4

G I

The Guided Inquiry

Regina (Gina) F. Frey and Susan E. Shadle

Listen to your students. They need to have a chance to explain so be present and be comfortable in the silence as they struggle with an explanation.

—A POGIL practitioner of 10 years

As described in chapter 1, the POGIL pedagogy is an integrated combination of intentionally designed guided-inquiry activities and a focus on process skills involving the active engagement of student teams that are facilitated by an instructor. POGIL activities are structured according to the learning cycle (described in Chapter 1). The activities of a POGIL classroom frame the thinking that students will do during class. The effective implementation of guided inquiry requires the active engagement of students in constructing ideas and mastering material (Bodner, 1986; Driver, Asoko, Leach, Scott, & Mortimer, 1994). Because this approach is different from the kind of classroom that most teachers experienced as students, many do not have good models for what it might look like. For this reason, it is important to frame POGIL pedagogy by exploring how guided inquiry is situated in the larger context of active learning strategies and how the pedagogical approaches fall into the category of inquiry-based learning. This chapter provides a review of active learning and its value for supporting student learning in the classroom, with a special focus on cooperative learning that is relevant to the POGIL classroom. The implementation of the learning-cycle–based guided inquiry of POGIL, described in chapter 1, will then be situated in the larger context of the various forms of inquiry-based learning. Last, while this chapter focuses on the guided-inquiry component of the POGIL pedagogy, it is important to recognize that in the classroom implementation of POGIL, the guided-inquiry and process components are highly integrated.

What Is Active Learning?

There are many definitions for *active learning*; however, most share some common characteristics with the definition proposed by Bonwell and Eison (1991) in which *active learning* is defined as strategies that focus on "involving students in doing things and thinking about what they are doing" (p. iii). Similarly, Prince (2004) described active learning as "any instructional method that engages students in the learning process . . . [and] requires students to do meaningful learning activities and think about what they are doing. . . . The core elements of active learning are student activity and engagement in the learning process" (p. 1). Michael (2006) describes active learning as "[t]he process of having students engage in some activity that forces them to reflect upon ideas and how they are using those ideas" (p. 160). He continues by saying that active learning should require "students to regularly assess their own degree of understanding and skill at handling concepts or problems in a particular discipline . . . [and the] attainment of knowledge by participating or contributing" (p. 160). More recently, Freeman and colleagues (2014) synthesized a definition of *active learning* from written definitions collected from faculty during biology seminars on active learning. According to this definition, *active learning* "engages students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert. It emphasizes higher-order thinking and often involves group work" (Freeman et al., 2014, p. 8414).

In an active learning class, students often work or discuss problems and concepts in small groups or pairs, where part of the process involves reflecting on or discussing the reasons behind the concepts and the solutions to the problems and activities. The inclusion of student reflection is a critical component because metacognitive strategies have been shown to improve learning (Bjork, Dunlosky, & Kornell, 2013; Donker, De Boer, Kostons, van Ewijk, & Van der Werf, 2014; Lopez, Nandagopal, Shavelson, Szu, & Penn, 2013). There are a range of techniques and approaches that have been developed to support active learning in the classroom. These techniques include easily implemented approaches that do not require much change in an instructor's current approach, such as the pause method (Rowe, 1986), note comparisons, and short activities or questions where students discuss and work in groups. Other easy-to-implement strategies include think-pair-share (Lyman, 1981); concept tests (Crouch & Mazur, 2001; Mazur, 1997); and use of personal-response systems, which can be technology oriented using clickers, cell phones, or low-technology options such as cards or hand raising (Caldwell, 2007; Gauci, Dantas, Williams, & Kemm, 2009). Active learning techniques also include approaches in which most of the class time consists of students working in groups (e.g., inquiry-based learning, case studies, problem-based learning and team-based learning; Barnes, Christensen, & Hansen, 1994a, 1994b; Eberlein et al., 2008; Herreid, 1994, 2013; Pedaste et al., 2015; Sweet & Michaelsen, 2012). Other active learning techniques, such as classroom assessment techniques (Angelo & Cross, 1993) not only engage the students in their learning but also give the instructor feedback on students' learning. Last, there are active learning techniques that focus on writing in the classroom, for example, one-minute papers and reflective writing assignments (Bean, 2011; Reynolds, Thaiss, Katkin, & Thompson, 2012). This broad range of active learning techniques enables instructors to select and use strategies that best fit the learning outcomes and the design of their course.

Why Use Active Learning?

The incorporation of active learning into a classroom often requires that an instructor change teaching methods. Changing one's teaching methods requires some effort; therefore, knowing about evidence that supports the efficacy of active learning can help justify a transition to using active learning techniques in the classroom.

Several decades ago, in their research-based article "Seven Principles for Good Practice in Undergraduate Education," Chickering and Gamson (1987) included the idea that good practice in undergraduate education "uses active learning techniques" (p. 2) because active approaches increase student learning. For example, a variety of active learning approaches have been shown to help students reset their attention and more effectively engage in the learning process (Bunce, Flens, & Neiles, 2010; Nilson, 2010). Active learning methods have also been shown to build critical thinking skills by encouraging students to verbalize and try out ideas (Tsui, 2002). A study conducted in history and political science courses showed that students who engaged in collaborative exercises and role-plays outperformed students who received more teacher-centered instruction on standard assessments of student learning (McCarthy & Anderson, 2000).

Some of the most comprehensive evidence for the efficacy of active learning has emerged from discipline-based education research in the science, technology, engineering, and mathematics (STEM) disciplines, especially science, engineering, and math. Meta-analyses of the effectiveness of active learning in undergraduate STEM education (eg., see Freeman et al., 2014; Haak, HilleRisLambers, Pitre, & Freeman, 2011; and Vickrey, Rosploch, Rahmanian, Pilarz, & Stains, 2015) show clear learning advantages for students in active learning courses. Since there is a wide range of active learning strategies, it can be useful to consider the effectiveness of different active learning categories. Prince (2004) summarized the effect of active learning in the following areas: (a) use of short activities in a traditional lecture, (b) use of activities that engage students in the learning process, (c) use of collaborative learning, (d) use of cooperative learning, and (e) use of problem-based learning. The literature supports the conclusion that all five forms of active learning improve student learning, though to different degrees. The biggest gains typically came through collaborative or cooperative methods in which students worked together in groups to construct understanding (Eberlein et al., 2008; Prince, 2004). Michael (2006) published summaries of active learning in the learning and cognitive sciences, educational psychology, and discipline-based education research in the physical and life sciences. Michael (2006) concluded,

> There IS evidence that active learning, student-centered approaches to teaching physiology work, and they work better than more passive approaches. There is no single definitive experiment to prove this, . . . but the very multiplicity of sources of evidence makes the argument compelling. (p. 165)

A recent meta-analysis by Freeman and colleagues (2014) analyzed 225 studies that compared student performance in courses with traditional pedagogies to those using active learning pedagogies. The study showed that the use of active learning strategies improved student exam performance and reduced course failure rates across many STEM disciplines. "These results indicate that average examination scores improved by about 6% in active learning sections, and that students in classes with traditional lecturing were 1.5 times more likely to fail than were students in classes with active learning" (Freeman et al., 2014, p. 8410). As Wieman (2014) said in his commentary on the Freeman study, "One promising direction [that emerges] is that 'more is better.' The highest impacts are observed in studies where a larger fraction of the class time was devoted to active learning" (p. 8320).

These ideas are supported in disciplines beyond STEM. For example, studies have shown that breaking up a lecture with intentionally chosen active learning helps to address attention span limits and increase students' retention of material (Nilson, 2010). Similarly, there is evidence that the use of breaks for well-designed multiple-choice questions (e.g., via clickers) enhances student learning and metacognition (Nilson, 2010).

While a preponderance of evidence points to the effectiveness of active learning, research also suggests that successful active learning implementations require an understanding on the part of the instructor of how students learn and how the approaches used must be structured and facilitated to support learning (Andrews, T.M. Leonard, Colgrove, & Kalinowski, 2011). While modifications that instructors sometimes make to active learning strategies are not inherently bad, if they are made because the teacher does not fully understand the purpose behind the original evidence-based practice, the changes may decrease the effectiveness of the approach for supporting student learning (Andrews, T.C. & Lemons, 2015). Similarly, successful adoption of active learning requires alignment of the approach with a teacher's beliefs about learning (Polich, 2008). Hence, understanding both the theory behind the strategy and how to implement the strategy is essential for any active learning approach to effectively support student learning.

One subcategory of active learning approaches that has been shown to be highly effective for supporting student learning is inquiry-based learning (Hmelo-Silver, Duncan, & Chinn, 2007; Prince & Felder, 2006). We next turn to an examination of this approach and a discussion of how the POGIL pedagogy fits into the set of inquiry-based strategies from which teachers might choose to support student learning.

What Is Inquiry-Based Learning?

Inquiry-based learning can be defined as a collection of pedagogical approaches to learning, each of which is stimulated by a driving question or issue (Lee, 2012). In addressing the question or issue, inquiry-based learning involves students in the construction of new knowledge and understanding (Bell, Urhahne, Schanze, & Ploetzner, 2010; Minner, Levy, & Century, 2010). Like other active learning approaches, students are involved in doing things and thinking about what they are doing. Prince and Felder (2006) describe inquiry-based learning as an inductive teaching-and-learning technique. It is similar to case-based learning or problem-based learning in that students work with data, a model, a case, or a problem, through which the needed information is provided or uncovered. (This contrasts with other approaches that provide students with exposure to foundational knowledge and then create opportunities for students to actively apply ideas or see how they might be relevant or useful.) Inquiry-based learning thus begins with driving questions or problems that provide the context for learning; students engage with course content as part of addressing the question or solving the problem (Prince & Felder, 2006).

Because *inquiry-based learning* is often used as an umbrella term for a variety of inductive approaches, it is helpful to explore the different ways that inquiry-based pedagogy can be framed so that we can better understand the specific methods that the POGIL pedagogy leverages to support student learning. It is important to understand that these inductive approaches are designed to help students make broad generalizations from specific observations. Students are invited to make observations, discern a pattern, and make a generalized conclusion about a concept or an idea. Perhaps the simplest analysis of inquiry-based approaches is one that distinguishes between teacher inquiry, in which the teacher poses the driving question(s), and learner inquiry, in which the question(s) are posed by students (Smith, 1996). Following this basic distinction, Staver and Bay (1987) differentiate between open, guided, and structured inquiry. In their framework, represented in Table 4.1, *open inquiry* calls for the student to formulate both a question (or problem) *and* the procedures for solving it. Students draw conclusions based on data gathered from their own procedures. Staver and Bay's (1987) *guided inquiry* provides the student with a teacher-generated problem. In this category, the student designs the procedure to solve it, and the student generates results and discovers generalizations. *Structured inquiry* presents the student with both a teacher-generated problem and an outline for procedures that can be used to address the problem. In structured inquiry, the student does not know the results prior to the activity; the activity is specifically structured to enable students to discover particular relationships or ideas. Staver and Bay (1987) distinguish each of these categories from confirmation activities (e.g., "cookbook" laboratories and activities) in which concepts and principles are presented to students first and then students engage in activities that may be question driven but are structured to verify results, concepts, and conclusions they know in advance and expect to observe.

The guided-inquiry approach of the POGIL pedagogy is aligned most closely with Staver and Bay's (1987) structured inquiry because in a POGIL classroom, the instructor writes or selects an activity organized around a central question and the activity supports students to uncover particular ideas in the discipline. In so doing, the instructor selects the overarching focus of the inquiry and the guiding questions to which students will respond to help

TABLE 4.1
Inquiry-Based Learning Framework Based on the Role of Teacher and Student

		Driving question/problem posed by	
		Students	*Teacher*
Plan for solution posed by	*Students*	Open inquiry	Guided inquiry
	Teacher		Structured inquiry

Source. Staver & Bay, 1987.

them uncover general ideas and concepts. In a POGIL classroom, the activities are the mechanism by which students are introduced to ideas.

Another framework for describing different types of inquiry was developed by Levy and Petrulis (2012) and distinguishes between approaches that are designed principally to facilitate students' exploration of their existing disciplinary knowledge base and those that invite students to build new disciplinary knowledge (Levy & Petrulis, 2012). Similar to Staver and Bay (1987), Levy and Petrulis (2012) distinguish between whether the teacher or student poses the question that frames or drives the inquiry. But instead of asking who designs the method to address the question, Levy and Petrulis (2012) choose to focus on the purpose of the inquiry. That is, is the purpose to build new knowledge (inquiry for knowledge building) or explore what is known (inquiry for learning)? This results in four modes of inquiry, shown in Table 4.2. In inquiry focused on *identifying*, students explore the knowledge base of the discipline in response to guiding questions, problems, scenarios, or lines of inquiry formulated by the teacher. In *producing* inquiry, students pursue new questions or problems formulated by the teacher, for which the answers are not yet known. In *pursuing* inquiry, students explore the knowledge base of the discipline by pursuing questions, problems, scenarios, or lines of inquiry that they themselves have formulated; these are questions for which the students expect the answers to be previously known and the goal is to find out what is already known. Finally, in *authoring* inquiry, students pursue their own new driving questions, or problems, with the expectation that their findings will contribute to the knowledge base. (Note: While both *authoring* and *pursuing* categories might be viewed as similar to Staver and Bay's [1987] open-inquiry category [because they involve student-formulated questions], in spirit it is *authoring* that is most like open inquiry.) The guided inquiry of

TABLE 4.2
Inquiry-Based Learning Framework Based on the Focus on Inquiry

	Driving question/problem framed by	
	Teacher	*Student*
Inquiry for knowledge building; building new knowledge	Producing *How can I answer **this** open question?*	Authoring *How can I answer **my** open question?*
Inquiry for learning; exploring existing knowledge base	Identifying *What is the existing answer to **this** question?*	Pursuing *What is the existing answer to **my** question?*

Source. Levy & Petrulis, 2012.

the POGIL pedagogy is aligned most closely with Levy and Petrulis's (2012) *identifying* category because in a POGIL classroom the instructor selects the overarching focus of the inquiry to help students uncover ideas and concepts that are already part of the knowledge base.

Different types of inquiry-based learning are valuable in different contexts. For example, undergraduate research, well documented as a high-impact practice for student learning and retention (Kuh, 2008), falls into the open, or authoring approaches. While open inquiry presents rich learning opportunities for students (Lee, 2012; Spronken-Smith, Walker, Batchelor, O'Steen, & Angelo, 2011; Staver & Bay, 1987), it requires significant involvement from the instructor to ensure that the intended learning outcomes are realized. Further, managing individual students' open-inquiry projects requires a great deal of differentiated instruction. Thus, it is not always possible to adopt and is not always suitable for all course contexts.

> Individually, inquiry is like being a detective. But open-ended inquiry can be really frustrating. (It is often that way, even to trained scientists!) So, it is critical that inquiry in the classroom be guided. It helps students to gradually leave their comfort zone. And it allows students to explore and engage directly with the content and gain some deep understanding. To add students working in groups on top of the inquiry makes it even better because then they learn how to incorporate others' perspectives into their thinking about material. They learn how to explain things, they become more comfortable with competing ideas, and they learn that in some cases multiple ideas may be correct.
>
> —*Laura Lavine, Professor of Entomology, Washington State University*

The POGIL pedagogy is designed to introduce inquiry into courses in which existing disciplinary content is the focus of the course and in which instructors seek to have students build mastery and understanding by engaging in inquiry together. Thus, in a POGIL classroom, the teacher selects guiding questions to support inductive reasoning. The activity uses the learning cycle to support students in constructing knowledge about the disciplinary content related to a larger concept or driving question. The POGIL pedagogy has the advantage of being flexible in that it can be adopted in a variety of classroom settings and can be aligned with the need to cover particular content in a course. Importantly, POGIL activities are not add-ons that must be fit into the limited time teachers have with students. Instead, POGIL is designed to replace all or part of what might otherwise be delivered as a lecture or accomplished as a laboratory exercise. In this way, POGIL can be a very efficient strategy for introducing active learning into a course.

Guided Inquiry in the POGIL Pedagogy

Most inquiry methods use a phased framework to structure the inquiry (Eisenkraft, 2003; Pedaste et al., 2015). POGIL inquiry activities are structured according to a three-phase learning-cycle framework (Lawson, Abraham, & Renner, 1989). In a POGIL activity, the instructor chooses a driving question. For example, "What are the factors that govern the strength of a crystal lattice?"; "What forces govern fluid flow through a system?"; or, "What are effective uses of metaphor in poetry?" The question and the desired learning outcomes for students drive the design of the activity. If students complete the activity, they will be able to answer the overarching question. The activity structure is designed such that the learning-cycle components scaffold student learning through the activity.

> The structure of a POGIL activity is very robust. By design, it focuses student attention on important details, helps them form a strong conceptual foundation, and encourages further exploration. Because of this structure, I have much greater confidence in what students are taking away from a POGIL activity than in other activities I've tried because the questions I am asking are more deliberately designed.
>
> *—Shari Ultman, Professor of Mathematics, Boise State University*

Students are guided in a POGIL activity to explore and then master the knowledge base of the discipline. Each POGIL activity begins with a model (see Chapter 1) and the students move deliberately through a series of focused questions that guide students to notice particular features of the model, then to build generalizable conclusions, and finally to apply their new knowledge. This opportunity for students to figure things out (the exploration and concept-invention components)—to make meaning out of data, graphs, equations, text, or other information provided to them—serves as their initial exposure to the ideas and is one of the ways that POGIL is distinct from many other active learning approaches. While there are many other effective approaches to active learning (see, eg., Eberlein et al., 2008), they do not include this inquiry component that explicitly allows students to construct meaning from provided information. The POGIL pedagogy provides opportunities for application only after students have arrived at the generalized understanding of concepts. Importantly, POGIL activities are not collections of homework-like problems. They are generally *not* applications of course material that follow the introduction of material via a reading or a short lecture (i.e., the flipped classroom). In fact, it is the activity's use of the learning cycle, where scaffolding of exploration and concept-invention questions, in particular, occurs, that differentiates POGIL from other approaches.

We can illustrate this approach through a careful examination of an activity focused on the classification of matter (Appendix C). In this activity, the model is a collection of diagrams that illustrate particles (atoms and molecules). The first four questions are exploration questions. They point students at particular elements of the model. They give students information and definitions they will use to reason through new ideas. In this activity, these questions are assisting the students to distinguish among particles, atoms, and molecules. The fifth question is a concept-invention question because it requires students to generalize from the specific information to arrive at the definition of a *particle*. The four components (a–d) of the sixth question continue this concept invention by requiring students to figure out how the codes (chemical formulas) work. Question 6e asks students to apply their ideas about chemical formulas. This question ensures that the students have understood and can apply the concept.

Questions 7 through 12 constitute a new set of concept-invention questions. These questions send students back to details in the model and guide students to develop the concepts associated with how different types of matter are classified by chemists. Question 13 is an application question and allows students to use the knowledge they have built about notation and classification of matter. Question 14 is the last component of the concept-invention work students do in this activity. It requires students to choose their own language to describe the concepts they have constructed. (Such definition questions show whether the students understand the concept or can only use the information.) Questions 15 and 16 are further application questions. In these questions, students take their understanding and use it to answer new questions that require an understanding of how matter is classified and represented.

The *Classification of Matter Activity* is one that is used at the high school or introductory college level. Guided inquiry also works well in upper-division courses. Appendix C presents an annotated activity that illustrates the components of the learning cycle for an activity used in an upper-division chemistry course.

The meaning-making that students do in a POGIL classroom requires that they work with data, diagrams, and models, and that they work together to connect ideas to problem-solving strategies. This approach to active learning deliberately leverages the advantages of cooperative learning in which positive interdependence, individual accountability, and group processing are built into the structure of the course (Millis, 2010). Students engaged in inquiry in a POGIL classroom make meaning within a group of their peers. This resembles the way experts in a discipline construct meaning through dialogue (Repice et al., 2016). While experts certainly engage in some solitary thinking, their thinking adds to the discipline only when it becomes part of the academic discourse, and experts refine their ideas through dialogue with others. In addition to introducing students to strategies that parallel those used by experts in a discipline, students' participation in a group gives them a ready group of peers who can provide mutual support as they struggle with challenging ideas and problems. Finally, the opportunity to communicate and clarify their ideas within the group deepens their understanding of course material.

The Instructor in the Guided-Inquiry Classroom

In most active learning classes, including those using a POGIL approach, students are working on activities and discussing ideas, and the instructor is doing significantly less (or no) lecturing, compared to a traditional classroom. As with other types of active and inquiry-based learning, the teacher's role is one of a facilitator, and there is a move toward students' self-directed learning (Prince & Felder, 2006). A full implementation of the POGIL pedagogy involves a significant shift away from the traditional didactic lecture. Regardless of the scope of implementation, the role of the instructor changes. And, many instructors require support to develop, try out, evaluate, and refine their transformation from the role of "provider of information and knowledge" to one of "facilitator of ideas and learning."

It is important to note that in the implementation of a guided-inquiry approach, the content expertise of the instructor is just as important as in a traditional classroom. However, instead of using content expertise to develop and present a well-structured and clearly delivered lecture, content expertise is used to choose or write activities and is used in selecting the order in which activities will build on each other or connect to other course components. In addition, once the course has begun, the instructor's content knowledge is essential for listening to student thinking and knowing what piece(s) of information or thinking students might be missing. Through active facilitation at either the small-group or whole-class level, the instructor plays a critical role in filling in gaps for students, either through direct instruction (mini-lectures) or by asking questions to help students connect ideas and draw conclusions as they are learning. To implement and facilitate POGIL effectively, deep knowledge of the content is critical, as is an understanding of the ways that students think about material.

Getting Started With the POGIL Pedagogy

Based on the ideas presented in this chapter, it is essential that someone wishing to explore and adopt the POGIL pedagogy become comfortable with the teaching skills needed for an active learning classroom. Further, an effective implementation requires both the selection (or crafting) of guided-inquiry materials and the facilitation of their use in the classroom. How can one get started?

While some instructors who are new to POGIL shift their pedagogy entirely to the new approach, it is also possible to start with small steps. For example, one might start with having POGIL activities once a week, in recitation sections, or having activities that do not last the full class period. Another option is to begin with activities that follow the exploration phase of a POGIL activity to introduce students to a topic and to generate curiosity, thereby getting students interested in the topic and more engaged in the lecture that follows. As one becomes more comfortable with the shift away from full lecture, additional components of the approach may be added. In whatever way POGIL is integrated into a class, it is essential that the activity contain the opportunity for the students to explore the concept of interest by working with data, figures, graphs, or other models. Having this exploration precede the introduction of the concept shifts the lecture from being a set of "answers to questions that students have never asked" (Roberson, personal communication, January 2014) to a rich set of ideas and concepts that students are ready to incorporate into their knowledge base.

Summary

The POGIL pedagogy is one of a number of powerful active learning approaches that teachers should consider adding to their pedagogical toolbox. It offers an effective way to engage students and is an evidence-based structure around which inquiry can be built. While the transition to a POGIL classroom does require shifts in faculty practice and skills, POGIL can flexibly fit into many different classroom settings.

- Active learning involves students by having them participate in activities and/or discussion in class and think about what they are doing.

- Group work is often a component of active learning.
- Active learning is more effective than passive learning.
- The guided inquiry of POGIL is like structured inquiry or identifying inquiry. The activity uses the learning cycle to support students in constructing knowledge about the disciplinary content related to a larger concept or driving question.
- The instructor's role changes in the POGIL classroom from being the deliverer of information to being a facilitator who enables student learning.
- It is important to recognize that in the classroom implementation of POGIL, the guided-inquiry and process components are highly integrated.

Some students may complain that they have to do all the work, but keep reminding them that this is how people learn! The benefits to students are immense.

—A POGIL practitioner of 12 years

References

Andrews, T. C., & Lemons, P. P. (2015). It's personal: Biology instructors prioritize personal evidence over empirical evidence in teaching decisions. *CBE-Life Sciences Education, 14*(1), 1–18.

Andrews, T. M., Leonard, M. J., Colgrove, C. A., & Kalinowski, S. T. (2011). Active learning NOT associated with student learning in a random sample of college biology courses. *CBE-Life Sciences Education, 10*(4), 394–405.

Angelo, T. A., & Cross, K. P. (1993). *Classroom assessment techniques: A handbook for college teachers.* San Francisco, CA: Jossey-Bass.

Barnes, L. B., Christensen, C. R., & Hansen, A. J. (1994a). *Teaching and the case method: Instructors guide* (3rd ed.). Boston, MA: Harvard Business School Press.

Barnes, L. B., Christensen, C. R., & Hansen, A. J. (1994b). *Teaching and the case method: Text, cases, and readings* (3rd ed.). Boston, MA: Harvard Business School Press.

Bean, J. C. (2011). *Engaging ideas: The professor's guide to integrating writing, critical thinking, and active learning in the classroom*. Hoboken, NJ: John Wiley & Sons.

Bell, T., Urhahne, D., Schanze, S., & Ploetzner, R. (2010). Collaborative inquiry learning: Models, tools, and challenges. *International Journal of Science Education*, *32*(3), 349–377.

Bjork, R. A., Dunlosky, J., & Kornell, N. (2013). Self-regulated learning: Beliefs, techniques, and illusions. *Annual Review of Psychology*, *64*, 417–444.

Bodner, G. M. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education*, *63*(10), 873.

Bonwell, C. C., & Eison, J. A. (1991). *Active learning: Creating excitement in the classroom*. ASHE-ERIC Higher Education Report No. 1. Washington, DC: The George Washington University, School of Education and Human Development.

Bunce, D. M., Flens, E. A., & Neiles, K. Y. (2010). How long can students pay attention in class? A study of student attention decline using clickers. *Journal of Chemical Education*, *87*(12), 1438–1443.

Caldwell, J. E. (2007). Clickers in the large classroom: Current research and best-practice tips. *CBE-Life Sciences Education*, *6*(1), 9–20.

Chickering, A. W., & Gamson, Z. F. (1987). Seven principles for good practice in undergraduate education. *AAHE Bulletin*, *39*(1), 3–7.

Crouch, C. H., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics*, *69*(9), 970–977.

Donker, A. S., De Boer, H., Kostons, D., van Ewijk, C. D., & Van der Werf, M. P. C. (2014). Effectiveness of learning strategy instruction on academic performance: A meta-analysis. *Educational Research Review*, *11*, 1–26.

Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, *23*(7), 5–12.

Eberlein, T., Kampmeier, J., Minderhout, V., Moog, R. S., Platt, T., Varma-Nelson, P., & White, H. B. (2008). Pedagogies of engagement in science: A comparison of PBL, POGIL, and PLTL. *Biochemistry and Molecular Biology Education*, *36*(4), 262–273.

Eisenkraft, A. (2003). Expanding the 5E model: A proposed 7E model emphasizes "transfer of learning" and the importance of eliciting prior understanding (Teacher practitioner). *The Science Teacher*, *70*, 56–59.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410–8415.

Gauci, S. A., Dantas, A. M., Williams, D. A., & Kemm, R. E. (2009). Promoting student-centered active learning in lectures with a personal response system. *Advances in Physiology Education*, *33*(1), 60–71.

Haak, D. C., HilleRisLambers, J., Pitre, E., & Freeman, S. (2011). Increased structure and active learning reduce the achievement gap in introductory biology. *Science*, *332*(6034), 1213–1216.

Herreid, C. F. (1994). Case studies in science—A novel method of science education. *Journal of College Science Teaching*, *23*(4), 221–229.

Herreid, C. F. (Ed.). (2013). *Start with a story: The case study method of teaching college.* Buffalo, NY: National Center for Case Study Teaching in Science (NCCSTS).

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99–107.

Kuh, G. D. (2008). *High-impact educational practices: What they are, who has access to them, and why they matter*. Washington, DC: Association of American Colleges & Universities.

Lawson, A. E., Abraham, M. R., & Renner, J. W. (1989). A theory of instruction: Using the learning cycle to teach science concepts and thinking skills. *NARST Monograph, 1,* 1–136.

Lee, V. S. (2012). What is inquiry-guided learning? *New Directions for Teaching and Learning*, *2012*(129), 5–14.

Levy, P., & Petrulis, R. (2012). How do first-year university students experience inquiry and research, and what are the implications for the practice of inquiry-based learning? *Studies in Higher Education, 37*(1), 85–101.

Lopez, E. J., Nandagopal, K., Shavelson, R. J., Szu, E., & Penn, J. (2013). Self-regulated learning study strategies and academic performance in undergraduate organic chemistry: An investigation examining ethnically diverse students. *Journal of Research in Science Teaching*, *50*(6), 660–676.

Lyman, F. (1981). The responsive classroom discussion: The inclusion of all students. In A. S. Anderson (Ed.), *Mainstreaming digest* (pp. 109–113). College Park, MD: University of Maryland.

Mazur, E. (1997, March). Peer instruction: Getting students to think in class. *AIP Conference Proceedings, 399*(1), 981–988.

McCarthy, J. P., & Anderson, L. (2000). Active learning techniques versus traditional teaching styles: Two experiments from history and political science. *Innovative Higher Education*, *24*(4), 279–294.

Michael, J. (2006). Where's the evidence that active learning works? *Advances in Physiology Education*, *30*(4), 159–167.

Millis, B. (2010). Why faculty should adopt cooperative learning approaches. In B. Millis (Ed.), *Cooperative learning in higher education across the disciplines, across the academy* (pp. 1–9), Sterling, VA: Stylus.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, *47*(4), 474–496.

Nilson, L. B. (2010). *Teaching at its best: A research-based resource for college instructors* (3rd ed.). San Francisco, CA: Jossey-Bass.

Pedaste, M., Mäeots, M., Siiman, L. A., De Jong, T., Van Riesen, S. A., Kamp, E. T., . . . & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47–61.

Polich, S. (2008). Assessment of a faculty learning community program: Do faculty members really change? *To Improve the Academy, 26*(1), 106–118.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, *93*(3), 223–231.

Prince, M. J., & Felder, R. M. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education*, *95*(2), 123–138.

Repice, M. D., Sawyer, R. K., Hogrebe, M. C., Brown, P. L., Luesse, S. B., Gealy, D. J., & Frey, R. F. (2016). Talking through the problems: A study of discourse in peer-led small groups. *Chemistry Education Research and Practice*, *17*, 555–568.

Reynolds, J. A., Thaiss, C., Katkin, W., & Thompson, R. J. (2012). Writing-to-learn in undergraduate science education: A community-based, conceptually driven approach. *CBE-Life Sciences Education*, *11*(1), 17–25.

Rowe, M. B. (1986). Wait time: Slowing down may be a way of speeding up! *Journal of Teacher Education*, *37*(1), 43–50.

Smith, D. (1996). *A meta-analysis of student outcomes attributable to teaching science as inquiry as compared to traditional methodology* (Unpublished doctoral dissertation). Temple University, Philadelphia, Pennsylvania.

Spronken-Smith, R., Walker, R., Batchelor, J., O'Steen, B., & Angelo, T. (2011). Enablers and constraints to the use of inquiry-based learning in undergraduate education. *Teaching in Higher Education*, *16*(1), 15–28.

Staver, J. R., & Bay, M. (1987). Analysis of the project synthesis goal cluster orientation and inquiry emphasis of elementary science textbooks. *Journal of Research in Science Teaching*, *24*(7), 629–643.

Sweet, M., & Michaelsen, L. K. (2012). *Team-based learning in the social sciences and humanities: Group work that works to generate critical thinking and engagement*. Sterling, VA: Stylus.

Tsui, L. (2002). Fostering critical thinking through effective pedagogy: Evidence from four institutional case studies. *Journal of Higher Education*, *73*(6), 740–763.

Vickrey, T., Rosploch, K., Rahmanian, R., Pilarz, M., & Stains, M. (2015). Research-based implementation of peer instruction: A literature review. *CBE-Life Sciences Education*, *14*(1), es3.

Wieman, C. E. (2014). Large-scale comparison of science teaching methods sends clear message. *Proceedings of the National Academy of Sciences*, *111*(23), 8319–8320.