1 Introduction

"Active learning" is a common, and commonly misunderstood, term in education. Although instructors have used many of these approaches for generations, this is a relatively new formal pedagogical concept, based on developments in cognitive science. These developments have been thoroughly described elsewhere (e.g., McManus, 2001; McConnell, Steer, and Owens, 2003; Yacobucci, 2012), but in essence active learning refers to class time when students are actively engaged with the material instead of passively sitting and listening to a lecture (Prince, 2004). In other words, in an active learning classroom students are reading, writing, discussing class material, solving problems, and generally engaging in the higher-order thinking tasks of analysis, synthesis, and evaluation (Bonwell and Eison, 1991). However, it is important to note that these activities need to be purposeful; students resent anything that feels like a time-filling worksheet. The best way to achieve this is to ensure that activities are aligned to the learning outcomes of the lesson, which in turn are hopefully aligned to the learning goals of the course (Wiggins and McTighe, 2005).

In general, active learning activities involve some combination of cooperative learning, writing or sketching, and problem-based learning, which requires students to activate and build upon their previous knowledge to interpret, examine, and craft hypotheses about data and other real-world scenarios (Macdonald and Korinek, 1995; McConnell et al., 2003; Bean, 2011). All of these approaches have been shown to lead to increased student learning and engagement while also allowing students to practice the skills used by professional paleontologists and geologists. Cooperative learning allows students to benefit from peer instruction, which is known to increase learning and conceptual understanding, as well as interpersonal skills and camaraderie between students (Johnson et al., 1998; Crouch and Mazur, 2001; Lasry et al., 2008; Fagen et al., 2002; Smith et al., 2009; Osborne, 2010). Furthermore, studies have shown that geologists are most productive in teams (Rey-Rocha et al., 2002), and in general, teamwork is viewed as an important skill to learn in order to be prepared for almost all jobs today (National Research Council et al., 2013). Similarly, writing and sketching are shown not only to increase student understanding but also to allow students to practice skills and modes of expression used by professionals (Connolly and Vilardi (eds.), 1989; Keys, 1999; Lerner, 2007; Ainsworth et al., 2011; Hay et al., 2013; Quillin and Thomas, 2015). Problem-based learning has also been shown to increase student engagement and understanding (Kelso and Brown, 2009; Auchincloss et al., 2014; Colley, 2016).

2 Types of Active Learning Activities

One common concern with regard to active learning is that there is not enough time for these techniques, as there is "too much material to cover" (Felder and Brent, 1996; Lujan and DiCarlo, 2006). Setting aside that while lecturing allows instructors to present more material to the students, and active learning allows for increased student comprehension and success (Prince, 2004), this type of teaching does not need to completely replace in-class lectures for students to experience the benefits. If multiple techniques or activities are used, however, they can then be scaffolded so the students are led through the process of activating and building upon prior knowledge (Vygotsky, 1978; Linn, 1995). The following examines a few different types of active learning activities, arranged from those that fill the least class time to those that fill the most. These approaches are all well supported by pedagogical research to support student learning, and almost all of these activities can provide opportunities for students to write or sketch, both actions proven to increase understanding and critical thinking (Connolly and Vilardi (eds.), 1989; Keys, 1999; Lerner, 2007; Ainsworth et al., 2011; Hay et al., 2013; Quillin and Thomas, 2015), and all can easily incorporate paleontological specimens.

2.1 Relatively Brief Activities

The following activities all take very little class time, but they all provide students the opportunity to engage with the material and confront any misconceptions they may hold about it. All of these brief activities can easily be integrated into classes of any size and configuration; they work as well in a large auditorium-like room as in a small seminar-style room, as students in an auditorium can always talk to the students in the rows around them.

2.1.1 Just-in-Time Teaching (JiTT)

Just-in-Time Teaching (JiTT) is a technique that requires students to answer online questions before they come to class. Compared to traditional reading quizzes, which check for student comprehension, JiTT questions are open to interpretation, requiring students to apply information from the reading to produce complex answers (Novak, 2011). Often, too, the students do not have a great deal of prior knowledge on the topic, so the goal is not to assess student learning, but to root out common misconceptions and begin the process of having students think about the material to be covered before they come to class. Additionally, by moving this reflection and synthesis outside the classroom, JiTT can free up class time that was previously spent on review, making time for more active learning activities. Guertin et al. (2007) reported that including JiTT questions in their introductory nonmajor paleontology class allowed students the chance to reflect on their previous knowledge and create new knowledge, resulting in students who were more engaged and successful than students in a class without these questions.

2.1.2 Minute Papers

This technique, also referred to as free writing, involves asking students to provide a written response to a prompt. The idea is not to produce a long essay, but rather to spend two to five minutes putting thoughts on paper. Having to put their thoughts in writing has been shown to increase critical thinking in students (Bean, 2011). These prompts can vary, depending on the goals of the class: students can be given specific questions to answer ("describe a scenario that would let you become a fossil according to one of the preservation pathways we discussed" is a perennially popular question in my class, with students planning ever more elaborate ways to fall into a swamp or a giant puddle of tree sap or a tar pit), they can be asked to write everything they know on a specific topic ("name all of the dinosaurs you can think of"), or they can just write down the things they are most confused about. Additionally, these do not even have to involve writing, per se: students can also be asked to draw or sketch as well, an activity that has been shown to support learning in the sciences (Lerner, 2007; Ainsworth et al., 2011; Hay et al., 2013; Quillin and Thomas, 2015).

2.1.3 Pause Procedure

This method involves breaking up lectures with two or three short pauses, giving students the chance to talk with one another about the material they just heard and filling in gaps in their notes and understanding (Ruhl et al., 1987). This tends to be a student-driven activity, rather than a teacher-driven activity, as students ask each other about the points of the lecture that they found confusing. This provides the opportunity for informal cooperative learning, allowing students the chance to learn from each other (Macdonald and Korinek, 1995).

2.1.4 Classroom Response System ("Clickers")

This is similar to the pause procedure, except it involves asking the students higher-level conceptual multiple-choice questions about the material just covered in lecture and having students select their answers to the questions. A good question for this system is one that results in about a 40–80% correct rate (Smith et al., 2009), which then provides the opportunity for the students to discuss their answers with one another and then revote. Studies have shown that this method allows an instructor to immediately identify misconceptions and also for students to benefit from peer instruction and collaborative learning (Johnson et al., 1998; Crouch and Mazur, 2001; Fagen et al., 2002; Lasry et al., 2008; Fagen et al., 2002; Osborne, 2010). Increasingly, schools are adopting classroom response systems across campus, which might require students to purchase their own clicker to interface with the classroom response system, but this polling can also be done with colored index cards, a show of hands, using one of several free apps (e.g., Plickers), or having students visit or text Internet sites on their own devices (e.g., cahoot.com; polleverywhere.com). In fact, many of the online tools offer more flexibility than clickers, as they allow students to enter words or phrases as answers to open-ended questions, and also support image integration, which is important in a visual field like paleontology.

This technique is very flexible. These questions can be used to assess basic comprehension; for instance, when teaching about hypothesis vs. scientific theory vs. scientific law I ask students very straightforward questions to ensure that they understand the difference. ("A scientific theory becomes widely accepted by the whole scientific community and has not been proven wrong after 300 years of experimentation. Can it be promoted to a law?" The majority of students invariably select "yes," leading to an opportunity to discuss the theory of evolution.) However, it can also be used to ask students to make hypotheses about data: for instance, I have shown students pictures of fossils to interpret ("*Maisaura* ['caring mother lizard'] fossils have been found near nests filled with hatchlings with worn teeth. What conclusions can be drawn from that find?"), a technique that can be very powerful when combined with a system that allows students to upload their own free-form answer. Finally, this approach can also be useful to assess knowledge before and after a subject is introduced. For instance, before teaching the pattern of major evolutionary events in Earth's history, I poll students to see what they think that pattern looks like: spread evenly through time, a burst of activity early in Earth's history then only a few events, a burst of activity in the middle with a period of few events before and after, or a long period of very few events and then a great number of evolutionary events? Invariably, before the lesson, the majority of the class thinks that evolutionary events occur at regular intervals through Earth's history. I have found that asking the students to articulate this belief before they learn how relatively young animals and plants are in relation to the age of the Earth makes the truth all the more impactful to the students.

2.1.5 Think-Pair-Share

This technique is similar to the clicker question, but it also provides the benefits of free writing; in think-pair-share, students are first asked to write down the answer to a question on their own, and then discuss their answers in pairs or small groups. Once the group discussions are done, the class then discusses as a whole, with select groups reporting out (Lyman, 1987). This approach can allow an exploration of even more complex ideas, as the students have more time to not only consider their answer but also to explain and defend it to their peers. As an example, in class I tend to follow up the question about the *Maisaura* with a think-pair-share about the famous dinosaur trackway at Lark Quarry, asking students to examine images of the footprints and hypothesize (1) in what environment these tracks would have been made and (2) what types of behavior can be determined from these fossils. Think-pair-share activities also lend themselves well to sketching and to open-ended opinion questions. One of the liveliest classes I ever had was when I asked 80 students whether they agreed with the claim that we should not save modern animals from extinction as their extinction would simply be natural selection in action.

2.2 Team-Based Activities

These two activities take more class time, but they also provide students much more time to engage with the material and think critically about it. Although these team-based activities might seem more suited to small classes around seminar-style tables, I have deployed them all in large lecture halls too; students just have to be willing to work with students around them, an activity that often requires some encouragement by the professor.

2.2.1 Jigsaw Discussion

Jigsaws are an extension of the think-pair-share model, except rather than sharing and discussing answers with one another, in a jigsaw discussion, students actively teach one another. This approach involves breaking a problem up into pieces and having students in a group each be responsible for one piece. It then becomes the responsibility of each student to teach their groupmates their piece of the problem, so together the group attains proficiency in the whole (Tewksbury, 1995). This can be done with material in or out of class, and with small or large groups. For instance, I assign homework that asks students to read one of four brief articles describing a different evolutionary event, and then once they get into class they have to sit in groups of four, each having read a different article, and then they have to teach each other what they learned. Other times, I have students break into groups and research different fossil preservation mechanisms in class, and then each group is then responsible for teaching the rest of the class what they learned.

2.2.2 Problem-Based Learning

Broadly speaking, this involves having students work in groups to apply their knowledge to authentic problems: interpreting data, crafting hypotheses, testing models, working on case studies, and even doing authentic research (Kelso and Brown, 2009; Auchincloss et al., 2014; Colley, 2016). This can occur as a short activity that lasts 10–20 minutes, as a class-long activity, or as something scaffolded over some or all of the semester. Research has demonstrated that these activities can increase student learning, teamwork skills, and engagement (Prince, 2004). Problem-based learning has been applied with great success to upper-level paleontology classes taken by majors as well as introductory courses aimed at nonmajors (Kelley and Visaggi, 2012; Koy, 2012; Savarese and Schmidt, 2012; Schiappa, 2012; Sunderlin, 2012; Olcott et al., 2016). I often give students graphs and figures from published literature and then ask them to apply concepts covered in class to interpret the data; then as a class or for homework the students can read the original article to practice thinking like an expert. Examples of this are presented in Section 4.

2.3 Constructing Learning Teams

Almost all types of active learning require group work in one form or another. Cooperative learning is a powerful force in education, as it allows students to learn effectively from each other while also improving their teamwork skills (Crouch and Mazur, 2001). Although group work can be done in informal groups with students self-selecting teams, research has revealed that this can often result in problems. One study reported that 40% of students' worst group experiences were with self-selected teams, vs. 22% of their best experiences (Feichtner and Davis, 1984). In general, the research suggests that allowing students to self-select their teams leads to groups that are homogenous (Jalajas and Sutton, 1984), lack diversity (Kirchmeyer, 1993; Bacon et al., 1998), might not have all of the skills necessary for the task (Mello, 1993), and show clique behavior (Daly and Worrell, 1993). Thus, if active learning approaches are going to be used all semester in a majority of the classes, it is useful to have the students in formal learning teams. Research has revealed that being in permanent learning teams produces greater results than if students are placed in ad hoc groups each day, as they begin to feel that their team depends on them (Felder and Brent, 1996; Oakley et al., 2004) (which, in turn, helps increase their sense of belonging, another important element of student success [Strayhorn, 2012]). If students are to be placed in formal learning teams, all efforts should be made to ensure that the teams are balanced with regard to factors such as ethnicity, major, gender, and year in school (Oakley et al., 2004). One resource to support the creation of such teams is the Comprehensive Assessment of Team Member Effectiveness (CATME) (http://.info.catme.org) system, an online site that allows the formation of criterion-based teams: instructors select a list of criteria that they feel are important, the students are surveyed to collect the necessary data, the instructor weights how the criteria should be used, and the website then makes teams (Layton et al., 2010). However, for small enough classes this can also be done manually.

3 Benefits of Active Learning

When applied correctly, active learning is shown to increase student success (Redish et al., 1997; Hake, 1998; Laws et al., 1999; Olcott et al., 2016; Roberts et al., in press); a meta-study of studies on active learning revealed that students in active learning classes perform, on average, half a letter grade above students in traditional lecture classes, and the failure rates in traditional lecture classes are 55% higher than in active learning classes (Freeman et al., 2014). In general, students in active learning classes are shown to be more engaged, which in turn has been closely linked to student learning, success, and persistence (Carini et al., 2006; Kuh et al., 2008). These benefits do not require wholesale replacement of lectures; in fact, a study on the pause procedure revealed that just inserting three two-minute pauses per 45-minute lecture to allow students time to work in pairs to discuss the material and clarify any misconceptions improves student achievement significantly (Ruhl et al., 1987).

These techniques, particularly problem-based learning, have been shown to increase the self-efficacy of students (Dunlap, 2005; Baber et al., 2010). Self-efficacy, a person's belief about their capabilities to perform to a designated level (Bandura, 1994), has been linked to student success in general, as well as their likelihood of persisting in a major and field (Lenox and Subich, 1994; Lent et al., 2008). In essence, active learning allows students to practice the skills of paleontologists and geologists, thus increasing their confidence that they too can become a paleontologist or geologist.

Finally, this pedagogical approach has one further benefit for students: a recent survey of employers about what they are looking for in new college graduates revealed that the top three qualities they seek are “ability to work in teams” followed by “problem solving” and “written communication ability” (Grey and Koncz, 2017).

4 One Model How to Integrate Active Learning into a Paleontology Class for Nonmajors

It is often easier to understand how these approaches can be applied to an upper-level paleontology class: these classes are often small, with time already dedicated to students describing and thinking about fossils and how they can be used to solve geological problems. In these situations, it often only takes a few adjustments or a reframing of the question to add in many more active learning elements, and thus increase student engagement and success (Prothero, 2012). However, the idea of adding so many student-centered activities to a large class can feel overwhelming, especially as this type of class is so well suited to lecturing. That said, a large general education class full of nonmajors who are only there to fulfill a distribution requirement (Gilbert et al., 2012) is a class that could benefit from mechanisms to increase student engagement.

At the University of Kansas, all undergraduate students are required to take a natural science course regardless of their major, and this class is often their only college-level science class and the last science class they will ever take. For decades, GEOL 121: Prehistoric Life (now Life Through Time) from DNA to Dinosaurs, a large (ca. 100 students) introductory paleontology class for nonmajors, was taught as a lecture-based course. However, given the pedagogical benefits of active learning, and the fact that two of the most pressing issues facing humanity right now – climate change and the prospect of human-caused mass extinctions – can best be understood through a geological lens, I transformed the class. Now geology and paleontology are interwoven with the interconnected issues of human-driven extinctions and climate change and students actively explore and discover knowledge themselves, rather than passively receiving it.

In the current incarnation of the course, which still involves ca. 100 students, active learning activities have mostly replaced lecture. However, every class is structured similarly, so students know what to expect each day (Table 1). Each 75-minute class period includes time for students to reflect individually, in groups, and as a class on what they are learning

Table 1 Organization of a typical class day in "Life Through Time"

Class structure	Approximate time spent	Rationale
Top of class announcements and signposting	2 min.	Focus students on task
"Dinosaur of the Day" – student presenting about a dinosaur or other fossil they researched	5 min.	Problem-based learning: low-stakes research report
Discuss readings in group	10–15 min.	Use reading circles (Daniels, 1994) to focus discussion or jigsaw the readings so group learns from each other
Clicker question or two followed by small class discussion with groups reporting out	5 min.	Ensure that class is on the same page
Activity 1	5–10 min.	Often a think-pair-share so students express their opinion
Small class discussion with groups reporting out	5 min.	Ensure that class is on the same page
Activity 2	15–20 min.	Build upon knowledge, apply to real data
Small class discussion with groups reporting out	5 min.	Ensure that class is on the same page
Activity 3	5–10 min.	Small synthesis, often think-pair-share or free writing
Clicker question or two followed by small class discussion with groups reporting out	5 min.	Ensure that class is on the same page
End of class announcements and assignment of reading	5 min.	Get everyone ready for the next class

and why, to help them integrate their knowledge into a more coherent framework (Linn, 2000).

All of these activities are done in permanent teams, formed at the start of the semester with the help of CATME. Two different criteria are used to form the teams: they are designed, first, to ensure that the students on the teams have common blocks of time outside of class to work, and second, to ensure that the teams are balanced with respect to identified gender, self-declared ethnicity, and major to provide opportunities for students to interact with, learn from, and ultimately respect the views of people of different identities and backgrounds. Although this class is currently taught in a classroom designed for active learning, so each group sits and works at its own table, the first year this class was taught it was in a lecture hall; I assigned each group to specific seats so groups were composed of students sitting three by three in two rows, so the students in one row would turn and work with their teammates.

In addition to this day-to-day framework, the students spend the last third of the semester working on a series of assignments to scaffold them through their collaborative final class project, dubbed "PaleoCon." This requires student teams to pick a modern organism threatened with extinction and an extinct counterpart found in the fossil record. Students then research both animals: their modes of life, their habitat, their ecosystem, and their extinction threats and causes. This information is then used to produce three essays: one on the modern animal, one on the ancient animal, and a mitigation plan, explaining how the lessons from the extinct animal can be applied to help save the modern animal. Then, during finals week, the students present their findings to their classmates, the university, and the general public in a creative science fair–style event.

4.1 Types of Activities

All of the activities in class follow the same general format: students are provided authentic data to interpret and use to create hypotheses. The form of the authentic data varies. Some activities present graphs from published papers or raw data downloaded from the Paleobiology Database; for others, collecting the data is part of the activity. Thus, the activity will begin with students using the Internet to research facts, examining Google Street View treks to look at fossil collection sites, or just recalling and synthesizing information from previous classes.

Appendix 1 shows a long, in-class activity where the students have to interpret real data. The middle third of the class focuses on the Cretaceous, and this activity is handed out the day the Cretaceous is introduced. This activity generally takes about 20 minutes; students are given two maps of the United States – one labeled "marine" and one labeled "terrestrial" – and a list of marine and terrestrial Cretaceous organisms with lists of the states where their fossils have been found, information downloaded from the Paleobiology