How Can a Physics Course for Non-majors and Preservice K–8 Teachers Engage Students in the Process of Scientific Inquiry? A Case Study in Collaborative Curriculum Design and Implementation

Lynn M. Tashiro

This case study documents a collaborative process of designing a physics course across the academic cultures of science and education. It presents a model for how scientific inquiry might be integrated into an undergraduate physics course for non-majors and preservice K–8 teachers. Tools for managing and assessing guided and open inquiry are provided together with samples of student work. Evidence of student learning is investigated, with a focus on assessing students' ability to write a testable scientific question.

The paper is organized in five sections:

I. The context and resources for designing the physics course, Physics 100
II. The collaborators
III. The course
IV. Tools for managing and assessing inquiry
V. Evidence of student learning
VI. References

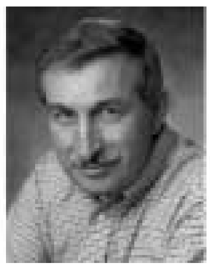
I. The Context: What was the Motivation for Designing a Physics Course for Preservice K–8 Teachers? What Resources Did We Have?

The design of Physics 100 was motivated by a desire to prepare our future teachers to meet the challenges of implementing national and state science standards. Of particular concern was developing a curriculum that would provide experience with and develop skills necessary to engage in scientific inquiry. In the fall of 1998 the National Science Foundation awarded funding to California State University Sacramento (CSUS) for project C-CUESST (A College

Curriculum for Elementary School Science Teachers). The goal of the project was to create an inquiry-based undergraduate physics course, Physics 100, for preservice K–8 teachers that would integrate scientific content knowledge with research-based knowledge about teaching and learning science. Faculty release time for the collaborators and the purchase of classroom computers were funded by NSF ($247K) and CSUS ($15K). This project was the first step in redesigning the entire preservice science curriculum at CSUS.

II. The Collaborators:Who Designed and Taught Physics 100?

Lynn Tashiro
Associate Professor
of Physics



Steve Gregorich
Professor of
Teacher
Education

Patricia McEgan
K-8 science teacher

Hugo Chacón
Assistant Professor
of Bilingual and
Multicultural Education

Lynn, Steve, Patty and Hugo are the collaborative team that planned and team taught Physics 100. Formal project evaluation is being conducted by David Jelinek, CSUS Assistant Professor of Science Education.

How Did We Design and Implement the Course and Who Did What?

The following timeline will help to understand the context of each team member's work:

- Lynn and Steve planned and put together materials for the guided inquiry lessons
- Search conducted for the third collaborator, the K–8 teacher in residence

Spring 1999 semester

- Patty joined the project full time as the teacher in residence

- Steve and Lynn team taught two pilot sections of Physics 100.
- Guided inquiry and open inquiry projects were tested
- Guided and open inquiry components modified as a result of formative evaluation feedback from students and project external evaluator

Fall 1999 semester

- Lynn and Patty team taught two sections of Physics 100
- Transitioned four additional sections of Physics 100 and part-time faculty to the inquiry-based curriculum
- Hugo joined the project
- Hugo and Steve began revision of the science methods course
- Hugo and Lynn redesigned and team taught the light and color unit

Spring 2000 semester

- Lynn taught two sections of Physics 100
- Patty and Hugo each taught a science methods course
- A limited enrollment learning community consisting of Physics 100, EDTE306 Science Methods and EDBM470 a field experience was piloted by Lynn and Hugo
- Patty began work on a master's thesis, which will use discourse analysis to investigate students' experience and perception of the open inquiry process
- Together with Professor Melanie Loo of biology, Lynn piloted an early field experience in teaching K–6 science for preservice teachers, ID111 Science in the Elementary School
- David, Lynn and Patty began evaluating students' ability to ask a testable question.

Course design and implementation timeline

The contributions of each team member were based not only on their areas of academic expertise but also as a result of individual interests and talents. Key contributions of team members are summarized below:

Lynn (physics content specialist)

- provided the science content and activities for the guided inquiry lessons ensuring a level of rigor acceptable to university physics and science faculty
- reviewed and presented literature on physics and K–12 science education
- created the structure and management tools for the open inquiry projects and poster presentations
- wrote learning objectives, the "know and do boxes," for each guided inquiry lesson
- evaluated students' ability to ask testable question

Steve (science methods specialist)
- organized, formatted and wrote the first draft of the student laboratory manual containing the guided inquiry activities
- researched, selected and constructed instructional materials, measurement tools and technology components in the sound and electricity units.
- operationalized the guided inquiry learning objectives, the “know and do boxes,” by focusing them on behavioral objectives.
- provided a global perspective of how our course fits into the teacher education program. As past dean of the School of education, Steve provided invaluable insight and help in obtaining administrative support for our project

Patricia (K–8 science teaching specialist)
- constructed the first draft of the open inquiry rubric used to assess the open inquiry projects. (It was modeled after a rubric she uses in her K–8 science classroom.)
- edited the laboratory manual improving it by the addition of focusing question for each activity.
- provided reality check on the content and process skill objectives in Physics 100, making sure activities and projects were relevant to state and national standards as well as science in the K–8 classroom

Hugo (science education and multicultural education specialist)
- designed guided activities in the light and color unit
- expanded our learning assessment plan by using oral presentations as the culminating open inquiry activity
- created a link between science methods, science in the K–8 classroom and Physics 100 by offering a Learning Community together with Lynn consisting of Physics 100, EDTE306 (Science Curriculum and Instruction) and EDBM470 (Teaching Science in the Elementary School)

Over the past three semesters all four of us have team taught some portion of Physics 100 together and participated in facilitating and evaluating the open inquiry projects.

Some important factors in facilitating collaborative work:
- **Matching personalities and teaching styles**
  Matching personalities and teaching styles is just as important as matching academic expertise in building a collaborative team. Project C-CUESST has a very precious collaborative component. All team members were flexible, constructively critical and willing to try just about anything to improve the learning in Physics 100. The team members shared enough common

knowledge and teaching philosophy to have productive discussions but were diverse enough in their thinking so that multiple viewpoints and solutions to problems were always presented.

- **Strong physics and pedagogy content knowledge by each collaborator**
  Each of the team members had a strong background in physical science and science education research. Steve was the science and technology instructor for the school of education and had been involved in the move toward inquiry in the 1970s. Patricia had a strong physical science background and was involved in the California systemic projects to improve K–8 science teaching. Hugo had been a high school physics teacher as well as a university science methods instructor, and Lynn, in addition to teaching undergraduate physics courses, has been involved with science education research and state systemic projects to improve K–8 science learning.
- **Providing physical space and opportunity for collaboration**
  Physically sharing office space and participating in each other's department meetings and social functions is important. At the beginning of the project Steve, Patty and Lynn moved into an office in the science building where Physics 100 is taught. During the project Steve, Patty and Hugo attended several physics department meetings and social events. Lynn attended meetings with CSUS education faculty and K–6 teachers within the school of education as well as at K–6 school sites in each of the local area districts. These small events helped each of us to observe the differences, understand the constraints and identify the opportunities present in the academic cultures of the university science departments, university education departments and K–6 classrooms.

Out of this collaboration emerged a practical model of an inquiry-based physics course. This model is described in detail in the following section.

III. The Course: What does Physics 100 Look Like?

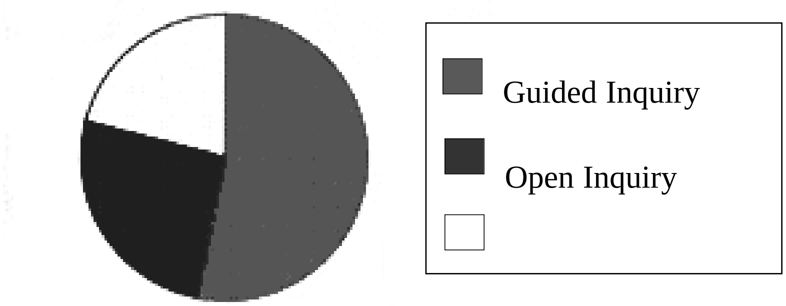
How is Physics 100 Organized?

Physics 100 meets for an hour and 40 minutes twice a week (200 minutes of "activity time" per week) in a laboratory style classroom designed to seat 24 students.

Topically the course is divided into three units, waves and sound, electricity and magnetism, and light and color. These topics were chosen to fit into the existing preservice science curriculum. Physics 100 is one of seven science courses required of preservice teachers and is the second of two physics courses required.

Instructionally Physics 100 is composed of a lecture/textbook component, a guided inquiry component and an open inquiry component. The approximate distribution of class time allocated for each component is shown below:

Distribution of instructional modes



What Do the Components Look Like?
A description of each component follows:

The Lecture/textbook component:

The lecture/textbook component is modeled after instruction that is traditional in the physics discipline. Weekly textbook reading from Hewett's *Conceptual Physics* is assigned along with end of chapter review questions, discussion questions and numerical problems. Lectures are integrated into the guided inquiry component and are used to introduce, formalize, or summarize concepts. The lectures are more like "minilectures" and are usually 10 to 20 minutes in duration and focus on a physicist's understanding of concepts. For example a minilecture is used to formalize, define and differentiate the electrical concepts of voltage, current, resistance and power.

The Guided Inquiry component:

The guided inquiry component is built on theoretical foundations of physics education research[1–5] and K–8 science education research.[6,7] The guided inquiry lessons have four phases we call "into," "through," "beyond" and "reflection."

The "into," "through," and "beyond" phases are similar to the phases in the learning cycle used with children[6] and the SCALE (Science Content And Language Expansion) cycle proposed as effective with culturally diverse children.[7] These three phases also include the four stages of the "modeling theory" 1. description, 2. formulation, 3. ramification and 4. validation presented by.[4]

The "into," "through," and "beyond" phases comprise the bulk of the guided inquiry lessons. The "reflection" phase can be thought of as the "student post-mortem" of the guided activity. Although this reflection or metacognition exercise was identified in physics instruction as the period in the lesson where "the most significant learning occurs,"[4,5] it proved to be the most difficult to integrate and make room for in the time allocated for guided inquiry instruction. Although there are a few formally written examples of "reflection" lessons in the guided inquiry lessons, most of the metacognition happens informally at the end of each lesson when the instructor and students discuss the "know and do boxes," which articulate what students should know and be able to do at the end of the guided inquiry lesson. More formal metacognition and thinking about learning lessons are being integrated into an experimental science methods course. This experimental course is offered in a learning community where students concurrently enroll in Physics 100, EDTE306 (Science Methods) and EDBM 470 (Teaching Science in an Elementary School).

For reference the "into," "through," and "beyond" phases are briefly described:

"into"

- probing for prior knowledge that requires students to expose their preconceptions and misconceptions about a concept or physical system
- determining relevant physical quantities to measure and include in the construction of a model of a system
- generating testable questions for a model and predicting outcomes of experiments based on a model

This stage may be initiated by posing a question or observation of a discrepant event (an event whose outcome is unexpected or counterintuitive)

"through"

- construction of a model for understanding observed phenomena
- designing experiments to answer the questions posed
- interpreting, debating, and defending experimental results
- validating, or debunking a model or prediction
- reflecting on the consequence of their experimental results
- presentation of results to peers

"beyond"

- deploying model to explain or predict the behavior of a related but new physical system
- applying a new skill or concept to another scientific discipline or personal event outside the laboratory

"reflection"

- students judging whether the goals articulated at the beginning of the lesson were achieved
- students reflecting upon and articulating which types of activities contributed most, and least to their learning

Some of the guided inquiry lessons were created by the collaborative team and some were modified from published texts such as *Physics by Inquiry* and Elementary Science Kits such as Science and Technology for Children (STC), and Full Option Science Systems (FOSS). Below are a few pages of the student laboratory workbook illustrating the “into,” “through” and “beyond” components.

1: Wave Motion

Everything we see and hear reaches us by waves.

Into

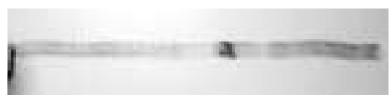
Activity A. What is your past experience with waves? Use drawings, words, and numbers to illustrate what you already know about waves and what you do not understand about waves.

1. What are some examples of waves?

Through

Activity B. Can we observe waves traveling through different media? Three stations are set up around the room containing materials that can be made to produce waves. Below are pictures of the materials used for the stations. The questions for you to answer are on the following pages.

Station 1: Pushing against one end of a slinky hung by strings from the celiling.



Activity F. Assessment: Construct and Observe a Wave

Beyond

Machine. Obtain a package of materials from your instructor and follow directions to construct a wave machine. (See directions for constructing the Wave Motion Machine in the Materials for Sound section at the end of this unit.) Observe waves that are created when you pull the fishing line taut and very gently and slowly twist your wrist just a little left and right, or

hold the machine very still and lightly tap one end of the soda straw nearst you.

1: How is the wave created?

2. What do you already know about waves?

Page 5

Station 2: Drops striking the surface of a puddle (milk carton & cake pan of water.

Station 3: Making waves with a jump rope.

Page 6

2. Identify the medium the wave is traveling through.

3. What direction is the medium vibrating?

4. What direction is the energy traveling?

5. What direction is the wave traveling?

6. Determine if the wave is longitudinal or transverse. Explain your answer using a diagram and words.

Page 10

The open inquiry component:

The open inquiry component was based on a model developed at the Institute for Inquiry at the San Francisco Exploratorium Museum and is described in "Volume 2 FOUNDATIONS, Inquiry: Thoughts, Views, and Strategies for the K–5 classroom."[8]

During the 15-week semester, students work in groups of four or five on three inquiry projects, one in each of the topic areas. Each project is assigned after students have had some concrete experience with phenomena in the topic area and is completed in a cycle of six class meetings. Each project begins with a student question that is then investigated by the group and finally presented in a scientific poster session. A timeline of an open inquiry cycle is shown below:

Timeline for student inquiry projects:

Day 1	Students are given the assignment of writing a testable question and investigation plan.
Day 2	Students discuss questions in groups and decide on one question to investigate
Day 3	Students are given 30 min of class time to work on inquiry
Day 4	Students are given 30 min of class time to work on inquiry
Day 5	Students are given 30 min of class time to work on inquiry and prepare poster
Day 6	One hour of class time is used for scientific poster session and peer evaluation of projects

An example of the open inquiry process for electricity and magnetism is illustrated below with the details of one of the six groups' experience described.

Day 1 Students are given the assignment of writing a testable question.

- Students are given an Inquiry Planning Sheet and Project Grading Criteria and asked to write a testable question and plan an investigation to answer the question.
- They have had 2 and a half weeks of textbook, lecture and guided activity instruction on static electricity and electrical circuits.
- The guided activities have instructed students on the use of the multimeter.

Inquiry Project Planning sheet

Name(s):
Inquiry Question:

What will you measure and what will you measure it with?

What will you graph?

List of things you will provide for the inquiry:

List of classroom materials you would like to use. (You may use any materials you have seen in class provided they are returned at the end of the class period. If you need something special consult your instructor):

Day 2 Students discuss questions in groups and decide on one question to investigate

- Each student is given two uninterrupted minutes to state and explain their question.
- Students then discuss the testability of the questions and choose one to pursue.
- If the group "gets stuck" the instructor facilitates the discussion
- When the group has come to consensus, they draft a group project planning sheet and review it with the instructor.

The questions this group is discussing are:

1. **How does the type of citrus used in a homemade battery (i.e. lemon battery) affect the voltage? Diana**
2. **How much do different diameters of wire affect the amount of charge through the wire? Andrea**
3. **Do different fruits provide different amounts of power to light a bulb? Neng**
4. **Which fruit or vegetable has the highest voltage or current? What causes this? Jenn**

During the conversation, the concepts of acidity and pH have come up as factors that might affect the voltage of their "fruit batteries" and the question the group agrees on is:

Does the pH level in different fruits affect their voltages?

For the next inquiry meeting the group plans to bring fruits, zinc and copper screws, and pH paper. They have also sketched out their experimental setup.

Days 3, 4 and 5 Students are given 30 min of class time to work on inquiry and prepare posters

Students use a multimeter to measure the voltage produced by inserting zinc and copper screws into a kiwi. The multimeter measures 0.82 V.

Andrea and Jenn match the color of the pH paper to the chart to determine the pH of one of the fruits.

Dianna, Andrea, Neng and Jenn spend their in-class time using a multimeter to measure the voltage produced by various fruits as a result of inserting copper and zinc electrodes in them. They also obtain a pH measuring kit from a local school supply store and test the pH level of each of their fruits.

In between class meeting times this group has been surfing the Internet for background research to help them make sense of the data they are collecting. They have used the interactive inquiry journal to ask the instructor questions and respond to instructor feedback on their inquiry project.

Day 6 One hour of class time for scientific poster session and peer evaluation of projects

On the poster presentation day groups are busy assembling their posters. Dianna, Andrea, Neng, and Jenn pose with their finished product.

Students explain their posters to their peers and instructors.

Students are given about 10 minutes to assemble their posters. Some will have them completed before coming to class. Posters are set at the ends of the long lab tables in class and each inquiry group divides in half. Half of the group will stay by their poster and half will move to evaluate another poster. After 20 minutes the students switch so that they all have a chance to explain and look at other posters. Students are given a peer evaluation form for the posters that is the same as what the instructor will use to evaluate the posters.

On this day Professors David Jenlinek and Elizabeth Kean from the school of education and Professor Joong Lee from the Department of Chemistry have come to look at the inquiry posters. Students have engaged Professor Lee in a discussion of the chemical reaction between their hot dog and the zinc coated paper clips they used as electrodes in their inquiry. “ Just what was that stuff oozing out of the hot dog?”

After the poster session, which lasts about an hour, students turn in a peer evaluation of one of the posters they examined. Students do not determine the grade of their peers but instead a student’s grade is determined by their ability to apply the open inquiry rubric. Students are graded on their ability to provide evidence to support the grade they award a poster in four categories: appearance and organization, graphs and charts, analysis, and conclusion. The grade for the inquiry project will be based on the poster, the inquiry journal, attendance and their peer evaluations.

IV. Tools for Managing and Assessing Inquiry: What Tools Did We Find Useful and Necessary to Manage the Guided and Open Inquiry Components?

Guided Inquiry Management Tools: The Student Laboratory Workbook and "Know and Do Boxes".

The student laboratory workbook and the "know and do boxes" were useful for managing the guided inquiry process. The 135-page student workbook was an absolute necessity to make the course transferable to other instructors teaching the course who had not participated in its design. The workbook gave a definite structure to the course, but left enough room to accommodate different teaching styles. Samples of workbook pages are illustrated in section II of this paper.

The "know and do boxes" articulate what students should know and be able to do at the conclusion of the guided inquiry lesson. Part of the first "know and do box" for waves is shown below:

Physics 100

<u>Concepts in Physics</u>

Know and do box #1

What students should know:

1. The definitions of wave characteristics: l(wavelength),v (speed) f(frequency), T(period) and A (amplitude).
2. Scientific models can be drawings, graphs, computer simulations, mathematical equations or physical manipulatives.
3. Different models illustrate different characteristics of a physical phenomena (for example waves). To explain physical phenomena more than one model may be needed.
4. v = lf, d=vt, and f=1/T are mathematical equations that model the relationships between different wave characteristics.

What students should be able to do for any observable wave:

1. Obtain numerical values for l,v, f, T, and A by:
   - applying the definitions of l,v, f, T, and A and using appropriate measuring tools.
   - using the mathematical equations and known values to find the unknown values. (ex. Given l and f find v)
2. List, describe, and explain 3 different models of a wave.
3. Identify characteristics of a wave that are correctly and incorrectly represented by a particular scientific model.

One disadvantage of using guided inquiry lessons to present science content (instead of lecture presentations) is that students may miss the important concept they were to “discover” because they are so involved in the correct or incorrect “doing” of the activity. Even after a whole class debriefing discussion at the end of each lesson, much as we would like to believe our clear articulation of the subject matter is enough, examination of student notes in their workbook indicates some students will still be unclear. The “know and do boxes” make the learning objectives concrete and by stating them in terms of what students should know and be able to do, we clearly operationalize them for the student. The 12 “know and do boxes” written for the semester serve as another medium for getting the important points of the guided activities across and since the end of the unit exam questions are constructed from the “know and do boxes” students also find them useful as study guides.

Guided Inquiry Assessment Tools: The Unit and Final Exams

End of unit and final exams are used to assess the students’ mastery of the learning objectives in the guided inquiry lessons. Some of the questions on the exam are fairly traditional for a conceptual physics course and consist of pencil and paper test questions requiring short answer explanations, drawings and calculations.

The Spring 2000 Exam 1 questions from unit one matched to the “know and do box” #1 illustrated above are shown below:

Questions from Physics 100 Exam 1 Spring 2000

1. Two children Jeremy and Jennifer are playing “high water low water” on the playground with a jump rope. The children are standing **3 meters** (300 cm) apart from each other. The jump rope has a knot in it, midway along its length. **Jeremy** shakes the rope up and down very hard to produce several waves. Here is a snapshot of what the rope looked like.

a) On the diagram above label one wavelength of the wave. Calculate one wavelength of the wave produced by Jeremy

b) In the picture, you can see the knot in the rope. The knot travels up and down (one complete cycle) in 2 seconds. Calculate the frequency of the wave.

c) Calculate the speed at which the waves move along the rope.

d) On the diagram above label the direction of energy travel and label the direction that the medium is vibrating.

e) Is this wave longitudinal or transverse? Circle one: longitudinal or transverse
Explain your answer using a diagram.

5. Any of the following can be used to model a sound wave:
- a) a compression wave in a slinky (made by compressing the coils on one end)
- b) a water wave created by dripping water into a pan of water
- c) the wave equation v = lf
- d) computer program Kaboom
- e) the wave machine made of straws and fishing line
- f) wave in a rope

i) List a model that correctly models the longitudinal nature of a sound wave. Explain how it demonstrates this wave property.

ii) List a model that correctly models the waves that are present in a panpipe. Explain your choice.

iii) Select one of the models above and discuss one way in which the model does not accurately represent a sound wave.

Indicate model selected:
Discussion:

In addition to these pencil and paper questions there is at least one problem on the exam that requires students to manipulate materials and measuring devices used in the guided inquiry lessons. For example, in the waves and sound unit, students are asked to use the computer program "Kaboom" to measure the frequency of a sound wave produced by blowing across the top of an empty soda bottle. In the electricity unit students are asked to construct a circuit with a battery and light bulbs and make current and voltage measurements.

Open Inquiry Management Tools: The Interactive Journals

Picture this: Six groups of students are working on different inquiry questions, each with different group dynamics, uncertainties about experimental procedure, questions about key concepts and interpretation of data. Each group needs your immediate attention and you have 30 minutes to help them all. Impossible? Yes, it is! This is the situation we found ourselves in when we piloted the open inquiry component of the course. Luckily there were three instructors during the pilot course and each group was attended to, but this was a luxury we could not count on for future semesters. We had a classroom management problem that needed to be solved if the open inquiry component was to survive beyond the pilot phase.

The use of interactive group journals turned out to be the key to managing this communication problem. At the start of the inquiry when students are discussing and deciding on a question they are given a folder to journal the progress of their inquiry and ask questions. The inquiry journal contains:

- The individual and group inquiry planning sheets
- A group organization sheet designating group responsibilities and an attendance record
- Daily progress reports on the inquiry that include: responses to instructor queries, diagrams of experimental set ups, data, background literature research, questions for the instructor, analysis of the data and action plans for the next inquiry meeting.
- Questions from students, requests for materials or references

A few pages from Diana, Neng, Jenn and Andrea's inquiry journal are reproduced on the next page followed by a short description of its contents. The complete journal consisted of 29 pages of handwritten notes and diagrams and 29 pages of background research. Most of the background research was obtained and printed from the Internet.

This is the same group shown in part III of this paper. Their inquiry question was:

Does the pH level in different fruits affect their voltages?

Pages from an interactive student inquiry journal

Inquiry Group Organization

♣ leader DIANA
• responsible for keeping the group focused on the project and making decisions about the direction of the inquiry

♥ recorder ANDREA
responsible for keeping the inquiry journal which includes:
• writing journal entries after each class period spent on the inquiry
• documenting experimental set up, procedure, and data

♦ materials manager NENG
• responsible for ensuring that all experimental equipment is available for the inquiry and is returned at the end of class.
• responsible for ensuring that adequate background literature is available for the inquiry.

♠ presenter JENN
• responsible for assembling the poster presentation. All text must be typed and graphs and charts should be computer generated when possible.

Inquiry attendance Record

Please have each group member initial every day that they were in class to work on the inquiry:

Name	3/28/00	3/30/00	4/4/00	4/6/00	4/?/00
DIANA	DS ✓	DS	DS ✓	DS	[illegible]
NENG	NC ✓	NC ✓	NC ✓	NC ✓	NC ✓
ANDREA	AC ✓	AC ✓	AC ✓	AC ✓	AC ✓
JENN	JD ✓	JD ✓	JD ✓	JD ✓	JD ✓

Journal checklist:

- ☑ Name of Inquiry
- ☑ Names of group members and group role assignments
- ☑ Inquiry Planning Sheets: one for each individual and one for the group question
- ☑ Copies of background research and references used
- ☑ Data Table
- ☑ Raw data (ex. actual Kaboom recordings or multimeter measurements)
- ☑ Daily progress reports which will contain your "journal evidence".

Page 1

4/6/00

JOURNAL ENTRY # 2

- Everyone brought the required materials
- Pineapple was omitted because it was too expensive (FS).
- (Fruits) were obtained & [illegible] on [illegible]
- pH paper was obtained at the [illegible] a teacher's supply store.
- Cu + Zn screws [illegible] obtained @ Home Depot [illegible] of each.

(apple, mango, grapefruit, tomato, kiwi, lemon, lime, banana)

Everyone chipped in $1 to cover the cost of materials

Questions

① why do we need Cu + Zn? why do metals work?

② what does pH have to do w/ voltage?

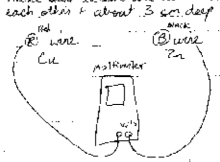
lower the pH, the higher the voltage

Good questions — find answers

Page 8

Procedure

Take each piece of fruit.
Place Cu screw in one end
Zn screw in other.
Make sure screws are about 5 cm apart from each other + about 3 cm deep into fruit.



Results	Volts	pH
Grapefruit	.95 ✓	2 pH
Kiwi	.84 ✓	3 pH
Lime	1.00 ✓	1 pH
Lemon	1.01 ✓	pH
Orange	.75 ✓	3 pH
Tomato	.84 ✓	4 pH
apple	.77 ✓	5 pH
banana	.83 ✓	5 pH

Page 9

Plan

- Jenn is going to be the official typist.
- She is typing materials, title, group members, question, + raw data.
- We are all going to do some research on pH levels and how it correlates to acidity level, + also why we needed to use Cu + Zn screws

NEXT MEETING

Formalize our analysis. Write up procedure, analysis, and conclusion

Decide on poster format.

We plan to buy our own poster board + put together our poster at a later meeting
[illegible] just take some poster paper [illegible]
Very good start — data looks good.

Questions
1. Did you evaluate the source, usefulness and accuracy of the background data you included? Did your fruit [illegible] up a holiday light? (If not why not)
2. Try searching under [illegible] [illegible] [illegible] Key word lemon battery [illegible]
3. The chem Ran may hold the key to understanding why pH level is

Page 10

Description of journal contents:

Page 1 of the journal is the organizational page. It is used to assign or record group responsibilities and keep an attendance record.

Page 8 contains a project status report and questions that the group has raised:

> **<u>Questions from students:</u>**
> **1. Why do we need Cu + Zn? Why do these metals work?**
> **2. What does pH have to do w/voltage?**
> **lower the pH, the higher the voltage**

Page 9 contains a description of the experimental procedure and data taken on that day.

Page 10 contains plans for the next inquiry meeting and the instructor's questions and comments.

> **<u>Questions and suggestions from the instructor:</u>**
> **1. Did you evaluate the source, usefulness and accuracy of the background data (and research) you included?**
> **2. Try searching under subject area of education, K–12 or university and key word lemon battery if you are surfing the net.**
> **3. The Rxn may hold the key to understanding why pH level is important, consult a chemist if possible, Professor Londa Borer would be good.**

Notes about the journal contents:

- Instructor question 1 was motivated by the background literature included with the journal. Portions of the literature were inaccurate and misleading and other parts were unrelated to the experiment.

- Instructor suggestions 2 and 3 were to help students locate more reliable and relevant resources for finding answers to the questions on page 8.

- An interesting observation: Most students used the computer as their primary source of background information. Some used CD ROM encyclopedias and most used the Internet to locate information. Almost none of them used the campus library or other available textbooks as resources.

The inquiry journals are collected at the end of each class period students are working on the inquiry and returned at the beginning of the next period. The time spent on giving students feedback is time well spent as they are eager and interested to read the comments made in the journal and are quick to respond to questions and suggestions. This is in contrast to the time I used to spend on grading weekly lab reports. My observation was that students would look at their grade and comments, but there was little indication that the grade or comments improved or encouraged student learning.

From the example above you can see that the journals are not formal laboratory notebooks. They are a place for students to think out loud and test their ideas. Their most important function is to keep the instructor informed of the direction of the inquiry and thinking of the group. With the use of the inquiry journals, students are able to work with minimal assistance during the class time designated for inquiry projects. There will occasionally be a group with a problem that is too big to be addressed by the journals, but these situations can be facilitated during the 30-minute inquiry period!

Open Inquiry Assessment Tool: The Open Inquiry Rubric

Assessment of the open inquiry projects is based on the journal, the poster presentation and peer evaluations. The journal and the poster are graded using a rubric. Being an active facilitator of the inquiry projects and observing the amount of effort and time students put into their inquiry projects can make it difficult to be an objective evaluator. Using a criterion-referenced rubric helps to objectify the grading and also gives students clear information as to what is expected of them. Students are given these rubrics at the start of the inquiry project so the rubrics also serve to manage student expectations of how the project will be graded.

To guide student and instructor thinking there is a rubric for each stage of the inquiry:

- The Question
- The inquiry process — The Inquiry Journal
- The poster

After our observation of several inquiry cycles we recognized the importance of developing collaborative work skills. Much has been written about the benefits of group work. However, group dynamics can be tricky to manage and students, even adult students, need some guidelines for working in a group. Since the open inquiry projects depend heavily on the ability of the group to function collaboratively, we felt the need to articulate some guidelines for behavior in a group. The last rubric is an attempt to describe some of the observable characteristics of a functional collaborative learning group.

P100 Inquiry Project Grading Criteria

The Question			
	Getting There	Got It!	Wow!!
Scope and Testability	• The question is too broad (it cannot be answered within the scope of this class) or too narrow (it can be answered by a quick test or by reading a reference book). • The question does not have a possible answer that can be verified by an experiment or test.	• The question relates to concepts in the course and requires some investigation or experimentation. • The question is testable. An experiment with well-defined and controlled variables can be designed.	• The question leads to a deep investigation of the course content and extends classroom learning by making connections to other science disciplines or phenomena outside the classroom. • The question can be tested in more than one way or on more than one level of accuracy or sophistication.

The Process — The Inquiry Journal

Background Research	• Uses only hearsay or personal opinion. • Uses only one reference or resource. (For example, just a textbook). • Reference makes incorrect or superficial connection to the inquiry question. *Journal evidence:* • *No copies of background research are provided or research materials make no connection to the inquiry.*	• Uses at least two reliable resources among science reference books and reputable internet sites. • Key science concepts are identified and references make connections between these key science concepts and the inquiry question. *Journal evidence:* • *Copies of background research necessary to analyze the question are provided and important passages or facts are highlighted.*	• Uses more than two resources, including science books, science journal articles, reliable internet sources and interviews. • References are used to construct correct understanding of key concepts. This understanding is used to explain the observation or results of the inquiry experiment. *Journal evidence:* • *Copies of background research are provided and important passages or facts are highlighted. In their analysis, students restate these passages in their own words and use the information to analyze their data and answer their inquiry question.*
Design of Quantifiable Test or Experiment	• The test did not measure anything. Results were not quantifiable as a table or chart. • The test had conditions or variables that could not or were not controlled. *Journal evidence:* • *Data was gathered but it did not provide any information on the question.* • *Variables that might affect the outcome of the experiment were not identified or discussed.* • *The experimental design was poorly described or illustrated.*	• The test used tools to make at least one measurement. Data was gathered that could be displayed in a chart or graph. • The test identified variables that were to be held constant and variables that were to be changed. *Journal evidence:* • *Data was recorded that provided information on the question.* • *Variables that might affect the outcome of the experiment are identified and controlled systematically.* • *Experimental design was clearly described and illustrated.*	• The test had more than one layer to it, or looked at the problem from more than one angle. More than one tool was used to make measurements or more than one test was designed resulting in more than one set of data to be graphed or charted. • Tests demonstrated understanding of a multi-variable problem by careful control of experimental conditions and variables. *Journal evidence:* • *Data was recorded from several trials or several different tests.* • *Variables that might affect the outcome of the experiment are identified and controlled systematically.* • *Several experimental designs were tried. Each design was clearly described and data collected was analyzed and used to improve the design or to design an additional test.*

The Process — The Inquiry Journal continued			
Experimental Procedure and Analysis	• A single test or experiment was conducted one time. The results were accepted, and a conclusion drawn based on one test. • Data was inaccurately or incompletely collected. *Journal evidence:* • *Only one set of data is recorded.* • *There is no description of the conditions under which the data was collected.* • *There is no attempt to "make sense" of the data in the context of background material or classroom concepts.*	• The experiment was conducted and analyzed more than once. • A dialogue about the question, experiment, results and background information led to the refinement of the question or experiment. • Enough data and background information were accurately collected to provide evidence to support an answer to the question. *Journal evidence:* • *Data from several trials of the same experiment were collected.* • *A narrative of what students throught about their data and why they thought it (analysis) connects the data to background research and classroom concepts.* • *Conclusions and modifications of the experiment as a result of analysis are recorded.*	• More than one test was conducted and analyzed more than once. • Much dialogue led to testing the question in a wide variety of ways, cycling often between testing and refinement of the question. • Data and background information was collected to support the answer to the question and led to a correct and thorough understanding of the key science concepts required to understand and explain the inquiry. *Journal evidence:* • *Data from several trials or different types of experiments is recorded.* • *A narrative of what students thought about their data and why they thought it (analysis) connects the data to background research and classroom concepts.* • *Modifications of the experiment as a result of analysis are recorded and implemented.* • *A conclusion and answer to the inquiry question that is supported by the analysis is written.*
Questions and Instructor's Comments	• Inquiry group did not respond to instructor's comments or questions on the inquiry. *Journal evidence:* • *There were no written responses to instructor's request for clarification or explanation of journal entries.*	• Inquiry group responded to instructor's questions or comments. *Journal evidence:* • *There were written responses to instructor's request for clarification or explanation of journal entries.*	• Inquiry group responded to instructor's question or comments and used the journal to pose questions and ask for help. *Journal evidence:* • *There were written questions as well as responses to instructor's queries.*

Journal Checklist:

- ❒ Name of Inquiry
- ❒ Names of group members and group role assignments
- ❒ Data Tables
- ❒ Inquiry Planning Sheets: one for each individual and one for the group question
- ❒ Copies of background research and references used
- ❒ Raw data (ex. actual Kaboom recordings or multimeter measurements)
- ❒ Daily progress reports that will contain your "journal evidence."

The	Poster Presentation		
	Getting There	Got It!	Wow!!
Organization and Appearance	• The presentation does not contain all key components in the checklist below. • The presentation is sloppy or illegible.	• The presentation contains checklist items, and they are all clearly labeled. • The presentation is neat in appearance. The text and most of the graphs and charts are typed or word processed.	• The presentation contains checklist items, and they are all clearly labeled. • The presentation is professional and interesting in appearance. All of the text and charts are computer generated and graphics or photos are used to enhance the presentation.
Procedure	• There is no description or an incomplete description of how and why the data were collected. • From the description it is not possible to understand the relevance of data to the question.	• There is a description of the experimental procedure and a list of the materials used. • From this description it is possible to see how the data is related to the inquiry question and how it might answer it.	• The description of the experimental procedure was a step-by-step account of what was don and why and what materials were used and where they came from. • From this description the experiment and its data could be reproduced by someone else.
Graphs and Charts	• Graphs or charts are missing or are incorrectly or incompletely labeled. • Graphs or charts do not represent data that is relevant to the inquiry question.	• At least one graph and one chart are presented and correctly labeled. • At least one graph or chart represents data that provides insight into the answer to the inquiry.	• Multiple graphs and charts are presented and all are correctly labeled. • All graphs or charts presented provide visual evidence of the answer to the inquiry.
Analysis (What you thought of your data and why)	• Analysis is missing or incorect. • Explanation or discussion of data show little evidence of logical reasoning. • Explanation of data doesn't correctly identify or use key concepts.	• Explanation of the data is made with logical rasoning and based on the correct understanding of key science concepts. • Explanation connects background research to data collected.	• Explanation of the data is made with logical reasoning and based on the correct understanding of key science concepts. • Explanation also addresses the limitations of the experiment and estimates the accuracy of the data collected (i.e., is able to give a + or - estimate of error on measurements made).
Conclusion	• The conclusion simply restates the data or analysis or says that they were "right" or "wrong" in their thinking.	• The conclusion answers the question and makes a statement about the significance or importance of the answer.	• The conclusion answers the question and makes a statement about how the answer generalizes to another phenomena or relates to an event outside of the classroom.

Presentation Checklist:

- ❒ Name of Inquiry
- ❒ Names of Group Members
- ❒ Inquiry Question
- ❒ Graphs and Tables of Data
- ❒ Description of Procedure
- ❒ Data Analysis
- ❒ List of References Used
- ❒ Conclusion

The Process — Group Work — The Inquiry Journal			
Management of the Cooperative Group	• Group members did not take responsibility for their assigned roles. Some group members were absent or otherwise failed to contribute to the group • The level of involvement and work load were not evenly distributed. One or two people in the group did all of the decision-making and work on the inquiry. *Journal evidence:* *:• There is no evidence of group planning. No written plan for what will be done next to make progress on the inquiry.* *• Group planning is vague and does not specify who will do what for the next inquiry meeting.*	• Each group member fulfilled his or her assigned role in the group. All group members contributed to the design of the experiment, collection, analysis and presentation of the inquiry data. *Journal evidence:* *• There is some evidence of group planning. There are written plans for what will be done next, but it is not clear who will be responsible for elements of the plan such as background research, material gathering (if you need something special not furnished in the classroom), etc.*	• Each group member took responsibility for his or her role in the group and involved the other group members in decision-making responsibilities and work to be accomplished associated with that role. (For ex. The presenter solicits input on what the poster should look like and assigns each group member to construct a piece of the poster presentation rather than constructing the entire poster alone. .• The workload was evenly distributed within the group. *Journal evidence:* *• There are written plans of what should be done next and who will do them. This list includes items such as background research, experimental design, collection of data, etc.* *• Each group member has a responsibility for the next inquiry meeting.*

The open inquiry rubrics have been a very useful tool for defining what we want students to experience and learn in the open inquiry process. The construction of these rubrics has forced us to describe what type of student work constitutes evidence of this experience and learning. Although the rubric will continue to be edited and refined, the many discussions among the collaborators have produced a rubric that adequately describes the evidence of student learning that we value in the open inquiry projects. We also have noted that as we more clearly articulated our expectations and what we value in the open inquiry projects to our students, the quality of the inquiry projects has steadily increased and more closely aligned with instructor expectations!

V. Evidence of Student Learning: What are Students Learning in the Course?

This is a big question, and it is one that can be answered by an infinite number of investigations. We have just started the process of evaluating the student experience and learning in Physics 100. Below are listed some evaluation questions we have begun to investigate and the data we have collected.

1. **To what extent have the inquiry based activities we designed enabled students to develop the ability to pose testable questions and design experiments to answer them?**

- We have collected students written questions and investigation plans at five points during one semester to chart the development of this ability (54 students).

2. **At what level of sophistication have cooperative groups generated meaningful conversations about science?**

- Audio tape recordings of open inquiry group discussions and student interviews have been collected for discourse analysis. Data collected over one semester for two groups (nine students).

3. **What are the students' perception of and attitudes towards the open inquiry experience?**

- Pre- and post-attitude surveys have been collected over three semesters for 240 students.
- Student self assessment data after the first inquiry project has been collected over two semesters (120 students).

The following discussion focuses on the first part of evaluation question 1:

To what extent have the inquiry-based activities in Physics 100 enabled students to develop the ability to pose testable scientific questions?

Introduction: What is the motivation for looking at students' ability to write testable questions?

Central to scientific inquiry is the concept of a question. The most useful questions in experimental science are testable questions also known in education literature as "operational questions"[9-11]. The ability to ask a testable question is the most crucial part of scientific inquiry[12] and a prerequisite to engaging in inquiry based learning. Being able to write a testable scientific question is a learning objective of the open inquiry instruction in Physics 100. To understand how experience with the open inquiry process and direct instruction affect students' ability to write a testable question, we conducted the following investigation.

Method:

To document students' ability to write testable questions throughout the semester we collected questions from each student at five points in the semester. These points were located before and after open inquiry projects and before and after direct instruction. There were two sections of Physics 100 and we collected five sets of questions from each section for a total of 247 questions. We then coded each student question as testable or not testable and examined the percentage of testable questions that were asked in each question set.

Procedure for collecting data:

Written questions and investigation plans from two Physics 100 sections (n=53 students) were gathered at five points during instruction in the spring 2000 semester. Questions were gathered using two methods. Three sets of questions were gathered using the Inquiry Project Planning Sheets and two sets of questions were collected using end-of-the-unit and final-exam questions. The following table compares and contrasts the two collection methods:

Method 1 Collection of student questions using Inquiry Project Planning sheets	Method 2 Collection of student questions using end-of-the-unit and final-exam questions
• Question was constrained to the general topic area being studied (waves and sound or electricity and magnetism or light and color) • Students were asked to write their question after two weeks of guided inquiry lessons on the general topic • Students were given four days to write their question. • Students wrote their question in the context of an investigation plan.	• Question was constrained to phenomena selected by instructor. (electromagnets or the interaction of light with plants) • Students were asked to write their question at the conclusion, four weeks, of the guided and open inquiry lessons on the general topic. • Students wrote their question as part of a one hour and 40 minute or two hour exam. • Students wrote their question in the context of an investigation plan.

Method 1, which uses the inquiry project planing sheets to collect student questions, is only used once in each topic area. Using this method more than once in a topic area would make it difficult to distinguish between an original student question and a question borrowed from a completed inquiry project since students will have observed multiple questions and completed inquiry projects in the topic area at the conclusion of that unit. For this reason Method 2 was used to collect additional questions and investigation plans from students. By constraining the questions to phenomena or topics not covered by completed student inquiries, in this case electromagnets and the interaction between light and plants, we could ensure the questions were conceived by the student and not borrowed from a previous inquiry.

A sample of the written materials used in Method 1 and Method 2 are shown below:

Method 1	Method 2
Inquiry Project Planning Sheet Name(s): Inquiry Question: What will you measure and what will you measure it with? What will you graph? List of things you will provide for the inquiry: List of classroom materials you would like to use. (You may use any materials you have seen in class provided they are returned at the end of the class period. If you need something special consult your instructor):	Final Exam Question Spring 2000 6. Light interacts with living things. In particular green plants need light to live and grow. (The process of turning light energy into carbohydrates that plants need to live and grow is called photosynthesis.) Materials are provided to help you think of a testable question about the interaction between light and plants. <u>Materials provided</u>* <u>Additional materials</u>: Lamp 2 light bulbs of different watts colored filters ruler green plant spectroscope *Note: you are not limited to the above list of materials. If your question or investigation requires additional materials please list and describe them above. a) Examine the materials and write one testable question about the interaction between light and green plants. b) Briefly describe your investigation plan. List variable(s) you will hold constant: List variable(s) you will change: List variable(s) you will measure: c) What will you measure and what will you measure it with? d) Illustrate a graph you might use to present your data. <u>Clearly label your graph axis</u>.

Experimental Treatments (Instruction) Affecting Students' Questions

We will examine the effect of open inquiry and direct instruction on students' ability to ask testable questions. The open inquiry process has been described in section III of this paper and the direct instruction on testable questions is described below:

Direct instruction on testable questions:

Although direct instruction on testable questions occurred over three class periods, the total class time spent on direct instruction was only about 20 minutes. Just before the third inquiry project planning sheet was to be completed, students were given 26 questions for homework (compiled from previous P100 inquiry planning worksheets) on electricity and magnetism and instructed to classify them as testable or not testable. They were also asked to identify common characteristics among the testable and non-testable questions. On the next day of class 20 minutes were spent discussing characteristics of testable and not testable questions. On the third day, a summary of that discussion in the form of the revised open inquiry question rubric shown below was handed out to students.

Getting There	Got It!	Wow!!
• The question is too general. It is not focused on a single concept, phenomena or observation. or • The question is too narrow. It can be answered by a quick test or by reading a reference book. or • The question does not have a possible answer that can be verified by an experiment or test. Most questions that begin with "why" cannot be answered with a test.	• The question is focused on a particular concept, phenomena or observation. • The question requires some investigation or experimentation. • An experiment with defined and controlled variables can be designed.	• The question requires investigation or experimentation where data can be collected. • Specific experimental variables are identified in the question.

Method of Determining the Testability of Students' Questions

The criteria and procedure for determining the testable or not testable classification of a student question was developed by Lynn, Patty, David Jelinek (CSUS Associate Professor of Science Education and NSF external project evaluator) and Professor Ron Tanaka (CSUS Professor of English).

Although questions had been collected in the context of planning inquiry investigation, the questions were coded out of context without reference to the proposed investigation plan. Lynn, Patty and David coded 73 student questions as testable and not testable according to the following criteria:

Testable and Not Testable Question Criteria

Testable: A question is testable if an experiment might be set up to answer the question.

Not Testable: A question is not testable if an experiment cannot be set up to answer the question.

Testable or Not Testable classification was *not* based on the following:

1. How narrow or broad the question was
2. How easy or difficult the implied experiment might be
3. How important or interesting the question was

Although questions were reported as either testable or not testable for this investigation the questions were also coded into the following subcategories for future analysis.

Testable Question Subcategories:

T as is = Question is testable as it is written. It explicitly identifies independent, dependent variables and criteria for measuring or evaluating the outcome of the implied experiment.

T reph = Question is testable. It may need to be rephrased for clarity or to explicitly state variables or measurement criteria.

T too narrow = question is testable and will add to a students' experiential base of knowledge but is too narrow or shallow to lead to or improve conceptual understanding. A quick experiment or observation will answer this question. It is too narrow to lead to an inquiry project.

T no mat = Question is testable, but materials or equipment is not available or practical in the context of a classroom.

T concept error = Question is testable but it assumes or is based on an incorrect conceptual understanding. This misconception can be clarified by an experiment.

Not Testable Question Subcategories:

NT why = Question is not testable because it asks "why" something happens or exists.

NT what is = question is not testable since some "what" questions cannot be answered by a test (i.e, what is an echo?). Asking what something is is asking for a description of a phenomena or an observation.

NT too general = Question is not testable because it is too general, it is not focused on a single phenomena or concept. It is unclear as to what the independent or dependent variables might be.
NT how = Question is not testable because it asks how something happens. Investigations are not usually done to answer "how" questions.
NT (mat) Question is not testable because materials do not exist anywhere to

NT concept error = question is not testable because it assumes or is based on an incorrect conceptual understanding that cannot be clarified by an experiment.
NT not question = what the student has written is not a question. For example a statement written with the intention of proving the statement with an experiment.

Of the 73 questions coded by Lynn, Patty and David there was agreement on the testability of all but one question suggesting a high interrater reliability among them. Fifty of the 73 questions were also coded by English Professor Ron Tanaka and his English 20 Critical Thinking Class. Interrater reliability was low between the English 20 group and Lynn, Patty, and David. This indicates that the criteria for testable and not testable questions is not definitively articulated. In applying the testability criteria the biggest problems we are aware of are:

- use of the criteria depends on the reader's ability or inability to envision the experimental setup required to answer the question
- the criteria do not address how much a reader might infer from a question that is unclear grammatically.

The only syntax pattern all the raters identified as important was beginning a question with the word "why." All raters concluded that questions that ask "why something is so" or "why something happens" cannot be answered by a test.

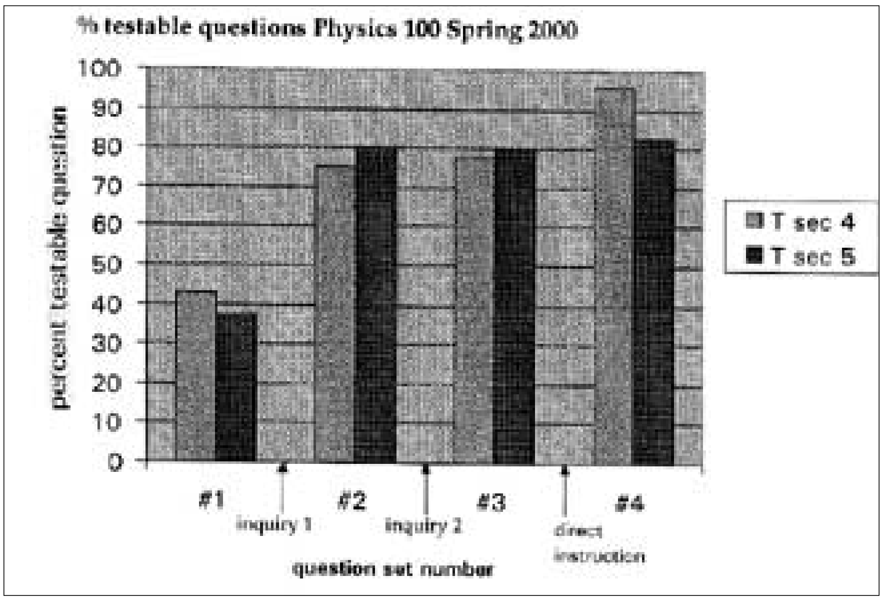
The Timeframe of Data Collection:

To understand the time frame of data collection and its relationship to instructional interventions, time is measured in units of class meeting days. Physics 100 had 31 class meeting days in the spring semester. (The course met twice a week for 15 weeks plus one day for the final exam.) The Inquiry Project Planning Sheet was used to collect questions on class days 5, 17 and 25. Written exams were used to collect questions on class days 22 and 31. Open inquiry projects were completed and presented on days 9, 21, 29 and 30. Direct instruction of how to write a testable question occurred over days 22, 23 and 24.

Below is a tabulated and graphed summary of the data collected:

Question Set	Method of Collection	Class Day #	Student experience at time of writing question	P100 Sec. #	Total # of questions collected	% of questions testable
1	1	5	No open inquiry experience	4	28	28
				5	24	24
2	1	17	1 open inquiry completed	4	24	24
				5	20	20
3	2	22	2 open inquiries completed	4	27	27
				5	25	25
4	1	25	2 open inquiries completed and direct instruction	4	23	23
				5	23	23
5	2	31	3 open inquiries completed and direct instruction	4	*	*
				5	*	*

*Data has just been collected and has not been analyzed



Preliminary Analysis:

Although the students had participated in four class periods of guided inquiry activities and were specifically instructed to write a testable question and plan an investigation to answer their question, less than 50% of the questions written were testable. After the first experience with open inquiry where students participated in the design, analysis, presentation and evaluation of a scientific investigation to answer a testable question, 75% of the questions written were testable. After a second experience with open inquiry there was a small increase in the percentage of testable question written, sec. 4 was 78% and sec 5 was 80%. We question whether this increase is statistically significant. After direct instruction on the characteristics of a testable question 96% of the questions asked by section 4 were testable (an increase of 18%). However only 83% of the questions asked by section 5 were testable (an increase of only 3%).

Tentative Conclusions

It appears that participating in guided inquiry lessons as we have defined them in Physics 100 does not enable most students to write a testable scientific question. Participation in group open inquiry project appears to improve some students' ability to write a testable question. Repeated participation in group inquiry projects without direct instruction does not appear to benefit students. Direct instruction as described in this study appears to improve the ability of some students, but may have little effect on others. Final data including question set 5 may provide more insight on our investigation.

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