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Best practices for online learning environments
Chris Impey and Matthew Wenger

Chapter 7

Education Through Exploration: A Model for Using Adaptive Learning to Teach Laboratory Science Online

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Adaptive learning technologies are becoming more common and they have the potential to transform the way laboratory science is taught online. In this chapter, we introduce adaptive learning, discuss the research supporting its effectiveness, and list prominent technology providers of adaptive learning. To ground this concept, we introduce the Education Through Exploration (ETX) model of digital learning design, which leverages adaptive learning and is specific to the sciences and laboratory science in particular. We use examples from our own work to illustrate both adaptive learning and the ETX model.

Chapter Outcomes

By the end of the chapter, readers will:

- Understand what adaptive learning is and why it is effective.
- Understand the Education Through Exploration model and its research foundation.
- Be able to start conceptualizing their own adaptive learning designs.
- Have a list of educational technologies that provide adaptive capabilities.

7.1 Introduction: What Problem Are We Solving?

Among the many reforms to science education that have been made in recent years is the push to make science laboratory activities resemble authentic scientific practices (e.g., Hofstein & Lunetta 2004). Laboratory teaching sections and activities have long existed to teach practical skills associated with a scientific discipline and to demonstrate the implications of concepts taught elsewhere in a class, whether through lecture, readings, or otherwise. Recently, there has been a move to shift the

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emphasis of such laboratory activities to demonstrate and reinforce "scientific habits of mind" and "understanding of the nature of science" (Hofstein & Lunetta 2004).

In practice, classroom laboratories fall between two end-members: the verification or "cookbook" lab and the authentic, inquiry-based lab. Inquiry learning has a long history, including the Learning Cycle (Karplus & Thier 1967; Lawson 2010) and its extension, the popular 5E model (Bybee et al. 2006). Even though inquiry-based teaching is demonstrably more effective across various metrics, it is not yet universally used (Brownell et al. 2012; Pearson et al. 2010; Blanchard et al. 2010; Hofstein & Lunetta 2004). This lag between best-practices recommendations and on-the-ground use stems from teachers' lack of awareness of these practices and their lack of expertise and comfort in using them.

As much as this gap is a challenge for in-person teaching, it is still more challenging for online teaching. As college and even high school courses have moved online, they have too often taken on the worst features of existing in-person teaching practices. In particular, this means instruction that relies on video lectures and simple, computer-graded quizzes (Koedinger et al. 2015; Toven-Lindsey et al. 2015). Although there is an overreliance on these kinds of passive learning in traditional classroom settings, online delivery further encourages their use because students are commonly learning asynchronously from their instructor and peers. To provide active learning online requires a system in which students' choices and inputs receive meaningful feedback. In this chapter we will discuss the concept of *adaptive learning* and the ways in which it can be used to provide this kind of feedback and thus enable effective active learning online.

Adaptive learning refers to a range of technologies that deliver a dynamically personalized learning experience to each student based on the student's right/wrong answers or their stated or inferred interests (Shute & Zapata-Rivera 2007; U.S. Department of Education 2013). By using these adaptive learning technologies, it is possible to design and build inquiry-based labs that can be delivered online for asynchronous use. The authors of this chapter and their collaborators have used this approach to create two online lab science courses, both drawing on astrobiology concepts, as well as a number of standalone inquiry-based lessons in astronomy, earth science, and other fields.

This chapter will have three main sections:

- An introduction to the concept of adaptive learning.
- A proposed instructional design model for the use of adaptive learning to create inquiry-based science labs.
- Examples of this model's use in astronomy and astrobiology education.

7.2 The *What* and *Why* of Adaptive Learning

Adaptive learning and related terms such as personalized learning and intelligent tutoring refer to various ways in which student data can be used to inform the instruction that is offered and to improve learning outcomes in computerized environments (Shute & Towle 2003; Shute & Zapata-Rivera 2007; VanLehn 2011; U.S. Department of Education 2013; Mavroudi et al. 2018). Adaptive learning as defined in this way has been shown to be more effective than comparable non-adaptive designs (VanLehn 2011; Ma et al. 2014; Kulik & Fletcher 2016). This section will touch on why adaptive learning is more effective and introduce some of the most readily available methods for adaptive learning.

The benefits of adaptive learning are best examined through the lens of a constructivist theory of learning (Fosnot & Perry 2005). Constructivism holds that learning is not a simple linear process, nor is the process of learning a given topic the same for different people. This is because each student must construct his or her understanding on a framework of their prior knowledge and experiences. That is not to say that the student must do this alone, however. A tutor, a peer, or in this case, an intelligent tutoring system can play a key role in helping the student build an accurate and complete understanding of a topic.

Learning with a tutor is more effective than learning independently for several reasons. The tutor can encourage metacognition, prompting the student to review material or test their understanding. The tutor can help diagnose errors and recommend new strategies or approaches. The tutor can also note connections across topics, opportunities for further learning, or next steps. The benefits of human tutoring have been well-studied (Bloom 1984; Cohen et al. 1982; Chi et al. 2001). More recently computer tutoring has been shown to have similar effectiveness under certain conditions (VanLehn 2011; Ma et al. 2014; Kulik & Fletcher 2016).

Although many different types of adaptivity exist, our discussion and use of it will be mostly limited to adaptivity that responds to a student's current actions, including what a given answer implies about the student's current content knowledge or what a given problem-solving strategy implies about the student's procedural knowledge (Figure 7.1(A)). This is in contrast to the more complex, algorithmic adaptive learning systems, which build a detailed *learner model* and use machine learning or expert systems to select an appropriate learning activity for each learner at each

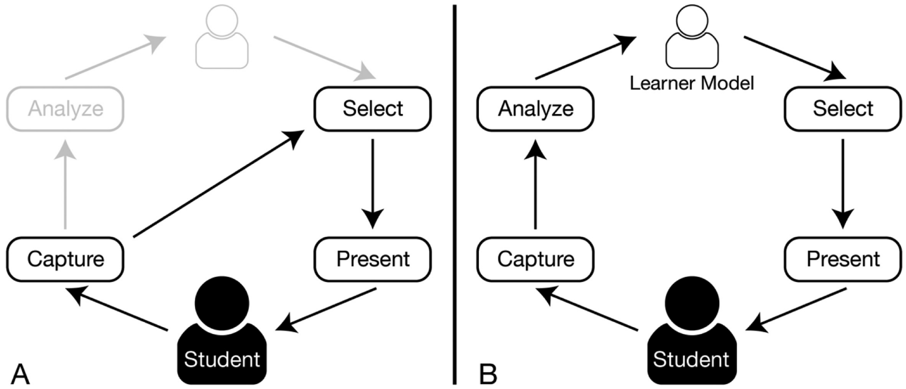


Figure 7.1. Schematic diagram of how adaptive learning functions (Shute & Zapata-Rivera 2007). The *student* performs actions within a lesson. Each of those actions are *captured*. In simpler adaptive learning designs (Panel A), those actions are used to *select* the next learning activity or content which is *presented* to the student. In more complex systems (Panel B), the student actions are *analyzed* using a *learner model* to determine what activity or content the student is presented with.

point in time (Figure 7.1(B)). Although these algorithmic systems are quite powerful, their use to date extends to only a subset of science topics. Moreover, creating a new course with such a system requires extensive resources to build and train the underlying computer models.

The remainder of this section will explain the types of student needs adaptive learning can address, how students who require support are identified, how this support is provided, and what adaptive learning looks like in an inquiry-based science lab. See the final section of the chapter for links to specific adaptive learning technology providers.

7.2.1 What Student Needs Can Be Addressed?

The most straightforward needs are those where a student only needs a reminder about a concept or procedure that he or she has learned before. This could be a formula, a definition, a classification scheme, or the order of a set of steps. We call these straightforward because we are assuming that the student already understands the concept and requires minimal instruction.

More challenging is the situation where the student has not learned some piece of expected prior knowledge. In this case, as opposed to the first, simply providing the formula may not address the knowledge gap—the student here needs *instruction* on the topic, not just a reminder. Similarly, a lesson or curriculum could be structured so that students encounter new topics in an unpredictable order. In this case, adaptivity could provide the appropriate instruction as needed based on the path each student takes through the lesson. This category also includes the issue of misconceptions, where the student thinks they understand the concept, but actually has inaccurate or incomplete knowledge.

Alongside these content-based needs, students may also need guidance or feedback about their approaches to studying, learning, or assessment. This could include not spending enough time or repeating the same approach to a problem through multiple failures instead of thinking of an alternative. Student needs related to metacognition, self-regulation, and other issues can be significant barriers to success, so adaptive designs have great potential here.

7.2.2 How Are These Needs Determined?

In the most basic type of adaptive learning, students might have the option of choosing to receive extra help or information, e.g., “Click here for a refresher on logarithms.” This is essentially non-automated adaptive learning and it can be desirable for optional or supplemental material. Using an adaptive design in this case allows students to choose how much they want to learn about the subject above and beyond the minimum amount that is required by the instructor. This design is not as well suited for gaps in knowledge, because the student (a) may not realize that they have a gap in knowledge (low metacognition) or (b) may not choose to spend the time to address this gap in knowledge (low self-regulation). A compromise, however, is to offer the supplemental material at the start of the lesson while also using automated adaptivity to detect students who struggle later in the lesson and who may benefit from the material they skipped at the start.

Automated adaptive learning infers gaps in skills or knowledge from the student's answers and other interactions with the learning environment. This can be done in a number of ways and with varying complexity:

- Adaptive content can be triggered in response to one or more specific responses to a single question. For example, if the answer was off by a factor of 1000, the feedback might suggest that the student forgot to convert meters to kilometers.
- On a more complex question, detailed and specific adaptive content can be triggered in response to a combination of particular wrong (or right) answers. For example, if a student had two answers that contradicted each other, the feedback could call attention to that without necessarily indicating which (if any) of the current answers was correct. These small corrections are helpful, but still keep the onus on the student to work through the problems on their own.
- There can also be another level of different adaptivity depending on the pattern of responses to the same question. For example, a student whose responses suggest a trend toward improvement can receive different feedback than a student who is repeating the same mistakes.
- The most complicated kinds of adaptive learning build a multi-dimensional model for each student and use that to predict what kind of activity will be most useful for that student at that current point in time. For example, in introductory physics, the adaptive learning system might determine that a student has mastered problems involving positive acceleration, but still struggles with negative acceleration. In response, the student could receive targeted practice on that topic.

7.2.3 How Is Adaptive Learning Delivered?

When it comes to the mechanism for how adaptive learning is delivered, we will introduce two broad categories: *adaptive feedback* and *adaptive pathways*. Adaptive feedback is delivered on the same "screen" as the question or activity that triggered the feedback and it typically aims to address one or more mistakes related to that question. This kind of adaptive design is appropriate when it is assumed that the student has made a minor error that can be easily corrected, such as the reminders described above. Adaptive feedback can also be useful when students work with detailed interactive simulations, because the feedback can responsively guide students to a correct solution, even through multiple small mistakes.

If it is likely that the student has a broader misunderstanding, gap in knowledge, or a durable misconception, then an adaptive pathway is the better design. Adaptive pathways are sets of questions and instruction that will only be shown to some students—those who meet some predetermined set of criteria and who are expected to benefit from this additional instruction. Although adaptive pathways can be brief and specific to the current lesson, this category also includes larger digressions and can even route a student back to material from previous lessons.

7.2.4 What Does Adaptive Learning Look Like for Inquiry-based Science Labs?

As noted in the introduction, there is a strong desire for greater use of authentic science in laboratory science courses. Inquiry-based laboratory courses are intended to help students learn scientific practices and ways of thinking. To be true inquiry, a lesson should offer the student some autonomy in identifying the question to investigate, selecting the methods or approaches to the investigation, and interpreting the results of the investigation. The obvious challenge in asynchronous online settings being that students who exercise such autonomy may struggle or get stuck and be without rapid feedback to get back on track. An adaptive inquiry lesson allows students to have autonomy to make a range of decisions. Students can take what turn out to be unproductive approaches to solving a problem, and adaptive feedback and pathways can be designed to help them *at the appropriate time*. That is, the adaptive design can allow students time to recognize and learn from these failed attempts.

7.3 The Education Through Exploration model

We began this chapter by talking about the need for online, inquiry-based science labs, the challenges inherent in providing them, and the potential for the techniques of adaptive learning to meet those challenges. In our own work we have designed and built a number of online, inquiry-based labs, from which our research and development team has defined a development model called Education Through Exploration (ETX). The core of this model is that curiosity—the desire to understand new things—and the satisfaction of discovery should be used to motivate students to master the skills of exploration, i.e., scientific inquiry (Figure 7.2). This approach to design and these courses fundamentally depend on adaptive learning. Without adaptive technology, it would be very difficult to provide students with enough support to work through meaningful problems in a fully-online environment.

The pedagogical ideas underlying the ETX design model are well-established in the conventional science education literature. The Learning Cycle (Karplus & Thier

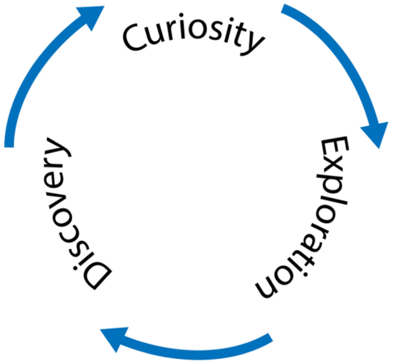


Figure 7.2. ETX learning loop. Curiosity drives exploration. Exploration leads to discovery. Discovery inspires further curiosity.

1967; Lawson 2010) consists of three phases: exploration, term introduction, and concept application. The popular 5E model (Bybee et al. 2006) extended this original Learning Cycle to include engagement and evaluation components. The Learning-for-Use model (Edelson 2001) describes somewhat similar steps: motivation, knowledge construction, and knowledge refinement. The ETX design model makes two substantive contributions to this body of thought. First, the ETX design model proposes the idea that curiosity is important not just as motivation, but an important outcome itself. Second, the ETX design model incorporates digital learning technologies, which changes what is possible in the space of inquiry-based learning and makes it far easier to inspire curiosity in students.

It is important to clarify that inquiry in ETX designs is guided inquiry, not open inquiry. Here, open inquiry refers to an activity in which students, not the instructor, generate the question and method of investigation in addition to being responsible for the ultimate interpretation of the results (Blanchard et al. 2010). Although open inquiry can be effective, researchers have criticized it as being less effective than guided inquiry or even non-inquiry (Klahr & Nigam 2004; Kirschner et al. 2006; Settlage 2007; Blanchard et al. 2010). In addition, for our purposes in building asynchronous online learning experiences, the difficulty of accounting for complete student autonomy in an open inquiry design makes it infeasible.

To design learning experiences that create the learning loop shown in Figure 7.2, we have identified a number of *design practices*, organized into three categories: *conveying authentic science*, *learning as a journey*, and *digital by design*. Our goal is that these practices lead to learning experiences in which an interesting setting, phenomenon, or question inspires curiosity to motivate students to explore; to experiences in which that exploration naturally takes the form of asking and answering scientific questions using observations and data; and to experiences in which answering those scientific questions inspires new and interesting questions for future explorations. These categories and practices are best thought of as heuristics, so there is some overlap among the categories and the exact use of the practices will vary from lesson to lesson, as illustrated in Section 7.4 of this chapter.

7.3.1 Conveying Authentic Science

The practices within *conveying authentic science* encompass the essential qualities of inquiry learning as well as features designed to spur curiosity and interest.

Most importantly, students using an ETX lesson should learn science by doing science, that is, by engaging in scientific investigation. This means that the students' activities should be motivated by a question or hypothesis, that students should be able to collect or compile data, and that students should apply scientific reasoning to draw a conclusion about the guiding question based on the available data. To be consistent with true inquiry (see Blanchard et al. 2010), ETX lessons should include opportunities for student choice, such as selecting a method of observation, order of investigation, data quality threshold, etc. Students should also be able to interpret the results of the investigation.

Another important aspect of an ETX design is the use of real-world and interdisciplinary problems. These related ideas provide both educational and motivational benefits. The complexity of real-world problems demands that students understand concepts in multiple contexts. Similarly, integrating concepts from multiple disciplines provides a better illustration of how science is used to solve complex problems than the traditional siloed introductory science course. Working on real-world problems can also be more compelling than working on abstract examples, particularly for students who are not majoring in science. In some cases, this could even be an opportunity for students to write or think about connections to their own major and how the scientific issue under discussion might be relevant beyond the immediate inquiry task.

Last, as much as possible these learning experiences should connect to the frontiers of knowledge in a given field. This is not only a demonstration of authentic science, but by posing questions without clear or certain answers there is an opportunity to discuss how science deals with uncertainty and how an unknown, but constrained, answer can still be useful. Moreover, in a research university setting, professors can look for examples from their own research.

The goal of conveying authentic science is supported by techniques from our third category—*digital by design*. It also provides useful constraints to our second category—*learning as a journey*—in that the process of reaching a final answer should be of equal importance to reaching the correct answer and that the assessments and adaptive feedback should reflect this ideal.

7.3.2 Learning as a Journey

The practices within *learning as a journey* serve to create learning experiences whose structure and flow support the ETX learning loop (Figure 7.2). As the name implies, an ETX learning experience should emphasize growth in knowledge and capabilities. It should demand an appropriate level of mastery, but the current goal(s) should be clear to the student and failure should always be used as an opportunity for learning.

Communicating the learning objective of an experience to the students allows them to monitor their progress and to better connect what they are learning to what they already know. This is important in an ETX learning experience too, but in addition to high-level learning objectives, we emphasize the goals of the scientific problem-solving activity that are specific to the lesson and those of the course as a whole. Including these tangible goals in addition to the more abstract learning objectives grounds those objectives and gives the students stronger motivation toward achieving both types of outcomes. The nested short and long term goals also serve to link concepts together across the course, which helps to cement understanding (cf. distributed practice). As an example, the "Marble Bar" virtual field trip in *Habitable Worlds* takes students to a visually complex rock formation in Australia. The lesson begins by asking students to discover "how this rock sequence formed." To move forward in the lesson, students zoom in to make a series of more small-scale discoveries before zooming out at the end to answer the larger, initial question.

ETX designs have numerous opportunities for students to learn from failure. Failure at a task in a learning environment is often interpreted negatively (by students, but also perhaps by teachers). *In actuality, failure is almost always a point at which learning can occur* (e.g., Kapur 2008). In ETX designs, or other kinds of adaptive learning, the use of adaptive feedback and adaptive pathways is a powerful tool for helping students to learn from failure. Most clearly, these instances are opportunities to better understand the specific concept or procedure around which the mistake was made. There are also opportunities to learn metacognitive skills from failure. Here, adaptive designs are even more powerful, because the system can track behaviors and responses to failure through time for each student. For example, a student who makes the same mistake several times in a row could benefit from reflecting on his or her strategies rather than just checking surface-level problems.

Related to learning from failure and consistent with the ideas in conveying authentic science, ETX designs emphasize the process and the steps required to solve a problem just as much as the ultimate answer to that problem. That is not to say that the answer is not important, but rather that reaching an answer without following a good process misses the point. In practice, this means that ETX designs might pose a conceptual question instead of or in addition to a calculation question. It also means that the choices and considerations of an experimental design should be a part of the learning experience.

7.3.3 Digital by Design

Cutting across all of these practices is the use of digital technologies, including visualizations or other multimedia, interactive simulations, and intelligent tutoring. The phrase *digital by design* is meant to imply that these designs are not constrained by the limitations of in-person learning. The starting point for a new digital learning experience design should be "what is the best way for a student to understand this topic?" In contrast, an in-person design necessarily begins with a compromise, namely, "what is the best way for a student to understand this topic *that can be done in a classroom*?"

The ideal activity to learn a specific concept may not be possible in an in-person class. Perhaps it is logistically challenging, expensive, or impossible. Perhaps it would take days, years, or millennia to experience in real-time. Any one of these can be overcome in a digital learning environment. This recommendation also means that an existing in-person learning experience need not, or perhaps should not, be the starting point when designing a digital learning experience. If the digital version can do something novel that is better, it should.

Active learning—the idea that students learn best when they are cognitively engaged—is not at all unique to digital learning, but it remains just as important in that realm as it is in-person. In the context of *digital by design*, active learning is both a trap and an opportunity. To call back to the chapter's introduction: it is easy to create passive digital learning experiences. However, digital learning also offers compelling and unique ways for students to learn actively, and this is the opportunity. Following from the other practices, and particularly *conveying authentic science*, ETX designs employ active learning through their focus on scientific exploration and discovery. Having access to a range of assessment types (simple questions, simulation-based questions, etc.) also creates more opportunities for students to learn actively.

Finally within *digital by design* is the use of adaptivity. Of course, this topic does not need special treatment in this particular chapter, but we will conclude this section by noting that while some aspects of digital learning go beyond what is possible in-person, there are some aspects of in-person learning, such as being able to receive immediate expert feedback from an instructor, that digital learning has only begun to replicate.

7.4 Examples of ETX Model and Adaptive Learning in Online Astronomy and Astrobiology Education

Using ETX designs, we have developed and deployed two adaptive, fully online undergraduate-level courses emphasizing astrobiology. In this section we will use these to illustrate the techniques described in the previous section. These examples were all built using the Smart Sparrow Adaptive eLearning Platform (Ben-Naim 2011). Smart Sparrow provides adaptive learning capabilities that can be built and modified entirely within a browser-based lesson authoring environment. Rapid end-user editing and customization has been important to the development of all of the examples we will show. All of the examples we will discuss are web-browser-based.

7.4.1 Habitable Worlds

Habitable Worlds is an online astrobiology course intended primarily for undergraduate non-science majors. At Arizona State University, it fulfills the quantitative science general education requirement. Unlike most traditional courses meeting this requirement, which have separate laboratory and lecture sections, *Habitable Worlds* has a unified learning experience that blends applied thinking and active problem solving throughout all lessons. Although it does include some short “lecturette” videos, these are primarily used to bookend the active learning. Additional information about *Habitable Worlds* can be found in Horodyskyj et al. (2018).

The course scaffolds the student experience narratively and intellectually with the goal of finding a habitable planet beyond our solar system. This goal is systematized and explained through the famous Drake equation (Drake 1961). The terms in the Drake Equation are used to introduce and motivate new topics. For example, the R^* term—the average rate of star formation—motivates learning about the properties of stars and the process of star formation, while the n_e term—the fraction of planets that are “Earth-like”—reveals the need to understand what an Earth-like planet is and in what circumstances one might exist. The course rewards mastery of the concepts related to each Drake equation term in the final project, where students must use their knowledge to find at least one of a handful of habitable planets orbiting 500 fictional candidate stars.

Habitable Worlds delivers inquiry learning experiences primarily through the use of interactive simulations, immersive and interactive virtual field trips (iVFTs), and basic inputs like checkboxes or multiple-choice questions. Adaptive feedback is used throughout the course. Any page with student input is programmed with multiple triggers to respond intelligently to students' activities on a page, which can range from simple numerical inputs to complex simulator set-ups. The interactive components are built so that actions within a simulation or iVFT can be "seen" and responded to by the adaptive learning system. This is critical to our ability to build meaningful inquiry learning in *Habitable Worlds*.

We will discuss two examples from *Habitable Worlds*. The first, a lesson about the properties of stars, reflects design elements used in numerous lessons across the course. The second, the course's summative, multi-week, final project, is an example of the novel approaches that are possible with fully computer-based instruction.

7.4.1.1 The Properties of Stars

The brightness–distance activity early in the course illustrates a number of the techniques described in Section 7.3 as well as how adaptive learning is used in *Habitable Worlds*. This lesson introduces the brightness–distance relationship, which is key to understanding later concepts including stellar luminosity and other properties derived from the luminosity. Figure 7.3 shows screenshots from an investigation in this lesson.

Although this lesson does not make use of cutting-edge science, it does provide students a chance to develop a foundation for scientific investigation. The lesson trains students to test a hypothesis for basic plausibility before moving forward. Here, if students propose that more distant objects are *brighter* than or the same brightness as closer objects, they are sent down an adaptive pathway that asks if this hypothesis is consistent with what they know from direct experience (Figure 7.3(B)). Later in the investigation, students are given the freedom to propose a methodology for collecting data. The adaptive design ensures that their methodology meets certain criteria, but otherwise students have agency over setting up their methodology. With adaptive feedback, we can even hold students to their methodology, so if they said that 20 data points were needed they must collect at least 20 before progressing. The predict–observe–explain cycle shown here is used across *Habitable Worlds* in various forms.

Another design highlight from this example is the way that a digital learning experience can provide instant feedback and allow the student to try several alternative solutions quickly. Apart from the fact that collecting apparent brightness data in-person would be difficult, overlaying multiple functional forms of the brightness–distance relationship would be slow and could distract from the actual learning objective. In addition, the next phase of the lesson allows the student to test whether the brightness–distance relationship for our solar system applies to stars of different luminosity—to test for the generalizability of their explanation. This is another important scientific principle and one that the digital, adaptive design readily supports.

What do you think is the relationship between brightness and distance?

☐ Objects will appear the same brightness at any distance.
☐ Objects will appear twice as bright when twice as far away.
☐ Objects will appear half as bright when twice as far away.
☐ Objects will appear a quarter as bright when twice as far away.
☐ Objects will appear an eighth as bright when twice as far away.

Your hypothesis:
Objects will appear the same brightness at any distance.

We must do a quick plausibility check on our hypothesis to see if it makes sense in a setting that we're *familiar* with, before applying it to one that we're *not familiar* with.

According to your hypothesis, all of these lights should *appear to have the same brightness.*

Do these lights all *appear* to have the same brightness?

☐ Yes ☐ No

Your Methodology
(check off when complete)

☑ Sufficient number of observations
☑ Good distance distribution of observations

Hypothesis under investigation:
Objects will appear half as bright when twice as far away.

Your predicted observations are now displayed as a line. Do your *actual* observations match what you *predicted*?

You have rejected your initial hypothesis. Select a new one, then compare it to the observations you have already made.

Objects twice as far are a quarter as bright

Graph manipulation has been disabled so that you don't erase your dataset.

Figure 7.3. Screenshots showing a predict–observe–explain cycle in the second *R** lesson. Students make a prediction about the mathematical relationship between distance from a light source and its apparent brightness (A). Adaptive feedback is used to check that this prediction is plausible (B). They then use a solar system simulation to plot this same relationship (C) and compare these observations to their initial prediction (D, prediction is overlain as a line). The cycle concludes with the student evaluating their prediction and identifying the true relationship if their initial hypothesis was incorrect (E).

Finally, through this example we can illustrate how adaptive learning designs can be iteratively improved. The brightness–distance activity has undergone a series of improvements that were informed by study of student learning analytics data collected by the Smart Sparrow platform. We reviewed the amount of time spent, number of attempts made, and patterns of wrong answers chosen by students. The first redesign sought to reduce the time and number of attempts spent on the "experiment" section by adding more detailed adaptive feedback and pathways to

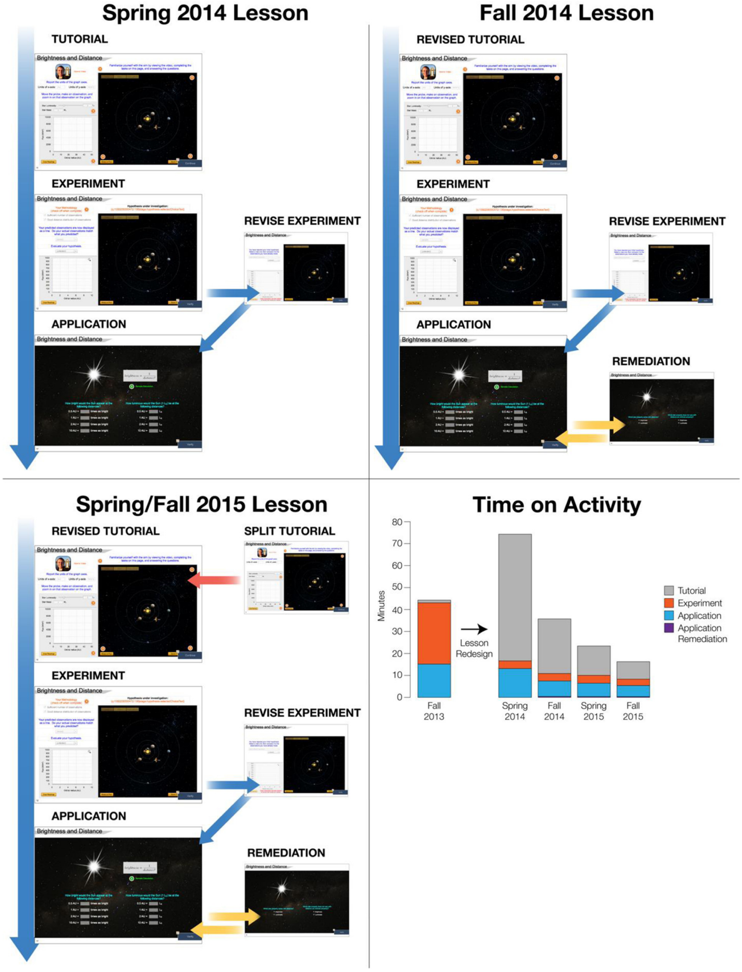


Figure 7.4. Panels illustrate the brightness–distance lesson structure across multiple revisions, beginning with the initial redesign in Spring 2014. The last panel shows how the length of time required to complete the lesson and its subsections changed following each revision. The final version successfully reduces the time spent on the experiment section without increasing the overall time required to complete the lesson.

the preceding tutorial section. As the graph in Figure 7.4 shows, the Spring 2014 change did reduce the time students spent on the experiment, but at the cost of much more time spent on the tutorial. Subsequent improvements in Fall 2014 and Spring 2015 reduced the total time required to complete the lesson to below the Fall 2013 baseline. Note that the learning objectives and summative activities were essentially unchanged across these revisions.

7.4.1.2 Habitable Worlds Final Project

In the *Habitable Worlds* final project, students are tasked with searching 500 candidate stars to find a habitable planet. To accomplish this, they must apply the skills they have learned from the course to complete calculations, build models of their star–planet system, and identify habitable worlds before the end of the term. Some of the project interface views are shown in Figure 7.5. Students are graded on their work in two ways: data quality and “scavenger hunt” objects found. These grades reflect the accuracy and appropriateness of calculations and the breadth of study, respectively. This summative activity not only tests for understanding of concepts from throughout the course, it also serves as a narrative endpoint for the course and represents a tangible accomplishment for students that demonstrates their achievement.

Because the project serves as the course’s final assessment, we do not provide adaptive feedback or pathways. However, a modified version of the course might

EDIT DATA

ASSESSMENT

Want to speed up your calculations? By spending your funding you can assess a column of your data (e.g. Distance or luminosity), and if your calculations are accurate enough, you'll have that column generated automatically for all stars and planets. Be careful, because each assessment will cost you whether it's successful or not.

OBSERVATIONS				ANALYZED DATA							
STAR	PARALLAX (″)	PEAK λ (nm)	APP. MAG.	DISTANCE (ly)	LUMINOSITY (L)	PEAK λ COLOR	TEMP (K)	CLASSIFICATION	MASS (M)	RADIUS (R)	LIFETIME (years)
ARTUS	0.183	366	+1.08	53.00	?	No Selection	?	No Selection	-	-	-
BABILMANA	0.346	833	+6.12	62.00	?	No Selection	?	No Selection	-	-	-
BARCYN	0.128	1,613	+13.44	23.00	10.00	Orange	10345	Main Sequence	2.000	3.500	1.500 Gu
BISQUATH	0.152	568	+4.91	22.00	?	No Selection	?	No Selection	-	-	-
BRUMIR	0.181	1,463	+11.93	12.00	?	No Selection	?	No Selection	-	-	-
CAERINO	0.126	461	+3.7	41.00	?	No Selection	?	No Selection	-	-	-
CAEVE	0.203	459	+2.63	623.0	?	No Selection	?	No Selection	-	-	-
DAIDRETH	0.056	449	8.74	43.00	?	No Selection	?	No Selection	-	-	-
GARUDHY	0.072	1,258	+12.75	66.00	?	No Selection	?	No Selection	-	-	-
GINA	0.055	870	+10.46	24.00	?	No Selection	?	No Selection	-	-	-

VIEWING 1-10 OF 14
TOTAL COLLECTED 14

PARALLAX (″) 0.128
PEAK WAVELENGTH (nm) 1613.0
APPARENT MAGNITUDE +13.44
METALLICITY 0.21

DISTANCE (ly) 23.00
LUMINOSITY (L) 10.00
TEMPERATURE (K) 10345
PEAK λ COLOR Orange
MASS, RADIUS & LIFETIME ARE ONLY RELEVANT FOR MAIN SEQUENCE STARS
MASS (M) 2.000
RADIUS (R) 3.500
LIFETIME (YEARS) 1.500 Gu

Figure 7.5. Screenshots from *Habitable Worlds* final project.

choose to more tightly scaffold this activity by building adaptive pathways that led back to the earlier lessons in which students first learned the concepts required by the project. The current version does offer some adaptive support by allowing students to use tools (simulations or equations) from elsewhere in the course. To unlock these tools for use in the project, students must have completed those earlier lessons, which serves to gate each student's progress to material that they have already learned.

7.4.2 BioBeyond

Like *Habitable Worlds*, *BioBeyond* is an online biology course, borrowing on astrobiological themes, intended for undergraduate non-science majors. Rather than learning how to locate habitable exoplanets, *BioBeyond* students learn about the processes of life and evolution, how life shapes and is shaped by geology, and what it means for a planet to be habitable. *BioBeyond* was designed and built via collaboration between Smart Sparrow and Arizona State University.

There are additional differences between the courses, some of which may be instructive for other adaptive learning designers. *BioBeyond* was designed to meet the common requirements for introductory biology, yet within these external requirements there was still room for creativity such as the decision to focus on astrobiology. *BioBeyond* often uses historical scientific discoveries as a narrative and scientific framework for its inquiry activities. This grounds the activities and could motivate supplemental activities related to those scientists or discoveries. Finally, although both courses employ active learning extensively, the design of *BioBeyond* uses interactivity on nearly every screen, adding in more opportunities for students to demonstrate understanding or check their work.

Our example from *BioBeyond*, the Time Traveler's Guide, showcases immersive, interactive virtual field trips (iVFTs). This technology is also used to a smaller degree in *Habitable Worlds*.

7.4.2.1 Time Traveler's Guide

The Time Traveler's Guide unit in *BioBeyond* makes extensive use of iVFTs and offers a good illustration of both adaptive learning and the ETX design practices. The premise of this unit is that the student can travel back in Earth's history in order to observe what organisms existed and what types of environments were present at three key points in time: 65 million years ago, 560 million years ago, and 3.5 billion years ago (Figures 7.6 and 7.7). The students make initial predictions about what they will find at each temporal destination and then use iVFTs to explore the three different environments. Using the adaptive learning platform, it is simple to remind students of their initial prediction and ask them to revise it once they better understand each paleoenvironment.

iVFTs are an excellent tool for active, inquiry learning. We discuss this digital learning technology and its application at greater length in Mead et al. (2019). Most obviously, iVFTs bring students to places that are difficult or impossible to access in-person and, for online learning, they bring the benefits of in-person

Click Ground View then Detailed view (it'll be on your left when in Ground View) to see this area of the outcrop up close. A couple of pieces of fossil evidence have been highlighted for you. They are surrounded with yellow plastic. Observe these closely. You can get a sense of what bone looks like here in the outcrop.

Continue to explore the area searching for other fossils within the zoom view. You can close this window by clicking the X in the upper right corner, and close the zoom view by clicking "Close Gigapan" in the bottom right corner.

Click next when you think you've identified a fossil or two.

Make sure you have the large image of the excavation site pulled up to continue. To find the site, click on Ground View then Detailed View in the virtual field trip. You may need to look around a bit.

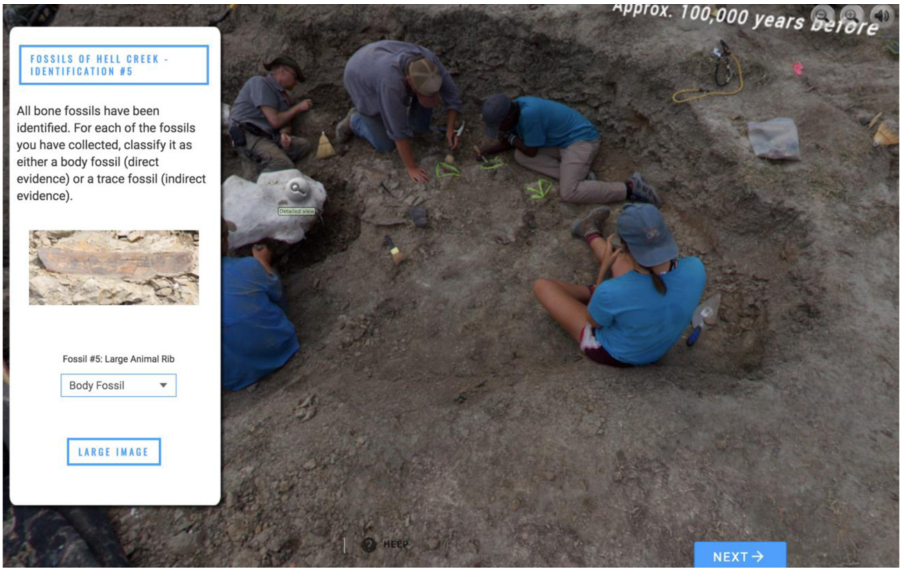
Let's do a tongue test to see if these objects are bone fossils. Select the one that you think is most likely a bone fossil and click Test to see if it sticks to your tongue.

○ ○ ○
● ○ ○
○ ○

No luck. Just a rock, or maybe some indirect evidence fossil. Let's test the rest of them.

Figure 7.6. Screenshots from the Time Traveler's Guide iVFT set 65 million years ago. The first panel shows how students are helped through basic navigation in the virtual environment. The second panel shows one of the ways students can collect data about the field site. The third panel shows a formative assessment. Note the adaptive feedback in the lower right.

education to the digital realm. In Time Traveler's Guide, students explore field sites in Western USA, and South and Western Australia, crossing not only geologic history but also the globe. Within these diverse and interesting sites, students are able to learn by applying simplified, but realistic scientific methods, including data collection. In the 560 million year ago lesson, for example, students find fossils in a rock outcrop and then use a dichotomous key to uniquely identify each organism represented.



FOSSILS OF HELL CREEK - IDENTIFICATION #5

All bone fossils have been identified. For each of the fossils you have collected, classify it as either a body fossil (direct evidence) or a trace fossil (indirect evidence).

Fossil #5: Large Animal Rib

Body Fossil

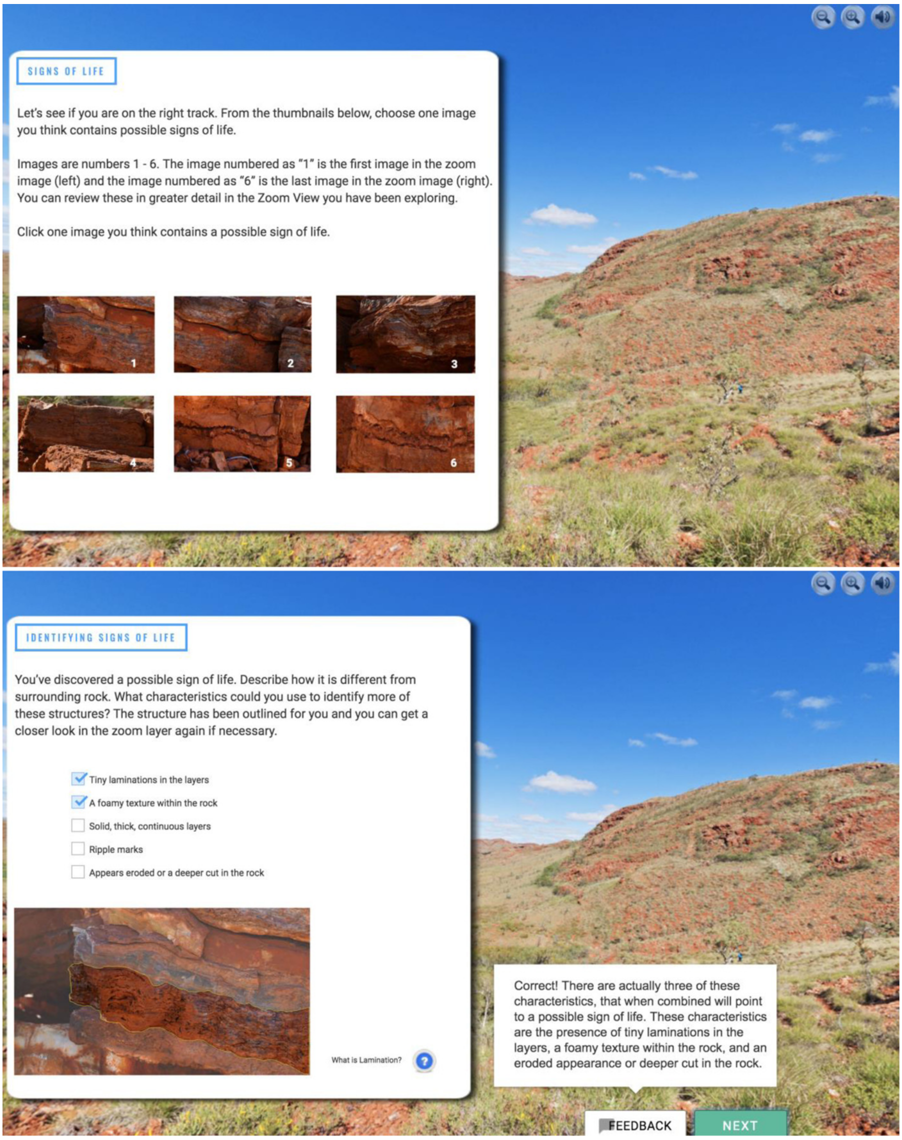
Figure 7.6. (Continued.)

7.5 Implementing Adaptive Learning

Adaptive learning designs, though not new, are far from the norm in online or computer-based learning. The slow adoption of adaptive learning is in part simple inertia—any change is difficult. It is also due to the real and perceived challenges of implementing adaptive designs. Our goals in writing this chapter were to provide instructors and other educational decision makers with the background information necessary to decide if adaptive designs meet one of their current needs and to provide these potential users with a foundation from which they can create or customize new adaptive learning designs. In this final section, we will briefly discuss some practical issues associated with implementing adaptive learning.

There are many educational technology companies that offer adaptive learning products. These companies and products each take a different approach in providing an adaptive learning experience to students. They also vary in terms of the subject diversity of available pre-made courses as well as how much control instructors have over making changes to those courses. Some well-known products (listed alphabetically) include:

- Acrobatiq: http://acrobatiq.com/
- ALEKS: https://www.aleks.com/
- Cerego: https://www.cerego.com/
- CogBooks: https://www.cogbooks.com/
- Knewton: https://www.knewton.com/
- Open Learning Initiative: https://oli.cmu.edu/
- Smart Sparrow: https://www.smartsparrow.com/



SIGNS OF LIFE

Let's see if you are on the right track. From the thumbnails below, choose one image you think contains possible signs of life.

Images are numbers 1 - 6. The image numbered as "1" is the first image in the zoom image (left) and the image numbered as "6" is the last image in the zoom image (right). You can review these in greater detail in the Zoom View you have been exploring.

Click one image you think contains a possible sign of life.

IDENTIFYING SIGNS OF LIFE

You've discovered a possible sign of life. Describe how it is different from surrounding rock. What characteristics could you use to identify more of these structures? The structure has been outlined for you and you can get a closer look in the zoom layer again if necessary.

☑ Tiny laminations in the layers
☑ A foamy texture within the rock
☐ Solid, thick, continuous layers
☐ Ripple marks
☐ Appears eroded or a deeper cut in the rock

Correct! There are actually three of these characteristics, that when combined will point to a possible sign of life. These characteristics are the presence of tiny laminations in the layers, a foamy texture within the rock, and an eroded appearance or deeper cut in the rock.

Figure 7.7. Screenshots from the Time Traveler's Guide iVFT set 3.5 billion years ago. In the first two panels, students are visually introduced to the ancient fossils that can be found at this field site. The third panel shows the use of Gigapan imagery, which allows students to explore a large fossil bed up close and search for the kinds of fossils they learned about previously. The fourth panel illustrates a drag and drop response format in which students compare the fossilized stromatolite texture to various modern rock textures. Note the adaptive feedback in the lower right.

The website EdSurge also hosts a tool that allows instructors to filter more than 50 current courseware products by features, including adaptive learning. This is found at: https://www.edsurge.com/product-reviews/higher-ed/courseware.

Now that you know what to look for, let's go out to see if there are more of these possible signs of life. However, be aware as you search, you may find the structures will appear in different shapes and thicknesses. But what they have in common is

- Lamination
- Foamy texture
- Eroded appearance

How many can you find? Click "Next" when you've found as many as you can in this area.

Now that you've identified the potential structures of life, your next question is probably, what are they? Here you see a few examples of communities of organisms or their remnants that exist today. Which of these organisms most closely resembles the structures observed here in the North Pole Dome?

Drag the image that most closely resembles the North Pole image into the box. Scroll down to see all of the possible images in the bank - there are four.

The image you have selected is of diatomaceous earth, which like the North Pole formations is made of remains of microorganisms, however, it lacks the lamination, foamy texture, and erosion of the North Pole formation.

Image Credits:

Figure 7.7. (Continued.)

In addition to varying by subject matter and focus, these existing products also vary in other ways. In some products, most or all instructional material is selected algorithmically—that is, that every student may receive a different set of tasks to complete. Others rely more on the learning designer to build a structured lesson, with adaptivity being used to support students along that path. Some products include a course "author," allowing local users, such as the course instructor, to make changes or even create new materials. Last, the use-cases for these products will differ, so it is important to consider whether a particular adaptive learning product can be used as a course supplement for an in-person course—as homework or as classwork in a flipped mode—and/or if it can be used as a standalone course delivered fully online.

Numerous other practical considerations exist. Although we cannot address them in detail, we will note them here. First, it is typically possible to connect an adaptive learning product to learning management systems (LMS), such as Blackboard or Canvas. Doing this not only simplifies the process of assigning lessons and recording grades, the use of "single sign-on" makes it easier for students to verify their credentials and gain access to the lessons. Second, although web-browser-based products are very convenient, when technical issues do arise, they can be very frustrating for students. It is necessary to ensure that students have reliable options for technical support, whether through the school or through the adaptive technology company. Finally, while adaptive learning is powerful and effective, there remains a need for an active instructor presence, particularly in fully-online courses. From our experience with *Habitable Worlds*, the discussion board helped instructors to identify common content issues as well as to form a personal connection with students in the class.

7.6 Conclusion

This chapter has introduced the concept and explained the fundamental mechanisms of adaptive learning technology. It also presented the Education Through Exploration design model, which relies heavily on adaptive learning, as one approach for offering meaningful and effective inquiry science learning online. The use of adaptive technology for science learning is in its early days and, therefore, far from reaching its full potential. Importantly, the fundamental tools and approaches for designing adaptive learning are certain to evolve and improve in the coming years. For example, the use of *learner model-based* adaptive learning and the application of machine learning to select learning activities has only just begun to influence online learning at large. Separately, social learning and collaboration have long been important to in-person settings. These are complicated to incorporate into the typically asynchronous adaptive learning systems, but research suggests that they could be very beneficial to some students. We encourage readers to reflect on their current teaching and explore ways that existing adaptive learning products could expand or improve their work. We also encourage the creation of new adaptive learning materials and continued innovation in this field.

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