this was happening. This is something that a biologist has to do every day and I thought it was extremely useful that we were able to get a taste of it in class. I have found that it takes multiple questions to come up with the best one and that it is important to make and answer questions all throughout an experiment."

Students in BIOL 150 are asked to take a pre and post knowledge survey as a part of their participation in the course. There are three questions presented to them in both surveys regarding scientific inquiry and they are asked to evaluate their confidence in providing a response to the question. The questions included are:

1) List the steps of the traditional scientific method.
2) Compare and contrast the steps of the traditional scientific method with the Inquiry Wheel.
3) Explain in your own words the stages of the Inquiry Wheel.

The potential responses that students are able to select from for every question in the surveys are:

1) I could answer this question with complete confidence.
2) I would be able to get most of the credit for answering this question on an exam.
3) I may be able to get part of this question correct on an exam.
4) I could not begin to answer this question right now.

Table 3 includes response data from 292 pre-knowledge surveys and 190 post-knowledge surveys administered in the 2010-2011 academic year.

We are pleased to find that knowledge confidence is increasing from the beginning to the end of the BIOL 150 course with respect to listing and explaining the stages involved in scientific inquiry (Table 3). As instructors, it is interesting and significant for us to know that slightly greater than 20% of our incoming biology majors do not feel that they are able to list the steps involved in the scientific method and be mostly correct (option 2) as first year undergraduate students. We believe that including one credit of course work and time in our major to discuss scientific inquiry as a skill and a process (as well as a variety of other topics) is worth reducing that number and increasing confidence among all our students as early and as often as we possibly can in our curriculum.

Multi-Session Labs

We have developed multi-session lab series to mimic scientific inquiry process in two of our four required core courses . In our cell biology laboratory course, students are introduced to peroxidase enzyme investigations similar to those explored and documented in a variety of institutions (Pitkin, 1992). The peroxidase enzyme assay lends itself to use in

Table 3. Biol 150 Knowledge survey responses for scientific inquiry questions.

Survey Question	**% Selected Among Possible Survey Responses**			
	1). Complete Confidence	*2). Mostly Correct*	*3). Some Credit*	*4). No Answer*
Pre-test 1	40.8	36.9	15.6	6.7
Post-test 1	77.9	20.0	2.1	0
Pre-test 2	0.7	8.1	32.3	58.9
Post-test 2	83.7	14.7	1.6	0
Pre-test 3	0.3	2.5	12.1	85.1
Post-test 3	68.4	27.9	3.2	0.5

the student lab for many reasons: simple assay with inexpensive supplies, makes use of equipment commonly owned by science departments, and links well to lecture content related to protein structure and enzyme function. The lab series we have in place consists of six two-hour labs. The activities pursued in this lab series and their respective placement within the stages of the Inquiry Wheel is outlined in Table 4.

In our botany core course, we have another multi-session lab series that operates a bit differently. In this course, students are exposed to scientific inquiry by performing ecological investigations with Wisconsin Fast Plants®, *Brassica rapa*. The students conduct their investigations in addition to other exercises in lab which expose them to general botany concepts and the diversity of the Plant Kingdom. Wisconsin Fast Plants® complete their life cycle from seed to seed in six weeks and allow for relatively inexpensive studies of many ecological questions. Students work both in and out of designated lab time to design and execute their experiments as well as collect data over the ten week term. The activities pursued in this lab series and their respective placement within the stages of the Inquiry Wheel is outlined in Table 5.

Our cell biology course is a pre-requisite for our botany course, therefore students are familiar with basic experimental design, statistics, and the format of communication in the sciences before taking botany and are expected to work independently with limited guidance from the instructor on all aspects of designing their experiments and analyzing and presenting their data. We feel that gradually building the many varied skills implied in scientific inquiry best prepares our students for the work they will each be required to fulfill in our senior inquiry courses and in their professional lives as future biologists.

Senior Inquiry

Our Integrated Reflection and Inquiry in the Sciences (IRIS) curriculum culminates in a senior inquiry course (3 credits) where we ask each of our majors to demonstrate their highest level of skills in scientific inquiry, reflection, information literacy, independent learning, and communication. In order to best suit the varied interests and post-graduate directions of our biology majors, we offer a variety of formats in which this graduation requirement can be filled. Students can participate in bench-top research (off-campus research opportunities, disciplinary research on campus with a faculty member, or our directed off-campus research program through Texas Medical Center). Students can also participate in a literature-based course of a specialized topic. Specialized topics include winter biology, epigenetics, ecology of food systems, cardiac diseases, comparative anatomy, molecular genetics, conservation biology, neuroplasticity, research in field biology, sex in animals, emerging infectious diseases, etc. All senior inquiry experiences are required to involve 1)Reading, searching, and discussing primary literature 2)Tracking scientific inquiry through the Inquiry Wheel and 3)Communication of scientific inquiry work through an accepted format in the sciences: paper, poster, presentation.

Student reflections from our senior inquiry courses help us understand how our students perceive and can articulate their own development as scientists and learners:

Table 4. Peroxidase Lab Series (Cell Biology).

Lab	Inquiry Wheel Stages	Activities
Important Skills in Biology	Observing Investigating the Known	Bio-Math Case Study Graphing Basics & Excel Graphing
Important Techniques in Biology	Observing Investigating the Known	Exposure to & Proper use of Equipment Absorption Spectrums Making a buffer & Adjusting pH
The Enzyme Assay	Investigating the Known	Performing enzyme assays Preliminary study: altering enzyme concentration. Asserting biological meaning
Developing Enzyme Experiments	Defining the Problem Forming the Question Articulating the Expectation	Large group discussion over enzymatic reaction and relevant variables Lab groups develop their own question, hypothesis, and experimental design
Enzyme Experiments	Carrying Out the Study Interpreting the Results	Introductory stats discussion Student designed experiments performed Data analysis (templates provided)
Enzyme Experiment Presentations	Reflecting on the Findings Communicating the Findings	Group presentations (template provided)

Student excerpt from Winter Biology SI reflection:

"Devising experiments is another large component of a biologists' learning process. I think I have successfully learned how to plan and execute an experiment. First, in cell biology, I remember planning our experiment as a group. We were trying to measure enzyme activity under different conditions so we included a control group and an experimental group and tried to limit the changing variables to only one. Then we carried out our plan and recorded the results, which we later interpreted. While studying circadian rhythm for my senior inquiry project, I planned another experiment. This time I paid closer attention to detail because the system I was studying was more complex than measuring enzyme activity. I also found it helpful to be explicit about the reasons for including certain aspects of the experiment. For example, I made sure to explain what reindeer I was using and why I was using them. I have learned how to effectively plan an experiment which is a crucial part of becoming a biologist."

Student excerpt from Conservation Biology SI reflection:

"I learned more from this senior inquiry project than what keystones are, how to restore forests, and what the overall definition of conservation is. To me this was not a biology class, well okay it was, but there was more to it, an underlying message within. While this class/project was disguised as a "biology class," I learned a wider spectrum of information and developed more skills than I would have in a biology class that concentrated on one thing, like genetics or anatomy. In biology classes you are usually only required to use a few skills like memorization, paying attention to specifics, and some sort of problem solving. In this class I had to use every skill that I have developed over the past three years at Augustana. In addition to using skills I developed in biology classes, I had to use skills I retained from chemistry, calculus, psychology, physics, and even Spanish to tackle this project. Toward the end of the project everything "clicked" and I finally realized that every class is intertwined. While the information professors are making you learn is important, the skills you retain from completing the class is the underlying message in every class. In this class the underlying message is to use all previous skills, develop them, while learning new skills at the same time. . . . This class showed me my strengths and weaknesses. The weaknesses I can work on and the strengths I will retain forever. I feel like everything I have learned and developed thus far has led me to this moment, to this project. I guess this is why they call this senior inquiry the "Capstone of your education."

While student reflections can help us to gauge how our curriculum has improved their own meta-cognition and their confidence in their scientific inquiry skills, we as a department, are still in the process of developing assessment tools that will allow for a much more comprehensive evaluation of student learning in our IRIS curriculum. Through our qualitative assessments thus far, we are encouraged to see that we are achieving important gains for our students and we look forward to sharing the rest of our story through quantitative measures as we move forward.

Table 5. Wisconsin Fast Plant® Lab Series (General Botany).

Weeks	**Inquiry Wheel Stages**	**Activities**
1 & 2	Observing Defining the Problem Forming the Question Investigating the Known Articulating the Expectation	Observations Group question development and hypothesis Independent research on treatments/rates Experimental Set Up
3 - 8	Carrying out the Study Interpreting the Results	Collecting data Data analyzed by student groups working independently
9 & 10	Reflecting on the Findings Communicating the Findings	Draft posters compiled and revised Posters presented at student symposium

Acknowledgements

We would like to thank Kevin Geedey and Steve Hager for their collaboration in developing our initial IRIS goals and senior inquiry proposal. We would also like to thank Rebecca Cook, our IRIS Coordinator as of 2010, for all of her insight, effort, and guidance in implementing and beginning to assess our IRIS program.

Literature Cited

Chickering, AW and L. Reisser. 1993. *Education and identity, 2nd Ed.* Jossey-Bass, San Francisco

Harwood, WS, R. Reiff,and T. Phillipson. 2002. Scientists' conceptions of scientific inquiry: voices from the Front. *Proceedings of the 2002 Annual International Conference of the Association for the Education of Teachers in Science* (Session S1): 1022–1052. Available at **http://www.ed.psu.edu/CI/journals/2002aets/02file1.asp**

Hofstein, A, Oshrit N, Kipnis M, Mamlock-Naaman R. 2005 Developing students' ability to ask more and better questions resulting from inquiry-type chemistry laboratories. *Journal of Research in Science Teaching* 42 (7): 791-806.

Perry, WG. 1968. *Forms of intellectual and ethical development in the college years: a scheme.* Holt, Rinehart and Winston, New York, Pages 64-223.

Pitkin, R. B.. 1992. Enzyme investigations for introductory courses. Pages 107–118, *in Tested studies for laboratory teaching, Volume 13* (C. A. Goldman, Editor). Proceedings of the 13th Workshop/Conference of the Association for Biology Laboratory Education (ABLE), 191 pages.

Robinson W. 2004. The inquiry wheel, an alternative to the scientific method. *Journal of Chemical Education*, 81(6): 791-792.

About the Authors

Stephanie Fuhr, Kristin Douglas, Jason Koontz, Lori Scott, and Dara Wegman-Geedey are all members of the Biology Department at Augustana College in Rock Island, Illinois. Each author has played a critical role in the creation and administration of **IRIS** (Integrated Reflection and Inquiry in the Sciences), our curricular model for intentional academic and personal growth among our undergraduate students.

Stephanie Fuhr serves as the laboratory coordinator in the department and teaches our Becoming Biologists first year course, laboratory courses, and a senior inquiry course in agro-ecology.

Kristin Douglas teaches courses in developmental biology, genetics, cell biology, and senior inquiry of advanced topics in genetics at Augustana. At the lab bench, Kristin maintains a research program investigating germ cell fate in *C.elegans*.

Jason Koontz teaches courses in botany, cell biology, and conservation biology. In both the field and the lab, Jason investigates patterns of genetic variation in rare *Delphinium* species to help guide management of the hill prairies they inhabit in western Illinois.

Lori Scott teaches courses in cell biology, genetics, and molecular genetics in the biology department. In the lab, Lori studies *Meiothermus ruber*, a thermophilic bacteria species, as a part of the Interpret a Genome Program through the Department of Energy Joint Genome Institute.

Dara Wegman-Geedey teaches courses in microbiology, immunology, public health, and virology at Augustana and leads a variety of experiential learning experiences for students in microbial research, clinical internships, and public health both domestically and abroad in Nicaragua through our Joining Education Through Service (JETS) program.

Mission, Review Process & Disclaimer

The Association for Biology Laboratory Education (ABLE) was founded in 1979 to promote information exchange among university and college educators actively concerned with biology learning and teaching in a laboratory setting. The focus of ABLE is to improve the undergraduate biology laboratory experience by promoting the development and dissemination of interesting, innovative, and reliable laboratory exercises. For more information about ABLE, please visit **http://www.ableweb.org/**

Papers published in *Tested Studies for Laboratory Teaching: Proceedings of the Conference of the Association for Biology Laboratory Education* are evaluated and selected by a committee prior to presentation at the conference, peer-reviewed by participants at the conference, and edited by members of the ABLE Editorial Board.

Citing This Article

Fuhr, S., Douglas, K., Koontz, J., Scott, L., and Wegman-Geedey, D. 2012. Using Scientific Process (as Defined by the Inquiry Wheel) to Guide Multi-session Inquiry-based Laboratory Experiences in the Biology Major. *Tested Studies for Laboratory Teaching,* Volume 33 (K. McMahon, Editor). Proceedings of the 33rd Conference of the Association for Biology Laboratory Education (ABLE), 390 pages. http://www.ableweb.org/volumes/vol-33/?art=22

Compilation © 2012 by the Association for Biology Laboratory Education, ISBN 1-890444-15-4. All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the copyright owner.

ABLE strongly encourages individuals to use the exercises in this proceedings volume in their teaching program. If this exercise is used solely at one's own institution with no intent for profit, it is excluded from the preceding copyright restriction, unless otherwise noted on the copyright notice of the individual chapter in this volume. Proper credit to this publication must be included in your laboratory outline for each use; a sample citation is given above.