

From Cookbook to Guidebook: Turning Demo Exercises Into Active Inquiries

A. Daniel (Dan) Johnson

Wake Forest University, Department of Biology, 1834 Wake Forest Rd, Rm. 226 ,Winston Hall,
Winston-Salem NC 27109 USA
(johnsoad@wfu.edu)

Active inquiry labs produce deeper, longer lasting learning for more students, but present design challenges. Unlike active lecture models, there are no published general design guidelines for active labs. Also, many STEM faculty do not have any direct personal experiences to guide their efforts. This workshop presented a “7 steps” general design model that has been used for over 10 years to create scalable active learning labs that serve more than 200 students per semester in multiple course sections. In Part 1 of the workshop, participants identified the primary barriers to development and implementation of active inquiry labs from the perspective of faculty and staff who implement and manage such projects. In Part 2, participants deconstructed a classic demonstration exercise, “Diffusion Through a Membrane,” and identified key points for revision. In Part 3, participants worked through key steps of a more active version of a diffusion exercise developed using the general design process. Participants were encouraged to adopt (and adapt) the new diffusion exercise immediately for their own courses.

Keywords: inquiry lab, diffusion, instructional design, assessment

Link to Supplemental Material: <http://www.ableweb.org/volumes/vol-39/Johnson/supplement.htm>

Introduction

In most settings, active inquiry will produce deeper, longer lasting learning gains than didactic and demonstration teaching methods. That said, there are significant implementation challenges.

1. **Lack of personal experience.** More seasoned faculty and even recent STEM graduates are more likely to have participated in “cookbook” labs. They have fewer direct experiences on which to call when trying to visualize an active lab’s design and flow.
2. **Mandated coverage.** A lab designer or instructor is not usually free to decide which concepts to focus on. Curriculum goals constrain what topics can be introduced in lab.
3. **Student resistance.** Students panic or revolt when asked to move out of their comfort zone. This can manifest in many ways, but most often shows up as lower course evaluation scores.
4. **Faculty and instructor resistance.** Active inquiry labs require different teaching skills and strategies than traditional labs. At least initially, faculty and graduate/staff instructors can feel less prepared or in control of labs than before.

5. **Lack of general design guidelines.** There are exceptional pre-existing active learning exercises, ranging from short in-class modules to semester-long project-oriented programs like Sea-Phage and Genomic Consortium for Active Teaching (GCAT). There also are many general design models aimed at reforming traditional lectures such as problem based learning (PBL), team-based learning (TBL), process-oriented guided inquiry learning (POGIL). Yet there are no general design models focusing specifically on creating active, inquiry-oriented labs.

We have been developing active, inquiry-oriented labs for more than 20 years at WFU. Based on our experiences and using general good instructional practice recommendations, we devised a “7 steps” general design model that we use as a starting point for assessing existing labs and developing new ones. Our general design model does not strictly adhere to one specific learning theory, so it adapts well to a range of topics and teaching situations. Other key benefits are:

- The same general process can be used both to review and update existing demo labs, and to design new lab activities.
- This method incorporates both initial assessment of prior student knowledge and multiple low-stakes formative assessments as central design elements.
- It reinforces the iterative nature of science by having student go through two cycles of exploration and reporting.
- Reusable guide questions provide a thinking scaffold that leads students to well-defined learning goals without squelching creative thinking.
- The overall structure trains novice undergraduate or graduate teaching assistants to be learning coaches, rather than training them to teach using lecture.

In Part 1 of the workshop, participants identified barriers to development and implementation of active inquiry labs from the perspective of faculty and staff who implement and manage such projects. In Part 2 of this

workshop, participants deconstructed a classic cookbook exercise, “Diffusion Through a Membrane,” and identified key points for revision. In Part 3, participants saw one possible version of a more active exercise on diffusion that was designed and developed using this 7-steps process model. In addition to the design process model, the new diffusion exercise is provided. The exercise can be adopted (and adapted) for use as a standalone active lab module, or used as a general instructor training activity.

The exercise presented here is not a lab we run ourselves. It was developed specifically as an example to show that even a very traditional demonstration lab exercise can be made into an active inquiry experience. Three examples of multi-week lab activities in our current lab program that use this design strategy are:

- Inter-species competition and population growth of common molds.
- Remote sensing using camera trap data from the Serengeti.
- Factors that control transpiration in bean seedlings and annual pansies.

Student Outline

Background

What Do You Know Already?

To begin lab this week, think about these 3 questions for a minute, then write down your responses in your notebook. (Hint: we'll be doing this for most labs this semester.)

1. What do you know about diffusion?
2. How do you know it?
3. Read the two situations described below. Are they examples of diffusion, or not? What is your evidence or reasoning?

Scenario 1: Your friend accidentally writes on the whiteboard with a permanent marker, but wipes it off immediately with alcohol, leaving no mark. The next day, your instructor also writes on the whiteboard with the same permanent marker, but leaves it over Spring Break. When everyone returns after a week, your instructor tries to wash off the writing with alcohol, but this time a gray outline of the writing remains on the whiteboard.

Scenario 2: Your instructor goes to the back corner of the lecture hall, unwraps a rotting onion, and puts it on the floor. They walk to the front of the room, and tell everyone to raise their hands when they FIRST smell the onion. Ten seconds later, the student sitting next to the onion raises her hand. More hands go up after a couple minutes. At 5 minutes, the young man sitting in the seat in the opposite corner of the lecture hall raises his hand.

Once you have answered for yourself, pair up with the other students at your table and discuss how you would answer them. If your thinking changes, do not go back and change your original responses; make notes about what changed, and why.

What Does the Whole Class Think?

1. Next your instructor will bring the class together to talk about these questions. Choose someone to be spokesman for your table.
2. When the group discussion is finished, look at your thoughts from earlier. Has your thinking changed any? If so, how? Remember, make NEW notes; do not go back and change your original responses.

Exercises

This week in lab, you must devise a way to demonstrate the process of diffusion through a membrane. Next week you will be exploring what factors affect the rate of diffusion.

Examples of materials available to you are listed in Table 1. This is not necessarily everything available, just materials that we try to keep on hand routinely. Your instructor may add some items, while others might not be available. Think too about other common things you could find in places like a discount store, home improvement store, or local grocery. If there is something you want to test that is not in the list, ask your instructor whether they could get it. Or better still, bring it in yourself.

Week 1: How Will You Demonstrate Diffusion Through a Membrane?

Planning Questions

Answer these questions in your notebook BEFORE starting to build or test anything.

1. What materials are you using?
2. How are you doing your demonstration?
3. Why are you doing it that way?
4. What are you measuring? How?
5. What do you expect to see? Why?

Running Your Demonstration

Once your lab instructor approves your demonstration plan, build and execute it. When you are done, summarize your results using the questions in the next section.

Summarize & Share Your Results

As before, answer these questions in your lab notebook.

1. What did you see? Did it match what you predicted?
2. What do your results mean? If you do not know, what do you THINK they mean?
3. Why do you think this IS or is NOT a good demonstration of the process of diffusion?
4. How could you revise this demonstration of diffusion to make it better?
5. What are 1-2 questions about diffusion that your demonstration doesn't answer?
6. AFTER you have answered Questions 1-5, pair up with your lab partners and decide how you will explain your demonstration and results to the rest of the class. Your lab instructor may want you to explain your results:
 - As a picture or image
 - In a written summary
 - As a presentation to the class.

How will you do it? What do they need to know?

TABLE 1. Materials for Your Demonstration & Experiment.

Potentially “Diffusible” Colored or Reactive Materials

- White latex primer (4-6 ounces is plenty)
- Poster paint (smallest containers available are sufficient)
- Chocolate milk (1, 8-oz. carton)
- Plain milk (1, 8-oz. carton)
- Food coloring (box of 4 colors in dropper bottles)
- Instant coffee (small jar)
- Red wine (sample bottle)
- Pond dye (or, solution of 0.1% bromophenol blue)
- Cider vinegar
- Baking soda

Liquid and Solid Carriers for Diffusing Materials

- Carboy of water
- Vegetable oil (1, 16-24 oz. bottle)
- Marshmallows (regular size, 1 bag)
- Scraps of balsa wood
- Scraps of Styrofoam
- 1-2 apples or bananas

Possible Materials for Your Membrane

- Saran wrap (small roll; generic is fine)
- Sandwich bags
- Latex, nitrile gloves
- Newspapers (from recycling bin is fine)
- Baking parchment paper
- Paper towels
- Coffee filters
- House wrap
- Parafilm
- Gauze pads

Containers and Miscellaneous Supplies

- Hard plastic beakers (glass is fine if plastic is not available)
- Plastic disposable bowls (for holding wet materials)
- Canning jars (pint) with lid rings (if available; not critical)
- Rubber bands of different sizes
- Strong string or dental floss
- Duct tape, masking tape, clear tape
- Centimeter rules (2-3)
- Permanent markers

Week 2: What Affects Rate of Diffusion Through a Membrane?

You already learned some things about diffusion last week. This week our goal is to start organizing our general understanding of diffusion more systematically. To begin lab this week, think about these questions for a minute, then write down your responses in your notebook.

What Do You Know Already?

1. What might make diffusion occur faster?
2. What might slow down the rate of diffusion?
3. How could you test those predictions or assumptions?

Once you have answered for yourself, pair up with the other students at your table and discuss how you would answer them. If your thinking changes, do not go back and change your original responses; make notes about what changed, and why.

This time, we are going to wait until everyone has conducted their own tests to share ideas.

Planning Questions

Answer these questions in your notebook BEFORE starting to build or test anything.

1. What materials are you using?
2. How are you doing your experiment?
3. Why are you doing it that way?
4. What are you measuring? How?
5. What do you expect to see? Why?

Running Your Demonstration or Trials

Once your lab instructor approves your plan, build and execute it, then move on to summarize your results.

Summarize & Share Your Results

As before, answer these questions in your lab notebook.

1. What did you see? Did it match what you predicted?
2. What does it mean?
3. Why do you think this IS/is NOT a good experiment for determining what affects the rate of diffusion?
4. How could you revise this follow-up experiment to make it better?
5. What are 1-2 questions about diffusion that your experiment doesn't answer?
6. AFTER you have answered Questions 1-5, get with your lab partners and decide how you will explain your demonstration and results to the rest of the class. Your lab instructor may want you to explain your results:
 - o As a picture or image
 - o In a written summary
 - o As a presentation to the class.

How will you do it? What do they need to know?

Connect Your Results with the Class Observations

Answer these questions in your notebook AFTER seeing or hearing what other class groups learned about diffusion.

1. Did another group see results that confirm your conclusions? Did anyone have results that contradicted your conclusions? Explain.
2. Did another group's results answer any of your unanswered questions?
3. Are there any changes you would make to YOUR experiment given what you have learned from other groups? What changes and why?
4. Can you make a more general statement now about what affects the rate of diffusion? How would you answer that question now?

Materials

The list of materials is in Table 1 in the Student Outline. This list is an example only. The materials list is extremely flexible; what is important is having a variety of materials in each of the main categories, and to use materials students are more familiar with, or see in daily life.

Students should have a bound paper or electronic notebook for collecting initial thoughts, documenting their experimental designs, and recording data.

Notes for the Instructor

While active, inquiry-oriented lab instruction seems to be everywhere, many lab programs still rely heavily on demonstration activities. An informal survey of the two workshop groups (n~45) found 3 out of 4 of participants still use demonstration (cookbook) exercises for more than 50% of their lab course activities. Less than 40% reported that they used exercises that extended 2 weeks or longer.

The 2-week exercise sequence provided in the Student Outline was designed using the Seven Steps General Design Model outlined in the next sections. It is both a working lab activity, and a “proof of concept” to show how even very traditional demonstrations can be re-imagined as more active inquiry-oriented experiences. The same general design model works equally well for building new activities.

The general design model combines three distinct types of inquiry (defined in Banchi and Bell, 2008). In the **structured inquiry phase**, the facilitator poses an initial question and provides an outline of a procedure, then asks students to formulate explanations of their results and analyze the data they collect. Structured inquiry is particularly useful for training students to collect data using unfamiliar tools, instruments, or analyses. In the **guided inquiry phase**, the facilitator provides a general research question or goal. Students must design then implement their own procedures to test a question or contribute to a solution, and communicate their results and findings. For design purposes, we subdivided guided inquiry further. **Pilot or exploratory inquiry** is an initial activity that lays the necessary groundwork for more extensive (and informative) guided inquiry. In practice, there is no hard, bright distinction between exploratory/ pilot and guided inquiry; the terms are relative positions on a continuum.

A General Design Model for Active Inquiry-Oriented Labs

Pre-Design Questions

These questions are a standardized way to collect data on existing lab units, and assess their potential for successful revision. They also provide lab designers with standardized criteria for monitoring activities under development. It is extremely easy to drift away from inquiry and build an overly scripted lab experience. Revisiting these questions several times during project development helps keep it on an inquiry-oriented track.

The 7 Steps General Design Model

Using data from the pre-design questions as a starting point, each lab unit is organized around this general framework. The full 7 steps model is ideal for lab activities spanning three weeks or longer but can be difficult to execute in one to two week units. For shorter lab units, the full seven steps protocol can be shortened to a “5 of 7” steps format for designing 1-2 week lab units. The full seven steps protocol is listed below. Following it are two different versions of “5 of 7” protocols. To make comparison easier, the two omitted steps were struck out rather than deleted.

The instructions for the diffusion exercise in the Student Handout section are an example of a “5 of 7” two-week lab. How each activity maps to a specific step in the model is indicated. Anyone wishing to compare the revised, active, version of the diffusion lab exercises to a traditional demonstration version can find the classic exercise in Appendix B.

Full Seven Steps Model

1. **Initial assessment.** Goals are:
 - Activate, uncover students’ prior knowledge
 - Align instructor expectations with students’ current knowledge level
2. **Structured inquiry** or training activity. Goals:
 - Developing key skills for guided phase
3. Reconvene and **debrief**
 - This is the first low stakes assessment
 - Also is first point where instructor can make corrections to student process skills
4. **Open exploration** phase. Goals are:
 - Students practice using their new process skills independently
 - Establish baseline data students can build upon during a subsequent guided inquiry
5. **Initial reporting**
 - A scripted low stakes assessment
 - Second point for corrections, by instructor and peers BOTH

6. **Guided inquiry phase**
 - Difficulty of the question and degree of freedom students have should be tailored to group's skill level.
 - Final activity is higher stakes; students must learn from and correct past errors.
7. **Final reporting**
 - This can be either as a group or individually, but ideally will have both.
 - Group reporting lets students learn from each other as a collaborative group, or attack similar questions with different approaches.
 - Concurrent individual reporting ensures individuals are still accountable, which reduces social loafing (students doing less than their share of the work, assuming the group will complete the work for them).
 - Ideally, final reporting reiterates questions asked in earlier steps. Students quickly learn low-stakes evaluations are directly relevant to final high-stakes evaluation.

Five of Seven Steps Version A

The author's department uses this version of the design model to build one-week standalone lab units to place between longer units that still reflect the central goals and principles of the overall approach to lab design.

1. Initial assessment
2. Structured inquiry or training
3. Initial reporting
4. Guided inquiry
5. Final Reporting

Five of Seven Steps Version B

The updated diffusion activity described in the Student Outline follows this version of the general design model. Table 2 below maps the elements of the student activity onto the general design model. The author knows several instructors who use a similar strategy for their project-based learning labs, where students must develop their own lab methods rather than rely on pre-developed assays or model systems.

1. Initial assessment
 - Corresponds to Week 1: What Do You Know Already About Diffusion?
2. Open exploration phase
 - Corresponds to Week 1: How Will You Demonstrate Diffusion?
3. Initial reporting
 - Corresponds to Week 1: Summarize and Share Your Results.
4. Guided inquiry
 - Corresponds to Week 2: What Affects Rate of Diffusion Through a Membrane?

5. Final Reporting
 - Corresponds to Week 2: Summarize and Share Your Results, AND Connect Your Results With Class Observations.

Suggestions for Specific Steps

Designing Assessment Guide Questions (Step 1)

The author tries to use some variation of the same three questions as part of each unit. Students soon learn to expect these questions, and receive positive reinforcement when they are prepared and so can respond successfully:

1. What do you know about (phenomenon being studied)?
2. How do you know it?
3. Is (example) an example of (phenomenon of study)? What about (counter-example)? What is your evidence or rationale?

The first questions helps students orient their thinking generally towards the topic, and surfaces current knowledge and misconceptions. Student responses can be very revealing; often instructors assume students know considerably more than students can demonstrate. The second question requires students to go beyond their "received knowledge" and express concepts based on evidence. If students cannot do so, that is a skills gap the instructor needs to be aware of and help students overcome. The third question probes students' understanding of the boundaries of specific concepts, and ability to apply their prior knowledge.

The specific questions are less important than asking similar questions for each topic. The author uses these questions because they address a routine skills gap in his student population (knowledge transfer). Other lab developers should find starting questions that are appropriate to their local students and can be reused routinely. For more on question design, see the review by Tofade (2013) and references therein, or the excellent guide "Asking Better Questions" by McComas and Rossier at (https://uwaterloo.ca/centre-for-teaching-excellence/sites/ca.centre-for-teaching-excellence/files/uploads/files/asking_better_questions.pdf).

TABLE 2. Mapping the Diffusion Lab to the 7 Steps General Design Model.

Step	Student Activities or Components of Lab Unit
1. Initial Assessment	<ul style="list-style-type: none"> • Lab notebook pre-writing activity with 3 prompts: “<i>What do you know about diffusion?</i>” etc. • Instructor’s debrief of the class as a group.
2. Structured inquiry phase	The revised diffusion activity described in the Student Outline does not include a structured inquiry, because students will be familiar with the materials they are using. This step should always be present anytime students must learn to use unfamiliar equipment (physiological recorders, for example) or methods.
3. Reconvene and debrief	
4. Open exploration phase	Week 1 Exercise: students must demonstrate diffusion through a membrane using commonly occurring materials.
5. Initial reporting	<ul style="list-style-type: none"> • Week 1 Notebook: planning questions, summary questions. • Sharing results with class at end of Week 1.
6. Guided inquiry phase	Week 2 Exercise: students identify factors that affect the rate of diffusion.
7. Final reporting	<ul style="list-style-type: none"> • Week 2 Notebook: planning questions, summary questions. • Summary presentation. • Follow-up questions connecting observations between groups.

Debriefs and Group Reporting (Steps 3 and 5)

Debriefing and group reporting are low-stakes opportunities for students to learn and practice critical thinking skills. The questions students answer during debriefs and reporting should scaffold the desired skills. Ideally, students should be told in advance what skills they will need to demonstrate, and be given examples of the types of questions they should expect. Alternatively, establish a set of general questions that students can expect routinely.

When debriefing the structured inquiry at Step 3, ask questions that focus on key steps in data collection, analysis, and interpretation. Ask students to:

1. Predict which points in the system they just learned are most likely to break or fail.
2. Identify and rank potential points for data collection errors.

The author favors these five questions for debriefing the initial exploration at Step 5, because they are almost universally applicable to any topic.

1. What did you do?
2. Why did you do it?
3. What did you predict you would see?
4. What did you actually see?
5. What does it mean?

When debriefing students at both Steps 3 and 5, try to ask 1-2 topic specific questions that connect the central topic of the module and the upcoming exploration (Step 4) or guided inquiry (Step 6.) Using the student exercise on diffusion as an example, debriefing questions in Step 5 that connect to Step 6 could include:

1. What did you learn about diffusion that you did not know before?
2. Based on the demos & data presented today, is rate of diffusion constant?
3. What is one factor that might affect the rate of diffusion?
4. Which factors do you think affects the rate of diffusion most?

Question 1 prompts reflection on new insights gained in the debrief that could be explored in the next stage. Questions 2-4 above are leading students to think about factors that alter rates of diffusion. This sets them up to explore these variables more systematically during the guided inquiry in Step 6.

Final Individual or Group Reporting (Step 7)

The format for final reporting will depend on the curricular goals of the lab program overall. For example, an explicit curricular goal of the author's lab program is to develop students' written technical communication skills. Given this goal, students write individual lab reports (in the form of a scientific article) at the end of each lab module. Other possible reporting activities are:

- Extended lab notebook entries.
- Group reports (written in collaboration with other group members)
- Oral presentations (may be delivered either live/in class or pre-recorded)
- Video posters (photos or slides with an edited narrative added)
- Electronic or printed posters
- Shared electronic concept maps or ontologies.

Common Mistakes When Designing Inquiry Assessments

1. *Scripting questions, assessments so they focus on specific outcomes, not process.* As a general guide, use more open-ended questions that require higher order thinking skills (synthesis, analysis, evaluation.) Use questions that require explanation (divergent questions) rather than questions with fixed answers (convergent questions.)
2. *Trying to eliminate all points of confusion and missteps.* Some struggle and confusion are necessary for deeper learning (Brown, 2014.) Focus instead on providing opportunities to uncover and resolve confusion earlier as part of the initial assessments. Make sure students understand that early confusion is expected, and that with practice and effort they can overcome it.
3. *Moving too fast.* It is tempting to move on when students say, "I understand this concept." Many students have significant gaps between their perceived and actual understanding of key biological concepts. The best way to surface these gaps (and help students learn to uncover their own) is to ask questions that uncover the gaps as part of the formative assessment. Uncovering knowledge gaps during final assessment for grades just erodes a student's confidence in their learning ability.

4. *Over-reacting to complaints and pushback.* Students are accustomed to having clear answers, and often struggle more until they get accustomed to the new format and expectations. Avoid making judgments based on student evaluations only, or on complaints from a minority. Instead look at the formative and final assessment data; are students' process skills improving over time for the entire cohort?

Other Questions From Workshop Participants

1. *How can we cover all the content?*
A perennial criticism of active inquiry is that it takes too long, and content coverage suffers. Yes, breadth of coverage is reduced, but expanding coverage with multiple unrelated lab activities is not helping students if they immediately forget it after the test, or cannot use and transfer their knowledge and skills to new situations. Students' retention time and skills transfer are dramatically improved by slowing down and giving students time to engage deeply with a smaller set of concepts.
2. *Won't students be confused without clear instructions?*

To some extent yes, which is the point. Inquiry instruction does not eliminate confusion, but rather makes it an explicit and acceptable part of the learning cycle. Overcoming initial confusion and correcting previous thinking errors provide positive challenges that deepen student learning.

3. *As the teacher, how will I know what to do? How do I manage the class?*

Facilitating an active inquiry lab unit requires a very different approach from traditional demonstration labs, where class management is largely about ensuring everyone stays on task and gets to the same end point. Class flow in an active, inquiry-oriented lab is less predictable. Lab sessions can be chaotic and loud, with the instructor's attention pulled in multiple directions. Instructors must be ready to adapt quickly to an evolving class experience.

On the positive side, active inquiry is much more fault-tolerant. Student interactions focus on cognitive coaching, not content delivery. Occasional mistakes or gaps in the instructor's content knowledge can be turned into learning experiences for students.

4. *How do I know I'm doing it right?*
If no students are complaining, you probably are doing it wrong. Do not be surprised when some students say on course evaluation that they do not like inquiry labs. Active inquiry inevitably makes some students uncomfortable, at

least initially. In the author's experience, positive feedback come later, once students have more opportunities to apply their new thinking skills and see how their earlier experiences helped them grow as learners.

After a few cycles, most inquiry-oriented instructors get a sense of what is normal pushback for their students. We regularly see 10-15% of students in first year labs rating at least one inquiry unit or activity poorly. Monitoring is easier once one or two routinely popular inquiry activities are embedded in the lab sequence. Ratings of the popular labs provide a baseline for comparison for new lab experiences, and are a way to normalize variation between semesters

There **are** some legitimate warning signs that should not be ignored but investigated.

- A sharp or widespread decline in student performance in a later unit in the semester.
- Students lose skills they demonstrated in a previous unit, especially if more than one instructor sees it around the same time.
- Declining participation by previously engaged students.
- Significantly fewer emails or in-person requests to clarify the exploration or guided inquiry steps.

Cited References

Banchi H, Bell R. 2008. The Many Levels of Inquiry. *Science and Children*, 46(2): 26-29.

Bell T, Urhahne D, Schanze S, Ploetzner R. 2010. Collaborative inquiry learning: Models, tools, and challenges. *Intl. J. Science Educ.* 3 (1): 349–377.

Brown PC, Roediger III HL, McDaniel MA. 2014. *Make it stick: the science of successful learning*. Cambridge, MA. Belknap Press. 313pp.

Tofade T, Elsner J, Haines ST. 2013. Best practice strategies for effective use of questions as a teaching tool. *Am J Pharm Educ.* 77(7):155

Acknowledgments

Many thanks go out to the undergraduate students, graduate teaching assistants, and faculty colleagues from WFU Biology for their innumerable suggestions and field testing of the model and tools presented here.

About the Authors

A. Daniel (Dan) Johnson is a Teaching Professor and the Core Curriculum Coordinator in Biology at Wake Forest University in Winston-Salem, NC. Since 1998 he has been developing inquiry lab activities and lab support resources across the range of biology. He also is the founder and director of The Adapa Project, an informal consortium of educators, educational researchers, students, and developers bringing best practices to the classroom that help more students learn science successfully.

Appendix A. Barriers to Active Inquiry Labs

One of the goals of this workshop was to identify major barriers to adopting active inquiry labs. Participants were asked to focus on barriers relevant to managing faculty and staff and instructors, not larger institutional curriculum or administrative barriers.

Participants brainstormed in groups of 3-5 to develop a list of personal barriers to adoption, then compiled a master list for their workshop session. Initial working lists created during the two workshop sessions were merged, yielding 5 general themes and 30 specific issues. The general themes are for convenience; most barrier issues could fit in more than one category. Of 30 issues identified, 16 were categorized as specific examples of larger issues, and placed under their larger inclusive issue as appropriate. Results are in Table A1.

TABLE A1. Compiled List of Participants' Barriers to Implementing Active Inquiry Labs

Themes	Issues
1. Initial development and implementation barriers	<ul style="list-style-type: none"> • Converting to active inquiry requires a large up-front time commitment. (<i>See Note 1</i>) <ul style="list-style-type: none"> ○ The range of topics available for active learning is limited. ○ Manuals are not available for active learning labs. • Do the instructors and lab managers know enough to do this effectively? (<i>See Note 2</i>) <ul style="list-style-type: none"> ○ Lab instructors need extra training to be able to conduct labs. ○ Many instructors never experienced active, inquiry-oriented teaching labs as students. They lack personal experience to guide them. ○ There is no scaffold or set of design guidelines for building active lab modules. (<i>Providing scalable design guidelines was a primary goal of this workshop.</i>) ○ Instructors who trained narrowly in one field may not have sufficient content knowledge to develop activities outside their own area of expertise.
2. Student, lab instructor, and faculty mindset and attitudes	<ul style="list-style-type: none"> • Time, anxiety management, both for students and for faculty, TAs, and staff. • Getting buy-in from lab instructors (be they faculty or TAs) and students (<i>See Note 3</i>) <ul style="list-style-type: none"> ○ Danger that faculty will reject active instruction as "not rigorous enough." ○ Student discomfort. They want to know the RIGHT answer, and are scared by anything that is not clear-cut. ○ Students will avoid thinking deeply if possible.
3. Student skills and knowledge	<ul style="list-style-type: none"> • Consistency between groups within a section. (<i>See Note 2</i>) • How much prior background, experience students have in experimental design. <ul style="list-style-type: none"> ○ Differences in ability to design experiments. ○ Level of thinking process skills varies between students.
4. Curriculum, pedagogical, and instructional issues	<ul style="list-style-type: none"> • How to align lab activities with course learning outcomes. <ul style="list-style-type: none"> ○ Coverage breadth vs depth. Active learning just takes too long. ○ How to connect to other goals, like writing skills development. ○ How to conduct formative, summative assessments. • How to guide students to an answer, not just tell them. • Setting reasonable boundaries on student experiments. <ul style="list-style-type: none"> ○ Managing different outcomes in one lab section. ○ Loss of control on the lab's outcomes. ○ Ensuring fair, accurate grading between course sections.
5. Lab Logistics and management (<i>See Note 4</i>)	<ul style="list-style-type: none"> • How to provide sufficient staff support for initial setup and in-class activities. • Managing supplies and resource; providing appropriate materials in a timely manner. • Storing materials for multi-week labs when lab room has more than one course. • Opening up labs for students to work after hours.

Follow-Up Notes, Comments on Selected Barrier Issues

Note 1: Development Time

Converting a lab program to active inquiry is stressful for staff and developers both; this is unavoidable, but also normal. What derails many new users is thinking their initial uncertainty will never end. The author's experience is that every new inquiry implementation goes through a shake-down period during the first 3-5 implementation cycles (semesters, quarters, or local equivalent). Major learning goals and logistical issues show themselves almost immediately (hence the uncertainty of the first iteration), but usually are resolved in the first 1-2 cycles. Remaining management and operational challenges usually settle out shortly thereafter. Failing to achieve the central learning goals or continuing to encounter major logistics problems after 4 cycles suggests: 1) the learning goals and activities are not well aligned; 2) instructors are not implementing the activities as designed; or 3) the exercise is beyond that student population's abilities, and may need revision.

Updating an entire course all at once is more stressful than a phased transition. The strategy we are using during our current lab curriculum transition at WFU is to design and implement new course grading and instructor management practices FIRST, and testing them in the context of our existing lab activities. Once the new management strategy is settled we will begin replacing current lab units with new modules. This approach lets us see management challenges against a background of labs we know well already.

One of the overlooked advantages of active inquiry labs is that multi-week activities use similar materials each week. This reduces development time and costs considerably. It also is a common misconception that every active learning module is unique. One of the primary goals for this workshop was to give instructors a standardized scaffold that could be repurposed easily for many topics. Also, as the 7-steps model shows, active inquiry modules reuse many of the same basic elements. Each new module requires less development time, because some reusable elements already have been created.

Note 2: Training Requirements

Developing and teaching active inquiry labs requires the instructor (and instructional designer if they are not the same individual) think about labs differently.

1. Content mastery is not a major goal; process skills development is the most important end point. The primary goals of active inquiry exercises are to prime students for learning, coach them through a scaffolded learning process, and provide frequent guidance and feedback on their progress towards well-defined goals.
2. This is not to say content is unimportant; rather, focusing on process skills first means students learn less content, but learn it more deeply and retain it longer with fewer misconceptions.
3. Students should spend most of their time and energy DOING science, not seeing it second-hand. As much as possible, students should be engaging in authentic processes of science (that is, how we operate as professionals.) The concept of "authentic activities" can be difficult to understand at first. One strategy is to imagine a student entering a mentored research lab experience. How will that student learn which questions are important? What techniques and thinking skills will they need? Which of these are critical, and which can wait for later? How will lab members train the student, and develop those skills? What benchmarks indicate the student has mastered those skills? The training and enculturation processes used in research labs are all examples of authentic activities. The goal is to bring as many of them as possible into the teaching lab.

These points need to be made explicitly clear to all instructors. Ideally, they will be included as part of new instructor orientation, and reiterated regularly.

Note 3: Resistance and Buy-In

Instructors who are new to active inquiry labs may be surprised by how many more complaints they receive from students. Several more experienced users in the workshops shared useful insights that can help novices understand the source of student resistance. It is no secret that students get to college primarily through memorization and recall. This is what students think learning is, it is what they expect, and what they know how to manage. Active inquiry overturns that familiar pattern, stressing critical thinking, valuing process rather than content knowledge, and allowing ambiguity in some areas but not others. Students are uncomfortable (if not overtly scared or hostile) because they are unsure of their ability to succeed anymore. This is one reason why formative assessment is so important; it provides students with early, frequent feedback during this crucial transitional stage in their development as learners.

When planning a new active inquiry implementation, it is a good idea to forewarn faculty, departmental evaluators, and divisional administrators to expect more complaints than usual. Providing data from formative assessments that show greater student learning gains goes a long way towards defusing faculty and administrative objections.

Note 4: Logistical Barriers

Providing appropriate materials in a timely manner is a legitimate concern when using active inquiry. Lab managers were quick to point out that they may have no idea what needs to be prepared until the last minute, and that they cannot set boundaries on student experiments. While this is possible, in practice we find students tend to ask the same questions over and over. This does not mean students are not thinking creatively, only that they have a smaller body of prior knowledge to call upon as they design experiments. Certain items get used repeatedly in multiple courses or exercises, so we keep them on hand routinely. Which specific items need to be on hand will depend on the particular exercises and student population, but we usually can predict what students will want to use within a semester or two.

We limit the scope of student experiments three ways. First, students have a defined time period in which to conduct their experiments, which limits their options. Second, we provide a list of routinely available materials; many students will not plan experiments that go beyond that list. Third, we require students to submit a formal experimental design plan outlining their rationale, a list of materials (with quantities) and how they plan to analyze the results. Students submit design plans online a week in advance, which gives lab staff time to prepare or obtain materials that are not already on hand.

Appendix B

Evaluating an Existing Lab Exercise

“Diffusion Through a Membrane” is a classic demonstration activity still used in many introductory biology labs. There are several versions, but the basic structure is the same in most sources. Workshop participants were given a copy of exercise (shown below) and a set of seven questions, then asked to evaluate the classical diffusion exercise in a think-pair-share discussion.

Analyzing a Classic Demonstration Exercise: “Diffusion Through a Membrane”

Basic Procedure

1. Fill a dialysis tubing “cell” with a solution of glucose + starch.
2. Tie the “cell” closed.
3. Float the “cell” in a small beaker of water.
4. At time zero and again after 20 minutes, solutions inside, outside of “cell” are tested using Lugol’s solution (turns blue-black in presence of starch), and either Benedict’s solution or a dipstick test (both indicate presence of glucose.)
5. Students should see and record these observations on a worksheet or in a notebook:
 - a. Solution inside “cell” turns black when Lugol’s solution is added (starch “+”), both at time zero, and at 20 minutes.
 - b. Water outside “cell” tests “+” w/glucose indicator (Benedict’s solution or equivalent) at 20 minutes but not at time zero.
 - c. The conclusion: glucose diffused out, but starch did not.

Seven Questions for Evaluating Active Inquiry in an Existing Exercise

1. What authentic processes, activities are students engaged in? Which activities from this exercise will working investigators or professionals use?
2. Where is the autonomous exploration? What unknown outcome or result can student work towards uncovering? (Note: “unknown” is relative; an outcome that the instructor can predict from prior knowledge alone can be entirely new to the student.)
3. Is there a positive challenge? Do students encounter a problem that they cannot solve initially, but do solve ultimately?
4. What skills are students developing? How do they demonstrate proficiency?
5. What, where is the formative assessment? Summative assessment
6. Are the reporting activities memorable, valuable, and/or building useful skills?
7. What are the logistics issues, local needs that must be considered?

Summary of Discussion of Diffusion Exercise

Several workshop participants pointed out that the classic lab demonstration develops pipetting, and data collecting and recording skills. It also requires students to make inferences from indirect observations. Overall though, both groups were unenthusiastic about the classical version of the diffusion exercise. The consensus was that:

- It lacks any positive challenge; students are reporting expected, predictable outcomes.
- It does not provide an opportunity to explore autonomously. Students have very limited opportunity to gain personally novel insights into diffusion, or synthesize elements of individual knowledge into a larger story.
- The reporting process is easy to do, but not very memorable. Each report is independent of the observations of others.
- Assessment is almost entirely at the end of the activity. There is no formative evaluation.
- Specific logistical concerns included:
 - Dialysis tubing is not something students are familiar with. It is hard to handle, easily contaminated, and tears or leaks. Also, its properties are fixed and not easily changed.
 - Benedict’s solution can be unstable and degrade during storage.
 - Lugol’s solution is hazardous waste.

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 teaching biology 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: Peer-Reviewed 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

Johnson, AD. 2018. From Cookbook To Guidebook: Turning Demo Exercises Into Active Inquiries. Article 10 In: McMahon K, editor. *Tested studies for laboratory teaching*. Volume 39. Proceedings of the 39th Conference of the Association for Biology Laboratory Education (ABLE). <http://www.ableweb.org/volumes/vol-39/?art=10>

Compilation © 2018 by the Association for Biology Laboratory Education, ISBN 1-890444-17-0. 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.