AN EXAMINATION OF TEACHER FORMATIVE ASSESSMENT PRACTICES IN HIGH SCHOOL BIOLOGY INSTRUCTION WHEN USING COMPUTER-BASED INTERACTIVE MODULES

by

MELISSA ANN JURKIEWICZ

(Under the Direction of J. Steve Oliver)

ABSTRACT

The purpose of this study was to explore how the integration of instructional technology into an introductory biology high school course supports and constrains teachers' formative assessment practices. The specific technologies involved in this study were interactive 3-D computer modules involving cellular transport, coupled with a web application, the SABLE system, which allows real time monitoring of students' work. Three secondary biology teachers were participants in the research. Interviews with those teachers and observations of their implementations of the cell unit were the primary source of data for the research.

Several characteristics inherent in the instructional technologies supported the teachers' formative assessment practices. The computer modules and the SABLE system elicited, gathered, organized, and stored evidence of student learning, enabling teachers to devote more energy towards interpreting and acting on the elicited evidence. The SABLE system allowed teachers to analyze students' work and modify instruction in real time, providing the opportunity to complete multiple cycles of formative assessment with each student. Through enabling teachers to monitor students' work, the SABLE system allowed teachers to maintain a connection to the process of teaching and learning. When interacting with the computer modules, students began to develop knowledge of science concepts and to construct a new vocabulary. The students' new knowledge allowed for teachers and students to share a context in which meaningful discussions about science concepts could occur.

Several characteristics inherent in the instructional technologies also constrained teachers' formative assessment practices. For instance, the cluster of open-ended response questions towards the end of the modules and the lack of an automated grading component hindered teachers' abilities to quickly assess the data from the open-ended response questions.

This research report discusses implications for science teacher educators and developers of instructional technology. Additional research is needed in order to understand the role of instructional technology as a catalyst for increasing the effectiveness of how teachers use formative assessment.

INDEX WORDS: Formative assessment, Technology-enhanced formative assessment, 3-D computer simulations, Instructional technology, Secondary science education

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DEDICATION

I dedicate this dissertation to my husband. During a long and stressful process, you patiently supported me, encouraged perseverance, reminded me of my ability, and made me laugh. I will always appreciate the sacrifices you made for me so that I could fulfill my dreams.

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CHAPTER 1

INTRODUCTION

As we have entered the 21st century, new challenges have been set before the education system, including the need to support the science knowledge development of students living in a rapidly changing global society. "Rapid changes in the world—including technological advancement, scientific innovation, increased globalization, shifting workforce demands, and pressures of economic competitiveness—are redefining the broad skill sets that students need to be adequately prepared to participate in and contribute to today's society" (National Science Teachers Association (NSTA), 2011, p. 1). Students in the 21st century need to be able to understand and analyze large systems, to think critically and develop innovative solutions to new problems, and to work with diverse people in diverse contexts (National Research Council (NRC), 2010; NSTA, 2011; Partnership for 21st Century Skills (P21), 2009).

The search for viable paths to maintain America's competitiveness in an ever-increasing technology driven global economy has narrowed its focus to STEM education (Duschl, 2008). The President's Council of Advisors on Science and Technology concluded that, "STEM education will determine whether the United States will remain a leader among nations and whether we will be able to solve immense challenges in such areas as energy, health, environmental protection, and national security" (2010, p. v). In particular, the knowledge and skills that students develop in science courses align with the knowledge and skills that 21st century students need to develop. The NRC (2010) explained,

> Science is seen as a promising context because it is not only a body of accepted knowledge, but also involves processes that lead to [21st century] knowledge . . . For example, developing and presenting an argument based on empirical evidence, as well as posing appropriate questions about others' arguments, may develop complex communication skills and nonroutine problem-solving skills. (p. 1)

As science education attempts to support the changing needs of its students, the demands placed on science teachers have changed as well. Although there are several teacher practices that support the developing 21st century student, two practices in particular have been receiving considerable attention within science education: formative assessment and the integration of instructional technology.

Formative assessment, sometimes referred to as assessment *for* learning, has been receiving considerable attention for supporting teaching and learning (Black & Wiliam, 1998b). Furthermore, the NRC (2001, 2007) has labeled formative assessment as one of several aspects that are of highest priority in science education because it plays a key role in promoting student learning. Formative assessment transforms traditional classrooms into student-centered classrooms (Henderson & Dancy, 2011; Smith, Douglas, & Cox, 2009). It is a discursive practice that promotes student learning by making student thinking visible. Teachers gather information about students' conceptual understandings so they know how and when to move students forward in their thinking. Also, making students' thinking visible makes students aware of their own thinking, which promotes the development of metacognition (Kuhn & Reiser, 2006). Furthermore, teachers activate their students' prior knowledge and aid them in testing, modifying, and constructing their knowledge (Minstrell & van Zee, 2003). Thus, formative assessment promotes student learning by making student thinking visible, supporting the development of metacognition, and activating prior knowledge.

Formative assessment is arguably one of the most important practices that teachers can utilize in order to improve teaching and learning in their classrooms (Black & Wiliam, 1998b). Wiliam (2007) stated that, "helping teachers develop minute-by-minute and day-by-day formative assessment practices is more cost-effective than any other strategy" (p. 184). The research literature has extensively documented that the implementation of effective formative assessment practices creates positive gains in student achievement (Black & Wiliam, 1998a; Crooks, 1988; Natriello, 1987). Black and Wiliam (1998a), after reviewing at least twenty studies, concluded that if teachers effectively implemented formative assessment, then the increases in student learning would be of a magnitude that could propel the United States into the top countries in the world on student achievement tests. These studies examined elementary through undergraduate students across various subjects and countries. Although all types of students demonstrated achievement gains, low-performing students demonstrated higher gains than high-performing students, which would lower the achievement gap while improving student performance overall.

In the midst of the reform movement away from assessment *of* learning, otherwise known as summative assessment, towards assessment *for* learning, technology in the classroom has been given increased attention. The earliest forms of technology used for educational purposes in formal school settings included writing utensils, paper, chalkboards, and textbooks (Kent & McNergney, 1999). Throughout the twentieth century, there were several technological revolutions that promised to transform the education system, and each of them have been less successful than anticipated, including the use of radio, film, and television. With the exception of computer technology, the most common types of technology consistently and effectively integrated into the process of teaching and learning are still pen and paper, chalk/whiteboards, and textbooks (Kent & McNergney, 1999).

Previous technological revolutions have failed to transform education because most of these technologies were developed for a non-educative commercial use and only later were marketed as powerful and effective educational tools. According to Lee and Winzenried (2009), school officials adopted each new promising technology and required teachers to use them without analyzing the educational purpose and value of them. They continued,

> What will become evident as one examines the technology introduced in the twentieth century was that virtually all of it obliged the teachers to dramatically change their style of teaching if they were to make extensive use of the technology. Rather than teachers being provided with tools that would assist their teaching, teachers were obliged to change their ways to suit the tools on offer. (p. 10-11)

Furthermore, film, radio, and television were inflexible educational tools that passively engaged students, required extensive financial resources and equipment, and often only indirectly related to curricular aims (Kent & McNergney, 1999).

Computer technology, including handheld electronic devices, software, the internet, and electronic presentation methods such as digital white boards, with its flexibility and wide range of applications offers more promise than its predecessors. It is able to accomplish the tasks of radio, film, and television while still offering other novel uses. According to the National Education Association (NEA, 2008), in public schools in the United States, the ratio of the number of students per computer with internet access is at an all time low of 3.8 to 1. With increased access to computer technologies, teachers' repertoires of instructional strategies have enlarged, and scholars feel that this will result in a change in teaching practices. According to Broadfoot (2007),

> We are still in the early stages of the digital technologies that will revolutionize the delivery of education in ways that we cannot yet envisage. But already the advent of interactive technologies of all kinds is making possible a personalized, instant and engaging pedagogy in a way undreamed of even five years ago. (p. 150)

In particular, interactive computer activities in science are becoming more frequently utilized as an effective instructional strategy that enables deep conceptual learning and higher fidelity in the implementation of formative assessments (Buckley & Quellmalz, 2013). The NRC (2009) released a report calling for an in-depth examination of computer games and simulations in the teaching and learning of science. They indicated that computer games and simulations offer a new approach to the teaching and learning of science that engages students and allows them to develop conceptual understanding of science concepts and participate in scientific practices. It is this kind of in-depth examination of an interactive computer technology that is at the heart of the research being reported here.

Research Purpose

The purpose of this study is to develop understanding regarding how an instructional use of interactive computer technology supports and constrains biology teachers' formative assessment practices. In particular, this study focuses on two specific computer technologies. The first technology involves three 3-D computer simulations that address the biological concepts of diffusion, osmosis, and filtration. The second technology is a web application, called Skills Assessment Based Learning Environment (the SABLE system), that allows for teachers to monitor students' work as they engage with the 3-D computer simulations. This study examines three secondary biology teachers' formative assessment practices as they implement an instructional unit in introductory high school biology in a unit on the cell in which they utilize the 3-D computer simulations and the SABLE system. By examining all of the teachers in their natural teaching environments implementing lessons using and also not using the aforementioned technologies, I identified ways in which the technologies, at times, allowed the teachers to extend their formative practices and, at other times, restricted the teachers from engaging in formative assessment practices.

Rationale

Both formative assessment and the integration of technology can support the development of the 21st century student, and both practices support students in taking ownership of their own learning and enable the development of deep conceptual learning allowing students to apply knowledge to new situations. Furthermore, utilizing technological tools such as computer simulations allows students to participate in scientific practices as they develop conceptual understanding. The use of technology can support the implementation of formative assessment and thus, test Russell's (2010) statement that "[g]iven the speed with which computer-based technologies can collect, analyze, and report information, computer-based tools have great potential to increase the efficiency and the individualization of formative assessment" (p. 135). Thus, it is important to understand how the use of 3-D computer simulations and the SABLE system support and constrain teachers' formative assessment practices.

While there is recognition of the potential for technology to support teachers' formative assessment practices, there is little understanding of how teachers use technology to support their formative assessment practices. This study aims to examine teachers' uses of two specific technologies in order to identify ways in which both support teachers' formative assessment practices. This study can provide information to science teachers and science teacher educators about effective pedagogies for implementing formative assessment with the use of technology. This study can identify vital and detrimental characteristics of technology so that software developers can develop and refine technological tools for educational purposes and science teachers and other education stakeholders can be more analytical in determining the value of technological tools. Lastly, this study can add to the knowledge of effective formative assessment practices in the context of an increasingly technological world.

Research Questions

Seeking to understand how two specific computer based technologies support and constrain teachers' formative assessment practices will help other science teachers, software developers, and other education stakeholders more thoroughly evaluate the value and usefulness of different technologies as they seek to develop and refine their formative assessment practices. Furthermore, software developers and education stakeholders will be more informed as to the important characteristics that technology needs to have in order to be a powerful tool to support and enhance teaching practices. Also, science teacher educators will gain a better understanding of the pedagogical implications of these two types of technologies enabling them to better support teachers in enacting formative assessment and effectively integrating technology. The over-arching research question that guides this study is: How do 3-D computer modules involving cellular transport, coupled with a technology that allows real time monitoring of students' work, support or hinder teachers' formative assessment practices during the implementation of a cell unit? The sub-research questions are:

1. How do secondary biology teachers enact formative assessment during an instructional unit on the cell unit in an introductory high school biology course?

2. How do secondary biology teachers conceptualize formative assessment?
3. In what ways do the data from the SABLE system influence future instructional decisions within a cell unit?

Definitions

Within the context of this study, the following definitions will be used:

SABLE system – The SABLE system stands for Skills Assessment Based Learning Environment. The SABLE system is a web application that allows for teachers to assign classes of students to the aforementioned 3-D computer modules. When students engage with the 3-D computer modules, the SABLE system allows teachers to monitor students' work in real time.

Formative assessment - Formative assessment is an iterative assessment practice involving both students and teachers in the process of teaching and learning for the purpose of identifying students' conceptual organizations in relation to learning goals in order to inform future actions aimed at supporting student learning. During the formative assessment process, teachers clarify learning goals for their students, and then, they elicit information from their students about their students' understandings, knowledge, and perhaps even feelings. Teachers use the elicited information to make informed decisions about instructional next steps to move their students forward in their thinking, and they provide formative feedback to their students to support the learning process. Students are responsible for paying attention to the learning goals and formative feedback and then employing strategies to move themselves forward in their learning. [Black & Wiliam, 1998b; Buck & Trauth-Nare, 2009]

Instructional technology - Instructional technology is "any device available to teachers for use in instructing students in a more efficient and stimulating manner than the sole use of the teacher's voice" (Cuban, 1986, p. 4).

Summary and Preview

In this chapter I presented two teacher practices within science education, formative assessment and the integration of instructional technology, that offer support in the teaching and learning process for the 21st century student. I presented the research problem, questions, and rationale. In Chapter two, I will discuss relevant literature clarifying the construct of formative assessment. Furthermore, I will describe the literature on the availability of instructional technology, factors that impact teachers' use of instructional technology, and research on technologies claiming to support the process of formative assessment. In Chapter three, I will describe my research design and procedures for data collection and analysis. Also, I detail my analytical process and framework. In Chapter four, I will present my findings in three major sections, discussing teachers' enactments of formative assessment, teachers' views of formative assessment, and teachers' use of the technology. Finally, in chapter five, I will summarize my study; discuss implications for science teachers, science teacher educators, software developers, and other education stakeholders; and describe future research directions.

CHAPTER 2

LITERATURE REVIEW

In this chapter, I provide an overview of the literature related to the two teacher practices examined in this study: formative assessment and the integration of instructional technology. The assessment literature lacks clarity about what constitutes formative assessment. One reason for this lack of clarity arises from the emphasis and value put on formative assessment by the various stakeholders including teachers, researchers, testing agencies, administrators, and policymakers (Frohbieter, Greenwald, Stecher, & Schwartz, 2011). In an attempt to clarify the term formative assessment, I situate it within the broad construct of assessment, describe its origins and key characteristics, and present and discuss a variety of formative assessment models. Describing formative assessment, provides clarity about the teacher practices being explored in relation to the integration of instructional technology.

In the second section of this literature review, I present statistics relating to teachers' access to instructional technology tools and discuss factors that pose potential barriers to the integration of technology. Understanding teachers' access to instructional technology and barriers they may face when implementing instructional technology, elucidates possible variables that may influence teachers' formative assessment practices while attempting to use instructional technology. Lastly, I discuss what education researchers know about how instructional technology is used to support teachers' formative assessment practices.

Types of Assessment

"The term *assessment* describes a range of actions undertaken to collect and use information about a person's knowledge, attitudes or skills" (Berry & Adamson, 2011, p. 5). Assessments usually fall into three broad categories: diagnostic, formative, and summative. As shown in Figure 1, the boundaries between these types of assessments are blurred; however, examining the purposes of each type of assessment can begin to draw distinctions between them (Wiliam, 2010).

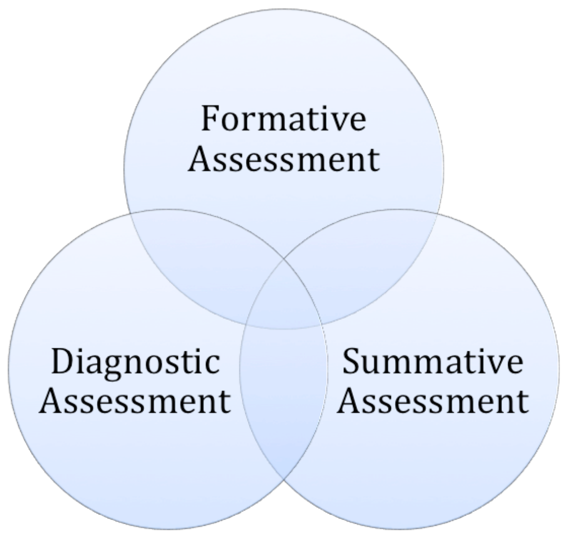

Figure 1. Venn diagram representation of the overlap between diagnostic, formative, and summative assessment.

Summative assessment and formative assessment are commonly discussed as lying opposite each other on a continuum. However, the continuum description implies an inaccurate relationship between formative and summative assessment. A continuum suggests a sliding scale depicting formative assessments gradually changing into summative assessments just as daylight slowly gives way to night. However, formative and summative assessments serve different purposes.

Summative assessment pertains to assessment *of* learning and occurs at the end of a learning period, such as at the end of a chapter, unit, or a course (Cizek, 2010). Summative assessments serve many functions including helping teachers to make inferences about a student's level of knowledge or skills, assigning grades, evaluating a program, and meeting accountability requirements. Formative assessment refers to assessment *for* learning and involves both teachers and students in the event of gathering data about students' levels of knowledge for the purpose of informing instructional next steps to more effectively guide the learning process.

Diagnostic assessments are conducted in order to determine strengths and weaknesses within a student's knowledge or abilities. According to Bell and Cowie (2001) "diagnostic assessment, . . . is viewed as a part of formative assessment" (p. 11). Classifying diagnostic assessment as a sub-category of formative assessment is an inaccurate description of the relationship between formative assessment and diagnostic assessment. A sub-category should possess the distinguishing characteristics of the over-arching category. For example, in non-fiction literature, both the sub-categories of science and history books meet the requirements of the non-fiction category through their depiction of fact-based accounts of real events, people, and phenomena. Diagnostic assessments identify students' strengths and weaknesses in relation to learning specific concepts, but it does not necessarily provide guidance as to the instructional next steps needed in order to support further learning, which is a defining characteristic of formative assessment (Wiliam, 2010).

Although diagnostic, formative, and summative assessments serve different purposes, their boundaries blur together because one assessment tool can serve multiple purposes. For example, a test provides teachers and students with a measurement of students' level of mastery of a certain concept (summative), identifies students' strengths and weaknesses with regard to certain concepts (diagnostic), and details student data that informs instructional next steps (formative). Wiliam (2010) provided an example in which a teacher gives a class section of students a test to assess their ability to order fractions from smallest to largest. The test has the potential to serve a summative function in that the teacher can examine the students' work and determine which students have mastered the assessed concept. Furthermore, the teacher can examine the data for diagnostic purposes as well and may notice that students scored lower when called on to evaluate fractions that did not have the number one as the numerator. However, the teachers can use the assessment data formatively when they can identify reasons why the students experienced more difficulty while ordering fractions without the number one as the numerator. Wiliam (2010) continued,

> . . . if the teacher can see from the responses that many of the students are operating with the naïve strategy that the smallest fraction is the one with the largest denominator, and the largest fraction is the one with the smallest denominator . . . then this provides information for the teachers that is instructionally tractable. Such assessments . . . situate the problem within a theory of action that can suggest measures that could be taken to improve learning. (p. 27)

Origins and Defining Characteristics of Formative Assessment

Scriven (1967) first coined the term formative evaluation to describe the act of evaluating programs and curricula. Bloom (1971) later co-opted Scriven's terminology and laid the groundwork for our modern understanding of formative assessment by conceptualizing formative evaluation as a process that could also be applied to teaching and learning for the purpose of improving teaching and learning (Cizek, 2010). Over the past two decades, formative assessment has been more clearly and consistently defined within a substantial body of research.

Bell and Cowie (2001) defined formative assessment as "the process used by teachers and students to recognize and respond to student learning in order to enhance that learning, during the learning" (p. 540). The Council of Chief State School Officers' (CCSSO) Formative Assessment for Students and Teachers (FAST) State Collaborative on Assessment and Student Standards (SCASS) defined formative assessment as "a process used by teachers and students during instruction that provides feedback to adjust ongoing teaching and learning to improve students' achievements of intended instructional outcomes" (2012, p. 4). In their definitions, both Bell and Cowie (2001) and CCSSO FAST SCASS (2012) restricted formative assessment to those practices that occur during instruction. Popham (2008) defined formative assessment as "a planned process in which assessment-elicited evidence of students' status is used by teachers to adjust their ongoing instructional procedures or by students to adjust their current learning tactics" (p. 6). Instead of confining formative assessment to practices occurring during instruction, Popham (2008) restricted formative assessment to planned practices. Black and Wiliam (1998a) defined formative assessment, stating, "[formative assessment] is to be interpreted as encompassing all those activities undertaken by teachers, and/or by their students, which provide information to be used as feedback to modify the teaching and learning activities in which they are engaged" (p. 8). I align with Black and Wiliam's (1998a) definition of formative assessment because it does not bind formative assessment to only those practices, which occur during instruction or were planned.

Although each researcher provided their own definition of formative assessment, they were consistent about the inclusion of four characteristics: it is an iterative process, it is seamless with instruction, it involves both teachers and students, and most importantly, it uses gathered information to guide the learning process. Formative assessment is a continuous and on-going process, which aims to gather information about students' current knowledge and understanding and utilizes that information to construct feedback to guide students' acquisition of further knowledge (Black & Wiliam, 1998b). Therefore, formative assessment is considered to be integral with instruction (Black & Wiliam, 1998b; Buck & Trauth-Nare, 2009; Frohbieter et al., 2011).

Although the nature of their engagement is directed from different points of orientations, both the student and teacher engage in the process of formative assessment. Teachers are responsible for setting clear learning targets, eliciting information about their students' conceptual understandings, and then, providing feedback to students about where they are in the learning process and how best to move forward. Students can be said to engage with the formative assessment process when they pay attention to the learning goals and feedback in order to better understand where they are in relation to the learning goals and then employ strategies to move themselves forward in the learning process. Finally, probably the most defining feature of formative assessment is that the information gathered by teachers and students is used to inform the learning process (Black & Wiliam, 1998b).

As shown in Figure 2, formative assessment enacted in the classroom lies on a continuum ranging from informal practices, usually occurring in the moment or "on-the-fly", to more formal practices that are planned and embedded within a curriculum (Shavelson & SEAL, 2003). Depending on its placement along the continuum, formative assessment practices may look very different. However, all formative assessment practices involving teachers can occur with the whole class, small groups, or individual students. The aim of these practices is to gather evidence of students' understandings and to use that information to make instructional decisions that promote student learning.

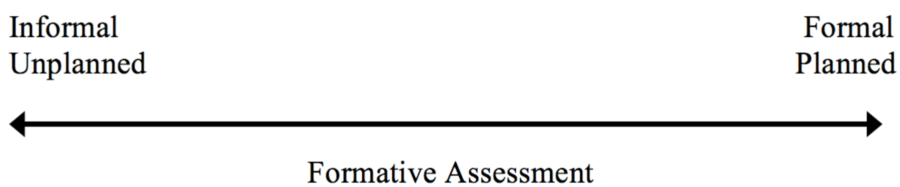

Figure 2. Types of formative assessment practices. Adapted from "On the Integration of Formative Assessment in Teaching and Learning with Implication of Teacher Education," by R. J. Shavelson, and the Stanford Education Assessment Laboratory [SEAL], 2003, Paper presented at the Biannual Meeting of the European Association for Research on Learning and Instruction. Padova, Italy.

Sometimes unexpected teachable moments arise during interactions between teachers and students and/or between students and their peers that can be used to probe for student thinking and to guide further student understandings. The study of formative assessment practices breaks apart those practices arising from unexpected teachable moments, informal formative assessment, and those which are planned for in the teacher's planning process, formal formative assessment (Bell & Cowie, 2001). Curriculum-embedded formative assessments are strategically placed throughout a unit in order to gauge student knowledge and allow for rapid teacher responses (Shavelson & SEAL, 2003).

Models of Formative Assessment

In this section, I will present three commonly cited models of formative assessment. Then, I will critique the models' utility in supporting my research study. Lastly, I will present a fourth model that provided guidance for this study.

Ruiz-Primo and Furtak (2006) examined teachers' informal formative assessment practices and identified four elements: teachers elicit information from their students, students respond to the teacher's elicitation, teachers recognize and acknowledge the student's response, and then, teachers use the elicited information to inform instructional next steps in order to support student learning. They termed this entire process an ESRU cycle, which is depicted in Figure 3. "Each step in the ESRU cycle serves a purpose toward collecting information about student learning, comparing it to the teacher's expectations, and taking action to move students toward learning goals" (Ruiz-Primo & Furtak, 2006, p. 208).

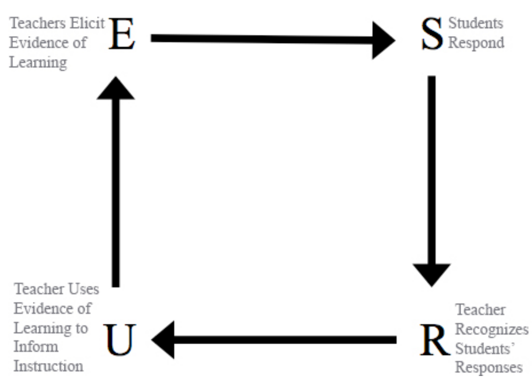

Figure 3. ESRU cycles. Adapted from "Exploring Teachers' Informal Formative Assessment Practices and Students' Understanding in the Context of Scientific Inquiry," by M. A. Ruiz-Primo, and E. M. Furtak, 2007, *Journal of Research in Science Teaching, 44*(1), p. 61. Copyright 2006 Wiley Periodicals, Inc.

The researchers differentiated ESRU cycles from initiate-respond-evaluate (IRE) originally described in Lemke (1990). IRE patterns involved cycles of teachers initiating questions, students responding, and teachers evaluating students' answers. First, in the elicitation phase, teachers are providing space for students to make their thinking visible and are collecting information about how students understand science practices and concepts. Secondly, teachers acknowledge student responses and "serve the purpose of the teacher validating each student's contribution as it is absorbed into the ongoing classroom narrative" (Ruiz-Primo & Furtak, 2006, p. 208) rather than making an evaluative judgment about the student's response. Thirdly, of which the researchers consider most important, teachers use the information they have gathered to inform instruction in a way that supports student progress towards achieving learning goals.

In Figure 4, Buck and Trauth-Nare (2009) used a similar model of formative assessment to Ruiz-Primo and Furtak's ESRU cycles. While the model begins with teachers eliciting information, students responding, and teachers recognizing student responses, the model highlights the idea that teachers use the elicited information to provide feedback to students and to make future instructional decisions. Furthermore, the model illustrates that students use the feedback to inform their own next steps in the learning process.

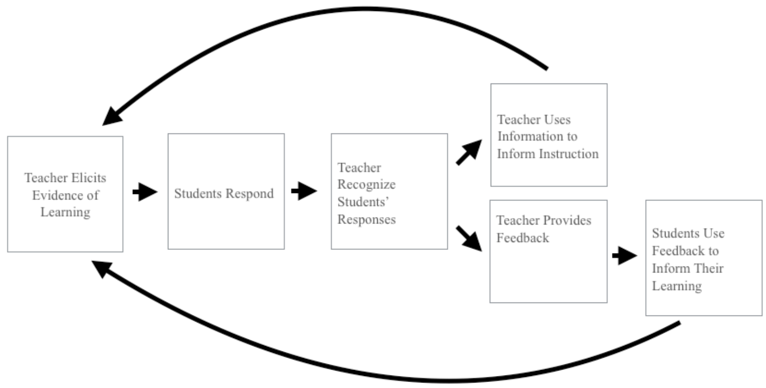

Figure 4. Model of formative assessment. Adapted from "Preparing Teachers to Make the Formative Assessment Process Integral to Science Teaching and Learning," by G. A. Buck, and A. E. Trauth-Nare, 2009, *Journal of Science Teacher Education, 20,* p. 477. Copyright 2009 by Springer Science+Business Media, B. V.

Bell and Cowie (2001) wrote about ten teachers' descriptions of formative assessment during the larger "Learning in Science Project." As shown in Figure 5, they model two types of formative assessment, planned and interactive. First, planned formative assessments involve a cycle of eliciting, interpreting and acting on knowledge. Purpose is situated in the middle of the circle and is informed by and influences each of the other three aspects. The purpose of planned formative assessments is typically to elicit information from a class as a whole. Teachers use this information to inform teaching. Usually, teachers elicit the information in a way that will create a record of the data, for example a quiz. Then, they differentiate relevant information from irrelevant information in order to interpret the data. Finally, they take one of several actions to enhance student learning.

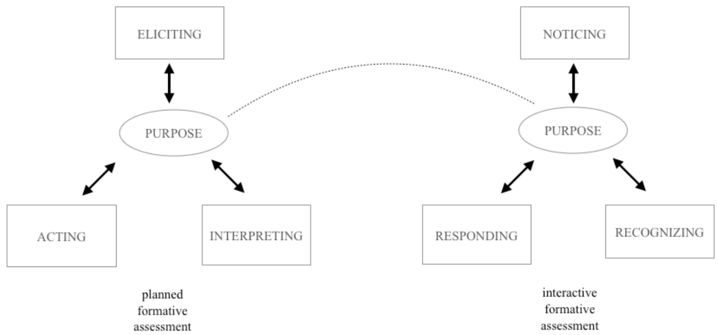

Figure 5. Model of formative assessment. Adapted from "Formative Assessment and Science Education," by B. Bell, and B. Cowie, 2001, Kluwer Academic Publishers, p. 91. Copyright 2001 by Kluwer Academic Publishers.

The model for interactive formative assessment is nearly identical to the planned formative assessment model, differing only in eliciting, interpreting, and acting being replaced by noticing, recognizing, and responding. Like before, purpose plays a pivotal role in this model. However, teachers perform interactive formative assessments in order to isolate the knowledge of individual students. They described it as a process that a teacher may plan to conduct but cannot plan how or when it will occur. The first step is for the teacher to notice student information in real time. Noticing differs from eliciting in that it never requires an active intervention from a teacher. If teachers are not paying careful attention, then they will miss data. This information is typically verbal and can be exposed through classroom discussions or other activities in which the students and teacher interact. Once they notice a piece of information, it is important for teachers to recognize its significance. Then, teachers respond in one of several ways, usually soon after the process began. Finally, Bell and Cowie unite the models by discussing the habit of teachers switching between the two models when their purpose changes.

For example, they may notice something in a planned assessment that leads them to an interactive assessment with a particular student.

All of the models are similar in that they highlight cycles of teachers gathering evidence of learning from their students and then using that information to guide their instruction. The models depicted by Ruiz-Primo and Furtak (2007) and Bell and Cowie (2001) deemphasize the role of the student in the formative assessment process, only showing students in the role of responding to teachers' elicitation events. On the other hand, Buck and Trauth-Nare (2009) included students alongside teachers as agents of formative assessment. In their model, students respond to teachers' elicitation events, receive feedback, and then, employ strategies to move themselves forward in the learning process. In addition, the Ruiz-Primo and Furtak (2007) model fails to connect ESRU cycles to pre-determined learning goals. Buck and Trauth-Nare (2009) indicated a connection to learning goals through their statement that students use teacher feedback to progress towards learning goals. However, they did not depict a relationship between teachers' actions and learning goals. Bell and Cowie (2001) clearly connected learning goals, or the "purpose", to cycles of eliciting evidence and providing feedback. Also, Bell and Cowie (2001) differentiated between planned and spontaneous, or "interactive", formative assessment.

The difficulty with all cyclical models is their failure to align in a realistic way to teacher practices. In actual classroom instruction, each step of the cycle does not always progress to the next step and the cycle frequently fails to complete. Therefore, researchers encounter difficulties with what combination of steps would constitute a complete cycle. For example, Ruiz-Primo and Furtak (2006) explained that one ESRU cycle may consist of multiple instances of eliciting evidence and student responses before the teacher recognizes the students' responses. Teachers may or may not complete the cycle and use the elicited information to inform instructional next steps. Regardless of the accuracy of these models, several aspects of them are constituted with unobservable actions that may occur internal to the teacher, such as recognizing or interpreting student responses. Therefore, while these models aided in my initial visualization of formative assessment, they proved unusable as a guide for conducting classroom observations and analyzing my data.

The National Research Council (2001) and the Assessment Reform Group (Broadfoot et al., 2002) described effective formative assessment practices as being guided by three questions: Where are you trying to go?, Where are you now?, and How can you get there? These pragmatic questions are easily understood by practitioners and also fit within the expanded framework provided by Wiliam (2007) through his five strategies for the effective implementation of formative assessment:

1. Clarifying learning intentions and sharing criteria for success
2. Engineering effective classroom discussions, questions, and learning tasks that elicit evidence of learning
3. Providing feedback that moves learners forward
4. Activating students as the owners of their own learning
5. Activating students as instructional resources for one another (p. 192)

Also, Wiliam (2010) created a model demonstrating the connections between the guiding questions, the effective strategies, and the agents of formative assessment (teachers, students, and peers) as shown in Figure 6. The model depicts teachers, students, and peers as clarifying learning goals and sharing criteria for success in order to answer the question: Where are we going? Furthermore, in determining the students' understandings, the teacher is responsible for eliciting evidence of learning through engaging students in a variety of activities. Teachers move students forward in their learning through providing formative feedback. Students and peers help elucidate their own and each other's conceptual understandings and support the progression of their learning through engaging in peer and self- assessment.

	Where the learner is going	**Where the learner is right now**	**How to get there**
Teacher	Clarifying learning goals and sharing criteria for success	Eliciting evidence of learning	Providing formative feedback
Peer	Understanding and sharing learning goals and criteria for success	Peer-assessment	
Learner	Understanding learning goals and criteria for success	Self-assessment	

Figure 6. Model of formative assessment. Adapted from "Research Literature and Implications for a New Theory of Formative Assessment," by D. Wiliam, 2010, In H. L. Andrade, and G. J. Cizek (Eds.), *Handbook of Formative Assessment,* Routledge, p. 31. Copyright 2010 by Taylor & Francis.

Wiliam's (2010) model of formative assessment shows the role of students, peers, and teachers in the process of formative assessment, and it identifies actions that relate to the process of formative assessment. This model provided a guide for my classroom observations and a method for coding my data. I will discuss Wiliam's (2007) five strategies for the effective implementation of formative assessment in more detail in chapter three.

Summary

In the above literature review on formative assessment, I adopted Black and Wiliam's (1998a) definition of formative assessment in which they characterized it as all of the activities in which teachers and/or students engage in, which provide information that is used to modify teaching and learning. I identified four key characteristics of formative assessment: it is an iterative process, it is seamless with instruction, it involves both teachers and students, and most importantly, it uses gathered information to guide the learning process. The research literature also described a continuum with informal and unplanned formative assessment on one end and formal and planned formative assessment on the other. Then, I critiqued three commonly cited cyclical models of formative assessment and concluded that none of them were beneficial for the collection and analysis of classroom observation data. Finally, I described Wiliam's (2007, 2010) model, which overlays his five strategies for the effective implementation of formative assessment with three pragmatic questions that guide formative assessment practices. Wilam's (2007, 2010) model is a useful analytical framework for identifying episodes of formative assessment during classroom observations.

Instructional Technology

Technology has been integrated into classrooms since formal schooling first began through the use of books, paper, writing utensils, and chalkboards. Each new technological development carried renewed yet unfulfilled promises of the revolutionizing power of technology for the educational system. However, computer technology has yet to reach its full potential and may in fact be the next revolution in instructional technology (Broadfoot, 2007). Instructional technology provides tools that support teaching and learning across disciplines supporting the shift in lecture-based instruction to reform-oriented, constructivist, and inquiry-based instruction (Culp, Honey, & Mandinach, 2005). Furthermore, Partnership for 21st Century Skills (2009) identified several skills that students need in order to maintain a global competitive edge such as moving beyond the ability to recall basic facts in relation to content and being able to think critically and apply knowledge to new situations to solve real world problems. Many believe that integrating technology into the classroom can help accomplish this task (Culp et al., 2005).

In order for instructional technology to be implemented during instruction, teachers and schools need access to such tools. Wells and Lewis (2006), in their report for the National Center for Education Statistics (NCES) entitled "Internet Access in U.S. Public Schools and Classroom: 1994-2005," documented the technological strides made in the educational system. In 1994, only 35% of public schools and 3% of instructional rooms had access to the internet, and in 2005, which was nearly a decade ago, almost 100% of U.S. schools and 94% of instructional rooms had internet access. Furthermore, in 2005, while 97% of public schools with internet access used broadband, only 45% of public schools and 15% of instructional room used wireless connections, limiting the use of laptops and other portable electronics.

Six years ago, the National Education Association (2008) reported that in public schools in the United States, the ratio of the number of students per computer with internet access was 3.8 to 1. However, the ratio did not account for the location of computers within the school, meaning they may or may not have been accessible to students. In 2010, Gray, Thomas, and Lewis published a report for the NCES documenting further progress in outfitting schools with technology. They reported that 97% of teachers had at least one computer in their classroom and 54% of teachers had access to portable computers that could be transported into the classroom.

Furthermore, 93% of classroom computers and 96% of portable computers had internet access. Also, "[t]he ratio of students to computers in the classroom every day was 5.3 to 1" (p. 3).

Factors that Influence the Integration of Instructional Technology

As recently as 2008, despite the advent of computer programs, web applications, and the internet, the most widespread use of instructional technology was still pen, paper, and chalk/white boards (Lee & Winzenried, 2008). Since the industrial revolution, technology enthusiasts have touted the revolutionizing power of educational technology, but these revolutions have never materialized to the level that was anticipated by their adherents. Private companies, with the aim of increasing profits, designed most technologies for commercial use and only later marketed them to schools as transformational educational technologies. Combined with the teacher-proofing culture of the 1960s and 1970s, many people believed in the power of the educational revolutions promised by radio, film, TV, and computers. While administrative use of technology, such as computerized grade books, have become integral to many modern classrooms, the use of instructional technology in schools has failed to match the adoption rate of technology in the home.

There are several factors identified in the literature that contribute to the low adoption rate of instructional technology. Ertmer (1999) described two general categories of factors that impede the integration of instructional technology. She labeled these as external (or first-order) barriers and internal (or second-order) barriers. External (or first-order) barriers represent factors that are extrinsic to teachers and include having a lack of access to technology, time for instructional planning, technical and/or administrative support, and professional development opportunities. Internal (or second-order) barriers categorize factors that are intrinsic to teachers. Second-order barriers relate to teachers' knowledge, skills, beliefs, and attitudes about teaching and learning and the role and purpose of technology, "as well as [teachers'] traditional classroom practices including teaching methods, organizational and management styles, and assessment procedures" (Ertmer, 1999, p. 51).

Hew and Brush (2007) conducted an international review of the literature in order to categorize the barriers to the integration of instructional technology. They located 48 studies reporting empirical research findings between 1995 and spring 2006. They identified insufficient resources as a major factor impeding the integration of instructional technology, which relates to Ertmer's (1999) first-order barriers. Hew and Brush (2007) further indicated that teachers lacked access to technology, time, and technical support. While teachers may have access to certain technology, such as computers, they may lack access to relevant and usable software. “To be widely used, the technology needs programs or content of immediate value that can be accessed readily” (Lee & Winzenried, 2008, p. 13). However, in some cases, schools may have ample technology, but teachers may lack access to the available technology. For example, computers may be located in laboratories, forcing teachers to compete for access. School leadership may place priority on certain courses, such as technology classes, putting teachers of other disciplines at a disadvantage in competing for access.

Kopcha (2012) noted that teachers often feel burdened by the extra time needed to alter their planning, teaching, and classroom management when implementing new technology. Kopcha (2012) was surprised to find “that teachers’ perception of time [in relation to the implementation of technology] was consistently negative, even as their access to technology and training improved and they learned more about teaching with technology” (p. 1118). Furthermore, schools are frequently understaffed in their technical support department, which leads to a bottleneck of unaddressed technological issues in classrooms. This inefficiency of support leads to a negative impact on teacher use of technology.

In addition to the three aforementioned resource related issues, Lee and Winzenried (2008) cited infrastructure and finances as extrinsic barriers. In modern times, access to broadband internet is a requirement to utilize most computer technologies and while access has improved, it is still limited. Many school buildings required complete rewiring in order to enable broadband internet access and modern computer networking. Also, technology requires access to plentiful electrical outlets such as in the case of using laptop computers in a class of 30 students. Furthermore, adequate financing is required to overcome all first-order barriers. "While undoubtedly there will be some variation across the OECD nations, in general terms salaries have consumed approximately 85-90 per cent of the recurrent allocation to schools. The remaining 10-15 per cent of the monies has to pay for all the other annual expenses, be it cleaning, utilities, books or instructional technology" (Lee & Winzenried, 2008, p. 13).

Other first-order related issues besides resources, infrastructure, and finances involve the given conditions in which teachers must work and other institutional factors. For example, teachers are assigned a certain number of students over a specified time interval during the school year. Teachers provide instruction in an assigned room with limited space with previously placed black/white boards, electrical outlets, and projectors. Furthermore, teachers are required to cover a set curriculum and manage their students while creating an environment conducive to learning. Many technologies are difficult to implement when students have less than an hour of available class time to engage in them. In addition, the pressures of high stakes testing can also dissuade teachers from using technology in place of more traditional means of instruction (Hew & Brush, 2007).

Instructional technology also needs to be supported by the institution that teachers work within. School leadership's involvement is critical to technology adoption. "One of the most important steps in achieving meaningful technology use is the development of a vision of how to use technology to achieve important education goals" (Ertmer, 1999, p. 54). However, according to Lee and Winzenried (2008), school and higher-level administrators have lacked leadership in efforts towards the integration of instructional technology. Not only do administrators need to support the integration of instructional technology, but they also need to understand what the technology has to offer and the infrastructure required to implement it. Implementation plans should be accompanied by an educational vision, defining the role of technology in teaching and learning. Lee and Winzenried stated, "In an interview with one of the main interactive whiteboard providers, mention was made of the company's concern in the mid 2000s of governments' preoccupation with rolling out the equipment, paying lip-service to the human change component and, as a consequence, seeing the technology sit idle" (2008, p. 16). Therefore, first-order barriers relate to access to resources, infrastructure, finances, the conditions teachers must work in, and support from leadership.

In regards to Ertmer's (1999) second-order barriers, teachers' beliefs and attitudes may interfere with their ability and willingness to integrate instructional technology. Teachers ultimately are the gatekeepers to the technology being used (Cuban, 1986). In order for teachers to adopt the use of an instructional technology, they need to believe that the technology will support student learning, know how to comfortably use the technology, and understand how to integrate the technology into their everyday classroom practices. In the past, instructional technologies have failed because their implementation was often intended to "teacher proof" instruction and thus, teachers were asked to adapt their teaching in order to use the technology as opposed to the technology adapting to their teaching practices (Rudolph, 2002). Implementation of technology can also be limited by teachers' knowledge and skills. In particular, teachers may lack the knowledge and skills required to use the technology competently, to make effective pedagogical decisions regarding the use of the technology, and to manage classrooms effectively while using the technology. According to Mishra, Koehler, and Kereluik (2009) ". . . educational technologies exist in the interplay between pedagogical knowledge, content knowledge, and technology knowledge" (p. 51). Therefore, teachers need support in learning how to use new technologies, but more importantly, they need support in constructing uses of technology that integrate into and support effective pedagogies.

Ertmer (1999) determined that barriers internal to teachers, such as their knowledge and skills, were more significant barriers than external barriers like availability of resources. However, realizing the constantly morphing technological landscape, Ertmer conducted a new study in 2012 to re-examine potential barriers to teachers' integration of technology. Ertmer (2012) found that teachers now have confidence in their technological knowledge and skills, which has become a primary enabling factor for their ability and willingness to integrate instructional technology. Both first and second-order barriers need to be considered when attempting to implement instructional technology.

Formative Assessment and Technology

There is a large amount of research that has examined technology and its use for assessment purposes, particularly the use of computers in summative assessment. Researchers investigated student performance in relation to methods of assessment such as assessment conducted on paper versus on the computer, or it focused "on ways that computers can be used to more efficiently estimate student achievement (e.g., adaptive testing)" (Russell, 2010, p. 125).

Research has begun to emerge that involves the use of technology to support formative assessment.

Most of the research investigating technology and formative assessment has described various implementations of technology and claimed that its use leads to increases in student engagement, motivation, and achievement through involving students in solving real world problems. According to these studies, students have reported that they enjoy using the technology and teachers indicated that students are more engaged in class and perform to a higher standard on assignments. Furthermore, they discussed ways in which technology has the potential to support an aspect of formative assessment such as providing feedback or engaging students in peer or self-assessment.

For example, Isabwe (2012) reported on a newly developed tablet based technology called technology-supported peer-to-peer assessment (P2PASS), which consists of a centralized Learning Management System (LMS) that exchanges information with the teacher and his/her students via iPads. The tablet technology was used in a math course at a university in Rwanda. The technology allowed for teachers to assign math problems to their students. The students, using the iPads, completed the math problems and then, provided feedback to other students on their work. The students were also provided with the correct answers so that they could compare their work, as well as the feedback they received, to the correct answers. The author reported that 79 percent of the students expressed a positive view of peer feedback. They also indicated that they were more comfortable being assessed by peers than by a teacher and that the technology was easy to use.

In another study Jones, Georghiades, and Gunson (2012), discussed a technology used to provide feedback. "Tutors" used screen capture digital video technology to provide feedback to college students about their work. The researchers found that students enjoyed receiving video feedback, believing that the quality of usefulness of the feedback was improved over traditional methods of feedback. In another study conducted by McGuire (2005), the author discussed the development of a new technology called eVIVA, which reportedly supported formative assessment through the use of cell phones and the internet in an ICT course. Beyond detailing the development of the technology, the author discussed teachers' perceptions of the technology's usefulness to students, which included students increasing self-esteem and motivation, students gaining independence as learners, and students being more aware of their audience. Furthermore, Peat and Franklin (2002) reported on both formative and summative computer-based assessments implemented in a college introductory biology course. Computer-based assessment included weekly quizzes, practice tests, quizzes in each section of the computer-based learning modules, and special self-assessment modules. The authors reported that students, who engaged in these activities, expressed that the computer-based assessments gave useful feedback, helped to test and relate concepts, and aided in assessing their understanding of concepts. Therefore, there are several studies that detailed the development of technology, which documented teachers' and/or students' perceptions about the usefulness of the technology in student learning.

Several journal articles discussed different existing technologies and their potential to support the formative assessment process. Russell (2010) identified four potential uses of computer-based technology to support formative assessment:

> (1) systematically monitoring student progress to inform instructional decisions; (2) identifying misconceptions that may interfere with student learning; (3) providing rapid

feedback on student writing; and (4) collecting information about student learning needs during instruction. (p. 126)

During formative assessment, teachers collect data from students as a result of the students' progress through an instructional unit. The teachers need to analyze the data (which may be a large amount) to determine student progress towards learning goals. Several technological tools have been developed to support teachers in monitoring student progress. For instance, Russell (2010) described a palm-pilot software tool called the mCLASS:Reading that is designed to digitize written reading records for elementary students. Teachers used a handheld palm-pilot device to follow the text that their students are reading aloud and record errors as they occur. The data was then uploaded to a database and teachers could view and analyze it in various ways for each student or the class as a whole. The inclusion of digital copies of student readings allowed teachers to collect data more efficiently than using paper copies and the variety of presentations that the data could be viewed in assisted teachers in understanding and acting on the collected data.

In another example, Russell (2010) described two technological systems that allowed teachers to identify misconceptions that their students may hold about specific concepts. The Diagnostic Algebra Assessment System (DAA) and DIAGNOSER were two online assessment systems that contained short assessments to determine students' levels of understanding of specific algebra and physics concepts respectively. Beyond providing information about how well students understood specific concepts, for students who performed poorly, the technology also estimated the probability that they hold specific misconceptions related to the assessed concept.

During formative assessment, teachers need to provide feedback (step 3 in Wiliam's 2007 model, for instance) to students in relation to their progress towards achieving learning goals. Providing feedback on students' written assignments, especially on short-answer or essay questions is time consuming, and therefore, the provision of feedback is often delayed. Developments within technology have allowed the design of automated scoring software of which Russell (2010) identified programs such as Project Essay Grading (PEG), Latent Semantic Analysis (LSA), e-Rater, and Bayesian Essay Test Scoring (BETSY). Regardless of the exact automated scoring software, each program required calibration. In order to calibrate the software, human graders must first provide the computer with a small sample of graded text with scores. Then, both human graders and the computer grade a second sample. The resulting scores are compared, and if they align to a satisfactory degree, then the computer can be used. If they do not align adequately, then the calibration process continues.

During the formative assessment process, teachers need to collect information about students' current conceptions of the subject matter content during instruction and then use that information to guide further instruction. Typically, teachers question students, receiving information about student thinking from only a small number of students. Technology called student response systems or "clickers" have been developed to aid teachers in collecting information from each student during instruction. "Student response systems consist of a set of hand-held devices that students use to record responses to a question posed by the teacher" (Russell, 2010, p. 134). When using student response systems, teachers create questions, usually multiple choice, and all students select their answers with a devise. The students' results are displayed on a screen, showing the percentage of students who selected each of the possible answer choices. Based on the results, teachers make instructional next decisions. Russell explained a possible classroom scenario using a student response system:

> . . . a teacher who is helping students develop an understanding of how to calculate a statistical mean might present students with a table of numbers, ask the students to find the mean, and then present them with four answer options. One option might represent the actual mean, a second the mode, a third the median, and a fourth a common arithmetic error made while calculating the mean . . . if a substantial percentage of students select the median instead of the mean, the teacher may decide to spend more time differentiating a mean and median. However, if the majority of students selected either the mean or the response that represents a common arithmetic error made while calculating a mean, the teacher may opt to proceed with the lesson, but note that some students may need opportunities to improve their arithmetic skills. (2010, p. 134)

Furthermore, while using student response systems, teachers can choose to review an individual student's response.

This research examining the aforementioned uses of computer-based technology to support formative assessment focused on describing specific technologies and relating teacher and student perceptions. Few, if any, research studies exist that examined ways in which teachers use instructional technology that supports or hinders their formative assessment practices. Russell stated, "given the cost of purchasing and training teachers to use technology-based formative assessment tools, it will be valuable, where feasible and ethical, to employ research methods that allow stronger comparisons between current methods of formative assessment and computer-based solutions" (2010, p.136).

Summary

In this chapter, I discussed the relevant literature that informed my study. The literature review focused on two areas: formative assessment and instructional technology. This review provided clarification as to what constitutes formative assessment practices through a variety of models created by scholars in the area of measurement. Also, this review provided an overview of the literature on the potential barriers to the integration of instructional technology, which needed to be considered when examining teacher practices. Lastly, I found the educational research literature lacking in scholarship that assists in building an understanding of the ways in which teachers use instructional technology that supports and hinders their formative assessment practices. My study aims to begin to remedy this gap.

CHAPTER 3

METHODOLOGY

This study examined how the use of 3-D computer modules and the SABLE system supported and constrained secondary biology teachers' formative assessment practices during the implementation of the cell unit. In this chapter I describe the epistemological stance, theoretical framework, and methodology that guided my study. Then, I provide a detailed description of the participants, the 3-D computer modules, and the SABLE system involved in the study. Next, I discuss the types of data collected, the process of data collection and analysis, and the analytical framework. Lastly, I explain measures taken to support validity and reveal limitations to my research study.

Epistemological Stance

Epistemology refers to the nature of knowledge and, when the stance is stated, allows the reader to identify what knowledge is legitimate and possible. I approached my research study from a constructionist epistemology. Constructionism is most easily understood in contrast to objectivism, which views meaning as independent of human consciousness. When we, as objectivists, explore our world, we seek to discover meaning or objective truth. On the other hand, constructionism holds that objects have no meaning until they are observed and interpreted by the human mind. However, constructionism is not a purely subjective viewpoint. The human mind is not solely responsible for all meaning in an object, but rather an object plays an important role in defining its own meaning. “In this view of things, subject and object emerge as partners in the generation of meaning” (Crotty, 1998, p. 9). Furthermore, constructionists would argue that before humans were around to observe objects, they had no meaning. In essence, to use the timeless question, if a tree falls in the forest and no one were around to hear it, would there be a sound? Constructionists approach this question with the belief that while the tree definitely exists and its fall may cause vibrations in the air, if no one is present to interact with the event, then there will be no socially constructed meaning and the event did not exist. Thus, constructionism espouses that meaning exists in the interaction between the human mind and the natural world.

Constructionism can be described as both realist and relativist (Crotty, 1998). It can exist between the two, accepting, to some degree, the existence of the natural world but arguing that humans, through their interactions with and interpretations of the world, ascribe meaning and develop a social understanding of reality. Crotty cites an example from Stanley Fish that uses baseball to explain the existence of social constructions:

> 'Balls' and 'strikes' are certainly socially constructed. They exist as such because of the rules of the game. Yet they are real. Some people are paid as much as $3.5 million to produce them or prevent their production! They are constructions, and may change in their nature tomorrow if the powers-that-be decide to change the rules, but they are real, nonetheless. (1998, p. 63-64)

Because I adopted constructionism as my epistemology, my research is focused on the teachers and how they socially interact with the world, including their students, the curriculum, the computer modules, the SABLE system, and their past experiences, in order to interpret their students' level of understanding and learning progress during the teaching of a cellular transport unit. Each teacher has different viewpoints, which are all valuable and useful in understanding how they engage in the formative assessment process.

Theoretical Framework

Merriam (2009) describes a theoretical framework as "the underlying structure, the scaffolding or frame of your study . . . [it] is derived from the orientation or stance that you bring to your study" (p. 66). The theoretical perspective is the lens through which I view my world. It impacts the questions that I ask, the information that I gather, and the methods that I use to analyze and interpret my data. The theoretical perspective that frames my study is interpretivism. This theory stems from the work of Immanuel Kant and was later expanded upon by Edmund Husserl (Prasad, 2005). Also, interpretivism is commonly associated with the ideas of Wilhem Dilthey (1833-1936) and Max Weber (1864-1920) on *Verstehen,* meaning understanding, and *Erklären,* meaning explaining (Crotty, 1998). These two ideas, *Verstehen* and *Erklären,* are the subject of a long held discussion of the purpose of research methodologies in the natural and social sciences. Dilthey suggested that natural and social sciences require different research methods because they operate within different realities. As opposed to seeing a real separateness between natural and social reality, Weber believed that the distinction is logical, but it did not require a difference in research methods. Interpretive researchers, for the most part, accept a distinction, whether it is real or logical, between *Verstehen* and *Erklären.* They view meaning as being associated with the aim of the social sciences and the use of interpretivism and qualitative research, and they view explaining as being associated with the natural sciences and quantitative research. I too adopt the idea that there is a natural reality and a social reality, which are different from each other and that qualitative methods frequently aid in exploring the social world.

Interpretivism works well as my theoretical framework because many of its assumptions align with constructionism. According to Prasad, "All interpretive traditions emerge from a scholarly position that takes *human interpretation* as the starting point for developing knowledge about the social world" (2005, p. 13). Interpretivists reject the idea that a researcher can examine the social world through neutral eyes and identify universal patterns of human behavior, but instead, they look for socially constructed interpretations of the world (Crotty, 1998). Like constructionism, interpretivism assumes that a social reality exists in the human mind and meaning is socially constructed through the interaction of subject and object. For example, through my interactions with my coffee table, my peers, and my culture, I construct understandings of the characteristics and usefulness of coffee tables. Prasad offers another example discussing a mountain called Sleeping Buffalo:

> To most of us, Sleeping Buffalo is a mountain - to be climbed, gazed upon in admiration, and photographed. To the original native inhabitants who lived there long before the European presence, Sleeping Buffalo was exactly that - Sleeping Buffalo, a godlike awesome being demanding considerable reverence and respect. The rather obvious point here is that what we experience as a mountain might as easily be experienced as a deity or a supernatural being in another time-space context. The "reality" of both situations is *socially constructed* through acts of interpretation. (2005, p. 13)

Thus, constructionism and interpretivism have similar assumptions about knowledge and reality.

Using interpretivism as my theoretical framework requires that I interact with the teachers involved in this study in order to socially construct an understanding of how they enact formative assessment, and then, how the 3-D computer modules and the SABLE system support and constrain their formative assessment practices. My interactions with each teacher included several classroom observations and three interviews.

Methodology

The methodology refers to the strategy that gives shape to the research design and guides one's decisions on the research methods. The theoretical framework supports and brings to light the assumptions of the chosen methodology, and "[d]ifferent ways of viewing the world shape different ways of researching the world" (Crotty, 1998, p. 66). This qualitative research study attempted to follow the methodology of grounded theory, which is supported by constructionism and interpretivism. Grounded theory is derived from the work of Barney G. Glaser and Anselm L. Strauss in the 1960s (Charmaz, 2006). The purpose of grounded theory is to move beyond the description and exploration of the data to an explanation of the phenomenon under study (Birks & Mills, 2011). Theories emerge from and are grounded in the data. "The emphasis in grounded theory research tends to be on 'process' theory – that is, theory that addresses a sequence of actions and interactions among people and events that occurs over time and that pertains to a substantive topic" (Schram, 2003, p. 73). Therefore, the use of grounded theory fits well with my study because I sought to understand how teachers engaged in the process of formative assessment and how their interactions with the computer modules and the SABLE system supported or constrained their formative assessment practices.

The use of grounded theory carries with it several assumptions. Schram describes them as:

- Human beings are purposive agents . . .
- Persons act on the basis of meaning, and this meaning is defined and refined through interaction.
- Reality is negotiated between people (that is, socially constructed) and is constantly changing and evolving.

- Central to understanding the evolving nature of events is an awareness of the interrelationships among causes, conditions, and consequences.
- A theory is not the formulation of some discovered aspect of a reality that already exists "out there." Rather, theories are provisional and fallible interpretations, limited in time (historically embedded) and constantly in need of qualification.
- Generating theory and doing social research are part of the same process. (2003, p. 74)

There are several processes involved in conducting a grounded theory study that are discussed in more detail during the analytical process such as initial and intermediate coding and the use of the constant comparative method.

Participants

The participants involved in this study were three high school teachers who are employed at a suburban public high school in a southeastern state of the United States of America. During the previous school year, 2012-2013, at the participating school, approximately 3500 students were enrolled in ninth through twelfth grade of which 61% were white, 16% were African American, 12% were Hispanic, 7% were Asian, and 4% were other races. One quarter of the student body received free or reduced lunch. There are four different introductory biology courses at the participating school: collaborative, college prep (CP), honors, and gifted. Collaborative classes contain students who struggle academically and often times have individualized education programs (IEP). Furthermore, collaborative classes utilize two teachers to provide more individualized support for students. CP classes contain students who are likely college bound. Honors and gifted courses are more rigorous than CP courses, and gifted classes require students to achieve certain test scores. Using a grounded theory methodology, I chose my participants based on the goal of achieving maximum variation in the data. The teachers have been given pseudonyms to help maintain confidentiality. Table 1 provides a description of each participating teacher and class that I observed.

Linda and Diane attended a professional development training session during the summer of 2012 in order to learn how to use the 3-D computer modules. They implemented the 3-D computer animations in their classes during the 2012-2013 school year and planned to utilize these modules for the second time in their classes during the 2013-2014 school year. David did not receive any professional development training on implementing the computer simulations and the 2013-2014 school year was the first time in which he planned to implement the computer simulations. All of the teachers participated in a one-hour professional development to learn how to use the SABLE system a few weeks before implementing the cell unit. Furthermore, at least one person from the University of Georgia and/or the IS3D company (associated with the SABLE system) was present during the first implementation of the computer simulations and the SABLE system in order to support its implementation. The University of Georgia faculty and graduate assistants as well as IS3D employees did not assist with instruction, but they helped the teachers manage technological problems that arose and aided the teachers in utilizing the SABLE system for the first time.

Table 1

Participant Background Information

Participants	Ethnicity	Education	Years of teaching experience at the time of the study		Number of classes observed	Classes observed for the study
			K-12	Total		
Linda	Caucasian	B.S. in Biology Masters in Secondary Science Education	22	25	1	Gifted introductory biology
Diane	Caucasian	B.S. in Nursing Masters	4	15	2	College prep and Honors introductory biology
David	Caucasian	Ed.D Science Education	>25	>25	2	College prep and Honors introductory biology

Linda

Linda earned a Bachelor of Science in biology and Masters in secondary science education. Prior to gaining employment as a high school teacher, Linda worked as a lab techniques rotation trainer at a medical school for three years. Enjoying her teaching experiences, she became certified to teach both secondary science and mathematics, working as a high school teacher for 22 years. Previously, Linda taught, algebra, pre-algebra, algebra 2, biology, chemistry, physical science, anatomy and physiology, AP biology, and zoology. During the 2013-2014 school year, she taught gifted introductory biology to eighth and ninth grade students. I observed one of Linda's gifted introductory biology classes, which contained approximately 32 ninth grade students.

Linda provided a structured classroom environment for her students. When Linda's students arrived each day, they checked a cart located in the front of the classroom for handouts and an agenda as well as upcoming due dates for assignments was written on the board. Each day she taught for the entire class period, transitioning between activities smoothly. Linda employed a variety of teaching strategies such as lecture, lab, demonstrations, and worksheets.

Diane

Diane earned a Bachelor of Science in nursing and a Masters in an unspecified field. Prior to earning her teacher certification, she worked as a registered nurse. She has been teaching as a nurse, sex education teacher, and high school teacher for 15 years; however, she has been employed as a certified high school teacher for four years. Previously, Diane taught special education and physics. During the 2013-2014 school year, she taught collaborative, college prep, and honors introductory biology. I observed one of Diane's college prep and one of her honors introductory biology classes, which each contained approximately 32 students.

Diane's classroom management and style of teaching was very similar to Linda's. She created a structured classroom environment, and when her students entered, they collected any needed handouts from a table located in the front of the room. She implemented a variety of teaching strategies including lecture, discussion, labs, computer activities, model building, and small group activities.

David

David earned a Doctor of Education in science education. He has been teaching high school for over 25 years. Although David was certified to teach biology, he taught high school physics for many years. For the first time in over ten years during the 2013-2014 school year, David was assigned to teach collaborative, college prep, and honors introductory biology. I observed one of his college prep and one of his honors introductory biology class periods of which there were 30 and 32 students respectively.

David's teaching style differed from Linda and Diane's. Primarily, David lectured or assigned work from the textbook. Also, in almost every class period he discussed life skills such as, reading the chapter before learning about it, looking people in the eyes, studying, collaborating, reconciling religion and science, and maintaining competitiveness so that students have choices in life. He was a calm teacher and spoke at a medium to slow pace. He made connections between his personal life and his lectures, often sharing stories such as conversations his wife and he had about teaching, his care for his dogs, and his daughter’s volleyball playing.

Context of the Research Study

This study was located within the context of a larger study. A research team from the University of Georgia, involving experts from biology, science education, and veterinary medicine, collaborated to design and develop three 3-D interactive computer modules covering concepts related to cellular transport. After developing and testing the computer modules, the science education researchers conducted an evaluative study during the 2012-2013 school year in order to investigate the use of the 3-D computer animations in improving student learning, student enthusiasm for learning, and student interest in science. Furthermore, the SABLE system was developed and ready for implementation during the 2013-2014 school year. I conducted my study in the fall semester of the 2013-2014 school year.

3-D Computer Simulations

The computer simulations involve three interactive case studies designed to improve student learning of concepts related to cellular transport with each simulation focusing on either diffusion, osmosis, or filtration. Each of the three computer modules is set in the context of a case study where the students assume the role of a physician's assistant or veterinarian and they must collect data and prescribe a course of treatment in order to save the lives of their patients. All three of the computer modules follow a similar pattern and begin with an explanation of a real-life scenario and an introduction to the patient's symptoms. For the diffusion module, a woman has been exposed to chlorine gas and is having trouble breathing. For the osmosis module, a calf is suffering from seizures. For the filtration module, a diabetic man is suffering from swollen feet and pain in his extremities. After learning about the real-life scenario, the students work through a virtual physician's manual that provides the content knowledge students need in order to successfully treat their patients. Once the students finish the manual, they receive information about their patient, and then have the opportunity to navigate through the lungs, the brain, and a dialysis machine for the diffusion, osmosis, and filtration modules respectively. Each of the three explored areas are rendered using 3-D computer animation and feature interactive activities for collecting data. For example, in the diffusion module, the students collect data about the patient's oxygen levels, lung cell membrane thickness, and lung surface area. The collected data is then exported to a virtual patient record where the students compare their patient's data readings to normal, healthy readings. Next, the students receive information about treatment options. Then, they choose and administer a treatment, collect more data, and continue this process until they are able to bring all of the patient's data readings to normal, healthy levels. Embedded within the simulations are opportunities for the students to answer forced choice as well as free response questions involving relevant science concepts. Students have multiple opportunities to answer the forced choice questions correctly because they cannot proceed forward until they do so. On the free response questions, students have opportunities to analyze and interpret their data providing justification for their ideas.

The SABLE System

The SABLE system stands for Skills Assessment Based Learning Environment. The SABLE system is a web application that allows teachers to monitor their students' activity as they work through the 3-D computer simulations on diffusion, osmosis, and filtration. Teachers are able to input their classes to the SABLE system and assign them a computer module. When each student logs into the computer module, then teachers can monitor the students' activity on the SABLE system.

Figure 7 is a picture of the SABLE system interface taken after a class completed one of the computer modules. The SABLE system interface displays the students' names in a column on the left side of the screen, and across the top of the screen are numbers that represent the questions within the computer module. Each box in the matrix represents a specific student's answer for a specific question within the module. As the students are completing the module, the SABLE system fills in each box within the matrix with an information loaded color scheme. White boxes indicate that the student has not answered that particular question. Blue boxes represent open-ended response questions that students have answered, and teachers would need to click on the box to see each student's answer and could then also grade it. Green, yellow, and red boxes represent forced choice questions that students have answered, respectively indicating that students required one, two, or three or more attempts to answer the question correctly.

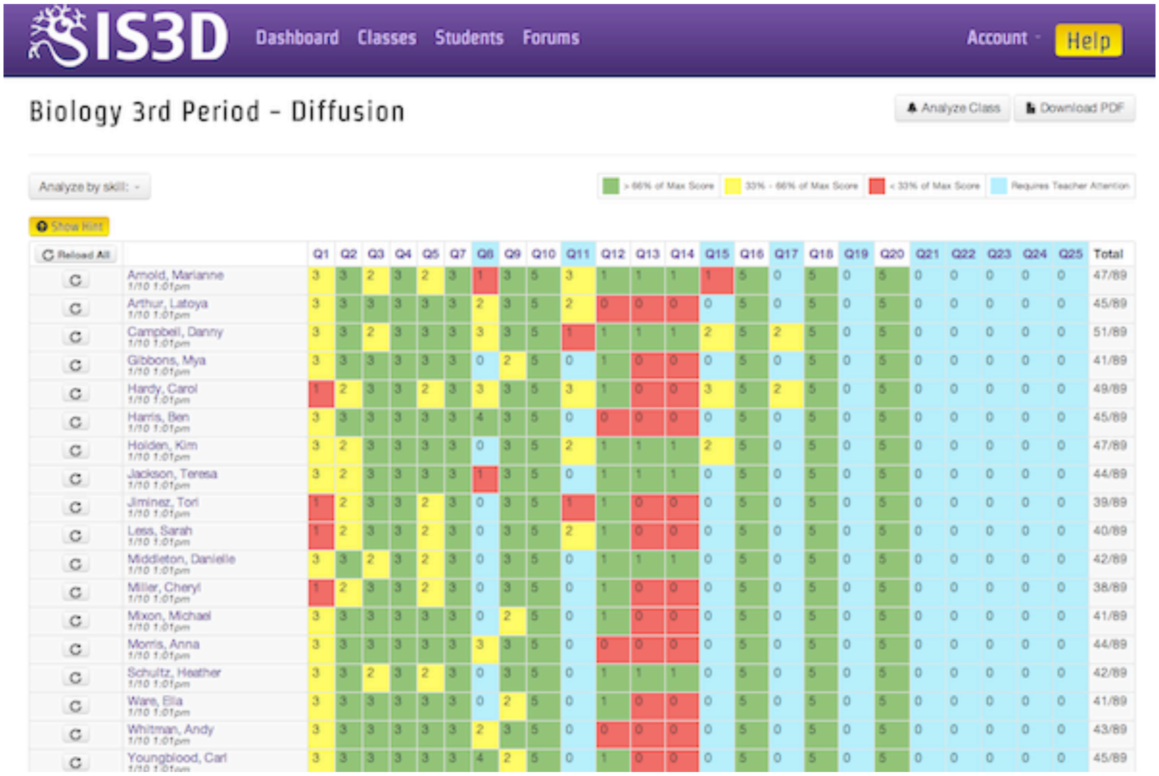

Figure 7. The SABLE System Graphic Interface Organized by Question within the Module. Reprinted from *Cogent Education*, 2014, Retrieved from http://www.is3d-online.com/assets/sablef792fa7cab305b23e6e9340a2d0f1218.png. Copyright 2014 by IS3D, LLC. Reprinted with permission.

The SABLE system contains other tools besides the user interface. For example, the teachers can click on the question box, at the top of each column of answers, in order to see a screenshot of the actual question that was asked. Furthermore, teachers can click on the answer boxes in order to elicit more information. For instance, when teachers click on the blue boxes, they can view their students' typed answers as well as the original question. The SABLE system provides a detailed rubric as to how to assign points to the answers for free-response questions and an example of an exemplar answer. The teachers can choose to provide typed feedback to each student for each free-response question within the SABLE system and send that feedback to the students through their online accounts with the SABLE system. The SABLE system automatically grades the forced choice questions. Furthermore, the SABLE system aligns each question within each computer module with one or more scientific skills including core concepts, data analysis, data interpretation, hypothesis and reasoning, predictions, and communicating findings. As opposed to viewing the interface in Figure 7, teachers have the option to view their students' strengths and weaknesses organized by scientific skill as shown in Figure 8. For example, teachers can view the percentage of prediction questions that each student answered correctly.

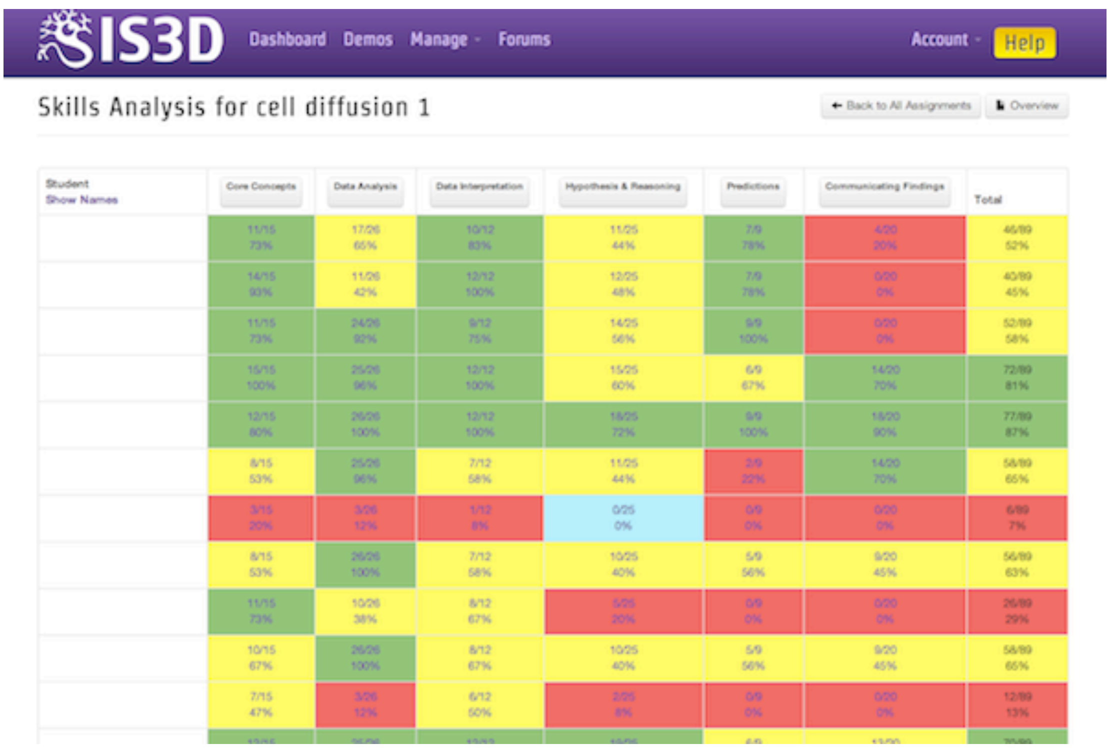

Figure 8. The SABLE System Graphic Interface Organized by Scientific Skill. Reprinted from *Cogent Education*, 2014, Retrieved from http://www.is3d-online.com/assets/sableskills-aee9f6d231fbcefa5d4ae71f989235ad.png. Copyright 2014 by IS3D, LLC. Reprinted with permission.

Data Collection

In order to have an in-depth understanding of how technology supports or constrains teachers' formative assessment practices, I first needed to conduct classroom observations in order to develop an in-depth understanding of teachers' formative assessment practices in their normal day-to-day classrooms as well as while they implemented the computer modules and the SABLE system. Then, I compared their normal day-to-day formative assessment practices with their enactments of formative assessment while implementing the 3-D computer modules and the SABLE system. Through this comparison of teachers' formative assessment practices with and without the technology, I was able to develop explanations about how the technology supported and/or constrained their formative assessment practices.

For this research study, I conducted classroom observations and semi-structured interviews. Table 2 illustrates the data collection schedule used in this study. I observed Diane and David's implementations of the entire cell unit during four of their classes. For Linda, I started observing her class after she introduced the cell unit and had previously covered the history of the cell theory and the cell organelles. During classroom observations, I maintained detailed field notes. My goal for the field notes was to capture as complete of a running transcript of the verbalizations in the classroom as possible. Having a running transcript of the verbalizations between teachers and students allowed me to gain insight into how each teacher and his/her students were co-constructing an understanding of the learning objectives and the progression of learning. During the observations, I initially typed my field notes in short hand and expanded them further before the end of each day. As I conducted the classroom observations, I also kept in mind my analytical framework, looking for evidence that the teachers were sharing learning goals and clarifying criteria for success, eliciting evidence of learning, providing feedback, modifying instruction based on the elicited evidence of learning, and engaging students in peer and self-assessment (discussed in more detail in the analysis section). Furthermore, when there were no verbalizations, I paid attention to information written on the board such as daily agendas, notes, or essential questions. I also noted the actions of the teacher such as if he/she walked around and observed students.

Table 2

Data Collection Schedule

Participants	**Observations**	**Interview 1 Date and Duration**	**Interview 2 Date and Duration**	**Interview 3 Date and Duration**
Linda	Gifted 10/15/13 – 10/29/13	10/18/13 ~ 33 minutes	10/31/13 ~ 24 minutes	12/18/13 ~ 47 minutes
Diane	College prep 10/23/13 – 11/07/13 Honors 10/15/13 – 10/29/13	10/24/13 ~ 11 minutes	11/07/13 ~ 24 minutes	12/20/13 ~ 21 minutes
David	College prep and Honors 10/18/13 – 11/06/13	10/21/13 ~ 5 minutes	11/05/13 ~ 17 minutes	12/18/13 ~ 34 minutes

I conducted three semi-structured interviews with each teacher. The protocols for each interview are in Appendix A. The first interview occurred towards the beginning of the cell unit and served the purpose of determining the teachers' goals for the cell unit, ideas about content that the students will struggle with, and thoughts on when and how to use the computer modules and the SABLE system. The second interview occurred after the teachers had finished implementing the computer modules and the SABLE system with the classes in which I was observing. The purpose of the second interview was to have the teacher, in addition to answering questions that clarified my observations, explain how he/she used the SABLE system, including what he/she paid attention to within the SABLE system and what the data in the SABLE system was telling him/her about their students' conceptual understandings. The third interview occurred about 45 days after the end of the cell unit. The reason for the delay was to give the teachers time to process their experiences with the SABLE system and the computer modules. The purpose of this final interview was to gather information about the teachers' views on both formative assessment and how the computer modules and the SABLE system supported or constrained their ability to manage and monitor student learning.

Data Analysis

In this section, I detail my analytical process. First, I describe the analytical framework that I applied to the data followed by a discussion of the use of the constant comparative method. Then, I detail my analytic process for the classroom observation field notes and the interview data. Although analytical frameworks are not usually employed with grounded theory studies, depending on the type and purpose of the data, researchers may code and compare "incidents" (Charmaz, 2006, p. 53). Applying this analytical framework, allowed me to identify "incidents" of formative assessment upon which I conducted further analysis.

Analytical Framework

For my analytical framework, I used Dylan Wiliam's (2007) five strategies for the effective implementation of formative assessment: sharing learning goals and sharing criteria for success, eliciting evidence of learning, providing formative feedback, activating students as instructional resources for one another (peer-assessment), and activating students as owners of their own learning (self-assessment). Below, each of Wiliam's (2007) strategies is discussed in relation to implementation techniques that promote effective formative assessment teacher practices. By describing implementation techniques for each strategy, I was better able to identify each strategy when analyzing my data.

Clarifying learning goals and sharing criteria for success.

When teachers clarify learning goals and share criteria for success with their students, they develop an understanding of the knowledge and skills they expect their students to develop and the criterion used to determine whether students achieved the learning aims. Co-constructing learning goals and criteria for success with their students is an effective method of clarifying learning intentions and success criteria (Wiliam, 2011). Similarly, Davies states, "When conversations about learning take place in the group, learners can check their thinking and performance, develop deeper understandings of their learning, and become more strategic in their planning and monitoring . . . experiences such as these prepare learners to take the risks necessary for learning" (2003, p. 17). Also, she suggests that criteria used for evaluation be revisited throughout the learning process to reflect student learning and refine the criteria that dictate high-quality work.

Some learning goals are more difficult for students to recognize, especially learning goals associated with scientific inquiry (Harlen, 2007). Thus, teachers need to engage students in discussions or activities to determine whether they understand the learning intentions of lessons. Furthermore, teachers clarify the learning goals and what success looks like when they discuss samples of work with students and provide rubrics for assignments, which can also aid students in self-assessment as they compare their current level of understanding to a future level of understanding (Wiliam, 2011).

Eliciting evidence of learning.

When teachers elicit evidence of learning from their students, they are attempting to make their students' thinking and their acquired knowledge visible so they have a better understanding of how students understand specific concepts. Teachers implement a variety of strategies to elicit evidence of learning. Black, Harrison, Lee, Marshall, and Wiliam (2004) point out that many teachers engage their students in question and answer sessions characterized by questions whose answers require recall and memorization and little if any time to think and respond. They suggest that teachers can enhance their formative assessment practices through re-envisioning both the purpose of questioning and the tactics employed to engage students in dialogue. Through increasing the wait time between posing a question and receiving an answer, teachers encourage more students to participate in the discussion because the lengthened wait time signals to them that they need to think about the question in order to construct thoughtful responses, particularly in classroom environments that value the sharing of ideas. Furthermore, simply asking questions is not sufficient; teachers need to pose open-ended questions aimed at revealing student understanding and anticipate the types of responses they may receive and possible ways in which to follow up on those responses.

Mary Lee Martens (1999) provided several examples of types of questions that teachers can use to promote classroom discourse that can access and foster student thinking. She identified seven types of questions: action, attention focusing, comparison, measuring and counting, metacognition, problem posing, and reasoning. Action questions involve instances when students are asked what would happen, hypothetically, if certain events occurred. For example, the osmosis module asks, "What happens to the concentration of free water molecules if you add salt to a solution". Attention focusing questions are those in which focus student thinking on specific information and observations. For example, in order to discuss osmosis, teachers may draw students' attention to what a gummy bear looks like after it has been sitting in water for a period of time (Diane, field notes, 11/01/13 CP). Comparison questions involve instances in which students compare and contrast items. For example, Linda asked her students, "So if cells are the same size, then what is different between the cells in an elephant versus a mouse" (field notes, 10/17/13). Measuring and counting questions require students to make quantitative observations. For example, Linda explained that the surface area is length times width and then, asked her students how many dimensions are represented with surface area (field notes, 10/17/13). Metacognitive questions are those in which students are asked to think about their thinking and about how they know what they know. For example, Diane asked her students, "Which organelles are the most difficult to remember?" (field notes, 10/28/13 CP). Problem posing questions ask students to develop solutions to problems. For example, in the diffusion module, students are asked to determine the order in which they will administer different treatments to their suffering patient. Reasoning questions involve asking students to justify and explain their ideas. For example, in the diffusion module, students are asked, "From what you learned in the diffusion manual, what factors could be responsible for the patient's low arterial oxygen?". Lastly, teachers commonly ask recall/factual questions in which students are asked to remember factual information. For example, David asked his students to list the three parts of the cell theory (field notes, 11/06/13 Honors).

Providing feedback.

Providing feedback occurs when a teacher responds to elicited evidence of learning in a way that communicates to students, either explicitly or implicitly, their current trajectory towards learning goals. Feedback can be written or verbal and sometimes involves modifying instruction. Hattie and Timperley (2007) identify three feedback questions that, when addressed, can be powerful in promoting student learning: "Where am I going? How am I going? and Where to next?" Formative feedback addresses those questions and focuses on a student's strengths, identifies a gap between what is known and what is desired to be known, and provides guidance on closing that gap (Black et al., 2004; Shute, 2008). When feedback identifies a gap between what students know and what they need to know, then teachers communicate to students where they are in the learning process, which can motivate students to identify strategies to move their learning forward (Shute, 2008). Furthermore, specific feedback identifying areas in student learning that need to be adjusted and guidance on how to make those adjustments decreases the cognitive load and uncertainty for students, which increases the likelihood that they will stay motivated to learn. According to Shute, "Goal-directed feedback provides learners with information about their progress toward a desired goal (or set of goals) rather than providing feedback on discrete responses (i.e., responses to individual tasks)" (2008, p. 161). When students are engaged in appropriate goal setting and monitoring, then their motivation for learning increases, which is required in order for student learning to occur. On the other hand, feedback that is numerical and simply ranks a student in comparison to a standard or other students and feedback, in the form of praise, that focuses on the student with no relation to the learning goal does not promote student learning and in many cases works against it (Black et al., 2004; Hattie & Timperley, 2007).

The learning goals and criteria for success determine the types of evidence of learning elicited, which, in turn, influences the types of feedback teachers provide to students. McMillan (2010) distinguished between formative assessment feedback practices that aim to promote the development of "simple knowledge" versus "deep understanding" (p. 45). Simple knowledge refers to students recalling factual knowledge while deep understanding engages students in problem solving, critical thinking, and the application of knowledge. McMillan (2010) argued that teachers who provide feedback to their students indicating whether or not they answered questions correctly engage in formative assessment practices that promote the development of simple knowledge. However, teachers support deep learning when they provide feedback that is more individualized and challenges students through asking follow-up questions, posing new problems, and making connections with prior knowledge.

Peer-assessment.

Peer-assessment occurs when teachers create a learning environment that is conducive to peers assisting each other with learning. This usually involves pairs or small groups dedicated to cooperative learning. While peer-assessment frequently involves the overt assessment of completed work, such as exchanging lab reports for editing, it also occurs in less explicit circumstances such as in small group work. In both scenarios, student learning is encouraged through students receiving feedback in a language that is familiar to them, performing the role of teachers with each other, and likely accepting peer criticism more easily than teacher criticism (Black et al., 2004). Furthermore, teachers can create opportunities in planned peer-assessment sessions to walk around the classroom and elicit evidence of learning through listening to student conversations.

Self-assessment.

Self-assessment is essential to learning and occurs when students reflect on their progress towards learning goals. "Students can achieve a learning goal only if they understand that goal and can assess what they need to do to reach it" (Black et al., 2004, p. 14). In order for students to identify learning strategies that work or need adjustment, teachers should frequently encourage students to self-assess through specific activities that ask students to reflect on their own learning. For example, a teacher might provide her students with paper discs, red on one side and green on the other, and ask them to flip to the red side if her lecture is going too fast. This requires students to maintain constant awareness of their progress towards learning goals. Furthermore, self-assessment develops metacognitive skills because students are "thinking about their thinking and their learning" (Davies, 2003, p. 17). These metacognitive skills empower students to monitor their progress towards learning goals and make adjustments to learning strategies when necessary.

Analytic Process

The constant comparative method is an analytic tool employed to organize data. The constant comparative approach is an iterative process that compares units of data and identifies similarities and differences between them (Butler-Kisber, 2010). Researchers move from initial descriptive codes to more conceptual and interpretive categories and theories through the iterative process of comparing data to data, data to codes, codes to codes, codes to categories, and categories to categories. This iterative process is a method utilized to organize the data so that a deeper conceptual and theoretical understanding can emerge (Butler-Kisber, 2010). A code represents a word or a phrase that captures the essence of the text in which it represents (Saldaña, 2013). A category is a grouping of codes that share some characteristic (Saldaña, 2013). For example, one of my codes is called “cell organelles.” This code describes data discussing cell organelles as a learning goal within the cell unit. Categories are more conceptual, and they combine multiple codes and demonstrate the relationship between these codes. For example, the code "cell organelles" combines with several other codes representing different learning goals within the cell unit to create the category called, “general learning goals within the cell unit.”

Since the constant comparative approach grounds itself in the data and develops meaning from the data, it is considered to be an inductive approach with its roots in symbolic interactionism (Freeman, 2008). A basic assumption of constant comparative analysis is that there is a shared context between the researcher and the participants in which meaning is co-constructed. A weakness of the constant comparative analysis emerges when working with data across multiple participants because "contextual elements are lost" (Butler-Kisber, 2010, p.24). However, its strength lies in its ability to find commonality among a multitude of participant perspectives of an everyday phenomenon (Butler-Kisber, 2010; Freeman, 2008). Thus, constant comparison is best used for dynamic, process oriented events in which there are multiple perspectives.

Analysis of the Classroom Observation Field Notes

In order to analyze the classroom observation data, first I applied Wiliam's five strategies for the effective implementation of formative assessment. I coded each observation using the comment feature in Microsoft Word. Then, for each class period that I observed and each of the five components of the analytical framework, I created a table including the date of observation listed chronologically and the codes pertaining to that strategy. Table 3 shows an excerpt of Linda's gifted biology class for the strategy clarifying learning goals and sharing criteria for success. Having a table for every combination of observed class period and strategy allowed me to easily view each teacher's implementations of the different formative assessment strategies for the entirety of the cell unit. I continued coding the data, asking questions such as:

- What methods did the teachers use while implementing each strategy?
- Who did the teachers interact with when implementing each strategy?
- How frequently did they engage in each strategy?

Setting aside the analytic framework, I also coded segments of the classroom observation field notes that represented the teachers' views, beliefs, and feelings related to formative assessment or the implementation of the technology. These segments of the data usually involved the teachers sharing their reflections about a lesson directly after the observed class period. For example, Diane expressed frustration to me after a class period in which multiple technology issues arose with the computer modules and the SABLE system.

Table 3

Linda Classroom Observations of Clarifying Learning goals and Sharing Criteria for Success

10/15/13
The teacher explains that the students will need to know the parts of the microscope and what they do.
She shows them on Powerpoint slides what the letter "e" should look like when being viewed under the different objectives.
10/16/13
The teacher puts up a picture of the letter "e" under scanning, low, and high power and asks, "if you are having problems, call me to you".
She shows several examples of finished posters from previous years. They need to have all of the parts for both plant and animal cells on the same side. Then, for the project, they have a rubric. She explains that the project is a visual learning tool or a study tool for the students so they need to put it together in a way that makes sense to them. In the analogy, they need to find the definition and the function of the organelle and put it into their own words so that they understand. Then, they need to think of an everyday object that is similar - an analogy - so for the nucleus - she defines it and describes its function - it is like a brain because . . . - follow this format to get all of the points. The rubric appears to be very detailed; she goes through it quickly.
She explains that they do not reteach the cell organelles because you should already know them and that they are responsible for them.
MLA style: She will return their ecology projects on Friday, but here's where most of you struggled with MLA. You can use a bibliography generator like easy bib. In general, a website citation - she shows example on slide - Author last name, first name - so if you don't understand how to use MLA citations, ask me.
She shows another project example with foam board. She says that although it was good, the foam board cheats you out of room. They need to follow the rubric and double check it.

Analysis of the Interview Data

I transcribed all nine interviews conducted for this research study. After conducting an initial coding of Linda's interview data, I reviewed the codes, my research questions, and the purpose of the study. Then, I developed a new analysis plan. I conducted seven rounds of initial coding for each interview, and for each round I looked for and coded data relevant to one of seven topics: clarifying learning goals and sharing criteria for success, eliciting evidence of learning, providing feedback, engaging students in peer and self-assessment, discussing views of formative assessment, and expressing ideas, thoughts, and emotions related to the use of the computer modules and the SABLE system. First, I performed initial coding on all of Linda's interview data using the comment function in Microsoft Word. During initial coding, I used a method referred to as subcoding. "A Subcode is a second-order tag assigned after a primary code to detail or enrich the entry" (Saldaña, 2013, p. 77). For example, while coding a piece of text as clarifying learning goals, I added a subcode, providing further detail to the code. A few of the subcodes that I applied to the code-clarifying learning goals included: structure and function of cell parts, based off of the standards, connections between and within units, application of knowledge, and alignment with computer modules. Then, I transferred each of the codes and subcodes into tables for each of the eight topics. Next, I compared codes to codes, organizing the data and allowing categories to emerge. I went through the same analytic process with Diane and David's interview data. Then, I combined Linda, Diane, and David's coding tables related to formative assessment and technology and conducted axial coding, allowing me to combine synonymous codes and determine categories that describe clusters of codes.

Table 4

Alignment of Research Questions, Types of Data Collected, and Analytic Tools

<table>
<tr><th>Research Question</th><th>Data Collected</th><th>Analysis Tools</th></tr>
<tr><td>How do secondary biology teachers enact formative assessment during an instructional unit on the cell unit in an introductory high school biology course?</td><td>Classroom observation field notes

Interview 1

Interview 2

Interview 3</td><td rowspan="4">Constant comparative analysis applying the analytical framework of Wiliam's five strategies for the effective implementation of formative assessment with the added component of impact on instruction

Types of coding used: subcoding, and axial coding</td></tr>
<tr><td>How do secondary biology teachers conceptualize formative assessment?</td><td>Classroom observation field notes

Interview 3</td></tr>
<tr><td>In what ways do the data from the SABLE system influence future instructional decisions within a cell unit?</td><td>Classroom observation field notes

Interview 2

Interview 3</td></tr>
<tr><td>How do 3-D computer modules involving cellular transport, coupled with a technology that allows real time monitoring of students' work, support or hinder teachers' formative assessment practices during the implementation of the cell unit?</td><td>Classroom observation field notes

Interview 1

Interview 2

Interview 3</td></tr>
</table>

To summarize my analytical process, I used Wiliam's (2007) five strategies for the effective implementation of formative assessment as an analytical framework to identify instances of formative assessment in the classroom observation field notes. I also applied the analytical framework to the interview data in order to identify aspects of formative assessment that the teachers discussed. In addition, I examined the classroom observation field notes and interview data for teachers' views, beliefs, and feelings related to the use and implementation of the computer modules and the SABLE system. Finally, I used the constant comparative method to explore ways in which the computer modules and the SABLE system supported or hindered teachers' formative assessment practices.

Validity

This study used data triangulation, collecting data at different times, in different spaces, and from different people (Denzin, 1978). Also, this study used within method methodological triangulation, meaning I used multiple data collecting strategies, including observations and interviews (Denzin, 1978). By collecting two different types of data from multiple people at different times and spaces, I will be able to construct a more complex understanding of ways in which the implementation of the computer modules and the SABLE system support and constrain teachers' formative assessment practices.

Limitations

Several limitations exist within this study. In order to capture teachers' enactments of formative assessment, I heavily relied on detailed field notes of classroom observations. Because formative assessment is a discursive process, I decided to record as close to a running transcript as possible of all of the verbalizations from teachers and students participating in teaching and learning. Consequently, I likely missed non-verbal nuances of the learning process such as student facial expressions communicating confusion. Furthermore, when students worked individually or in small groups and the teachers walked around observing and conversing with the students, I was only able to hear conversations between students and teachers taking place in proximity to me. In addition, I did not collect student work or interview teachers after each class to discuss changes they made during instruction, limiting my insight into teachers' methods of providing feedback to their verbalizations during the classes I observed.

In conducting a qualitative grounded theory research study, my findings are limited by the inclusion of only three participants. Grounded theory studies require the addition of new participants until theoretical saturation is reached. Although my theoretical assertions are incomplete, my findings still provide insight into how the computer modules and the SABLE system supported and constrained teachers' formative assessment practices.

Summary

In this chapter, I identified constructionism as my epistemological stance, interpretivism as my theoretical framework, and grounded theory as my methodology. Then, I provided detailed information about the research context, the participants, the computer modules, and the SABLE system. Next, I described the collection of classroom observation and interview data and detailed the analytical process, including the use of an analytical framework. I explained the role of triangulation in this study to support the validity of my findings. Lastly, I concluded with the identification of several limitations of this grounded theory study. The next chapter will present the findings of the data analysis along with discussion and interpretation of those findings.

CHAPTER 4

FINDINGS

The purpose of this research was to explore how the 3-D computer modules, featuring interactive simulations, and the Sable System supported and constrained teachers' formative assessment practices during the implementation of an instructional unit on the cell in an introductory biology class for high students. During the study, I focused on teachers' enactments of formative assessment while implementing lessons with and without technology as well as their statements during interviews about their views on the use of the technology and formative assessment. In this chapter, I aim to present the findings that emerged from my data during analysis. I present the findings in three sections: teacher enactments of formative assessment, teacher views on formative assessment, and teacher implementations of the technology in relation to formative assessment. In the first section, I analyzed both the classroom observation field notes and the interview data in order to describe the teachers' enactments of formative assessment. In the second section, I analyzed interview data and presented the teachers' conceptions of formative assessment. Lastly, analyzing both the classroom observation field notes and the interview data, I discuss the teachers' use of the 3-D computer modules and the SABLE system in relation to their formative assessment practices and their views on the ways the technology supported and constrained their formative assessment practices.

Teacher Enactments of Formative Assessment

In this section, I describe the teachers' enactments of formative assessment during the implementation of a cell unit. I utilized Dylan Wiliam's (2007) five strategies for the effective implementation of formative assessment to identify formative assessment practices, and each strategy represents a subheading in this section: clarifying learning goals, sharing criteria for success, eliciting evidence of learning, providing formative feedback, peer-assessment, and self-assessment. Wiliam (2007) discusses clarifying learning goals and sharing criteria for success as one category; however, I separated these two strategies when discussing them in the findings in order to distinguish between methods teachers used to engage in these two strategies.

The findings that comprise this section emerged from the analysis of classroom observation field notes and interview data. Relevant interview questions, a sample of which is presented in Table 5, aimed to elicit teachers' ideas in relation to Wiliam's (2007) five strategies for the effective implementation of formative assessment. The findings in this section relate to one research question: How do secondary biology teachers enact formative assessment during the cell unit? Understanding teachers' enactments of formative assessment with and without the 3-D computer modules and the SABLE system provides a context in which to explore characteristics of the technology that support and hinder teachers' formative assessment practices.

Table 5

Sample of the Interview Questions Related to Teachers' Enactments of Formative Assessment

Interview Questions
• What are the main concepts that you want your students to learn in the cell unit? • What concepts do you think the students will struggle with or find easy in relation to student learning? • How will you monitor the progression of student learning throughout the cell unit? • What role do students play in the managing and monitoring of their own learning? Or their peers' learning?

Clarifying Learning Goals

As was stated earlier, using Wiliam's (2007) schemata, teachers clarify learning goals when they develop an understanding of the types of knowledge and skills that need to be acquired by the students and then subsequently convey those goals to their students. Several categories of codes emerged in the data from both the classroom observation field notes and the interviews that relate to the process of clarifying learning goals. The findings that emerged from the analysis of this coded data will be grouped into the following categories: identifying learning goals, finding alignment between the computer modules and the identified learning goals, predicting student difficulties with learning goals, discussing influences on the development of learning goals, and communicating learning goals to students (see Tables 6 and 7). Each of these categories of findings will be discussed separately in the next sections.

Identifying learning goals.

All of the teachers developed over-arching learning goals for their students that were relevant to biology and science in general but not specific to any one unit within biology. Linda, Diane, and David identified the over-arching learning goal of requiring the students to be able to relate the science concepts within each unit to the real world. For example, Linda discussed the expectations she set for her students and stated,

> Now you need to understand how transport works so if you are diagnosed with diabetes or someone in your family is and they're suffering from kidney failure, what kinds of options are out there, and when the doctors are talking to you, you can ask important questions and understand what is best. (I3, Lines 433-437)

In discussing how the computer simulations supported her in achieving her learning goals, Diane shared, "I think all the research is, like, using real life learning situations to help students make connections and so they all are like relatable and relevant where a lot of what's out there isn't" (I3, Lines 129-131). Also, David shared his learning goals for the cell unit and said, ". . . how it [the science concepts the students are learning] can be related to something they can relate to" (I1, Lines 9-10).

All of the teachers also adopted the over-arching learning goal of students being able to move beyond recalling information to applying knowledge to new and different situations. In discussing her expectations for how the cell unit will progress in regards to student learning, Linda stated, "I do not want the kids to memorize and regurgitate. I expect them to be able to have that basic knowledge and then be able to apply it" (I1, Lines 64-65). Similarly, Diane shared, And then, they, um, are usually good with the vocab on diffusion and osmosis, but the application of it, and like, how does that affect the cell and make the homeostasis, and the hyper, like the tonicity - they always struggle with . . . even the honors kids struggle with like applying what they know. [Laughs] So that's kind of, I'll usually do labs and stuff designed at like inquiry because they're kind of all stuck in like rote memorization. (I1, Lines 32-41)

Diane and David did not articulate over-arching learning goals beyond those discussed above. However, Linda indicated that she also wanted her students to make connections with scientific concepts between and within units. She stated,

I want them [her students] to not see the cells as a separate unit, as an entity on its own. I want them to understand how everything that we've been doing builds up to this, and so I'm constantly referring them back to our [biochemistry] unit . . . I just want them to start making those connections and understanding that everything is composed of the cells and then how those function to either make you have a homeostatic mechanism that's functioning properly or that you could be out of whack and there's something wrong, you know, you have a disorder or a disease. (I1, Lines 10-20)

All three teachers shared general learning goals specific to the cell unit. Linda and Diane developed several learning goals involving the cell theory; the structure and function of cells, cell organelles, and the cell membrane; passive and active transport; and tonicity. Also, Linda developed learning goals about the history of the cell and the types, parts, and usage of microscopes. David, not having taught biology for over ten years, struggled to articulate learning goals for the cell unit. He indicated that students needed to be able to identify the parts of the cell but stated that beyond that, he was unsure of the learning goals. During the final interview, which occurred after the cell unit was implemented, David also identified cell transport and tonicity as learning goals for the cell unit.

Finding alignment between the computer modules and the identified learning goals.

There was significant overlap between the learning goals that the teachers identified for the biology course and the cell unit and the learning goals that they identified as being addressed within the computer modules. All of the teachers were similar in their views on the alignment of the computer modules with their learning goals. After having implemented the computer modules, Linda, Diane, and David explained that they helped them address the over-arching learning goals of having students apply knowledge and relate the science concepts they were learning to the real world. In discussing how the computer modules helped her address her learning goals, Linda stated, "So using the modules allows me to do some basic teaching in the classroom so the vocabulary is under their belt, . . . then take them into the laboratory in a computerized setting where they are actually applying what they have learned" (I3, Lines 32-37). In continuing to discuss the computer modules in relation to her learning goals, Linda shared, ". . . it [the computer modules] is a real life scenario that they [the students] were able to interact with and solve on their own, and because they were able to problem solve while they were doing it, it stays with them longer" (I3, Lines 60-62). Similarly, Diane described the useful characteristics of the computer modules noting,

> So what makes this [the computer modules] different is they're [the students] are not just going through the motions, it [the computer modules] has that critical learning, critical thinking component. Whereas a lot of it is just click, click, click and do, going through the rote part of it. This is much more challenging . . . using real life learning situations to

help students make connections and so they are all relatable and relevant where a lot of what's out there isn't. (I3, Lines 125-131)

Also similarly, David discussed the computer modules in relation to his learning goals noting, "So that realistic part of it [the computer modules] was very important that reference, you know, I thought giving them a reference so they can apply new knowledge to was very, very important" (I3, Lines 37-38).

In regards to the general learning goals specific to the cell unit, all three teachers pointed out that the computer modules supported students in learning about cell transport and tonicity.

Table 6

Identifying Learning Goals, Alignment of the Learning Goals and the Computer Modules by Participant, and Predicting Student Difficulties

	Identifying Learning Goals		**Alignment of the Learning Goals and the Computer Modules (after implementation)**	**Predictions of Student Difficulties**
	Over-arching for the Biology Course	**General within the Cell Unit**		
Linda	- Relate science concepts to the real world - Application of knowledge -Connections between and within units	- History of the cell -Cell theory - Structure and function of cells, cell organelles, and the cell membrane - Passive and active transport - Tonicity -Types, parts, and usage of microscopes	-Relate science concepts to the real world -Application of knowledge -Cell transport -Tonicity	- Active transport - Structure and function of the cell membrane and membrane proteins - Application of knowledge - Parallel and counter current exchange - Movement of solutes across a concentration gradient - Many different solutes are moving simultaneously
Diane	- Relate science concepts to the real world - Application of knowledge	- Cell theory - Structure and function of cells, cell organelles, and the cell membrane - Passive and active transport - Tonicity	-Relate science concepts to the real world -Application of knowledge -Cell transport -Tonicity	-Structure and function of the cell membrane -Application of knowledge
David	- Relate science concepts to the real world -Application of knowledge	-Identify the parts of the cell -Cell transport -Tonicity	-Relate science concepts to the real world -Application of knowledge -Cell transport -Tonicity	-Unsure -Vocabulary -Cell transport and tonicity (stated after the implementation of the unit)

Predicting student difficulties with learning goals.

The teachers identified the knowledge and skills the students would struggle with in regards to the cell unit as an aspect of their planning process. Each teacher shared these thoughts during an interview, in most cases, prior to the implementation of the cell unit. Linda listed several science concepts and skills that she predicted would pose difficulties for students: structure and function of the cell membrane and membrane proteins, movement of solutes across a concentration gradient, many different solutes are moving simultaneously, active transport, parallel and counter current exchange, and the application of knowledge. Similarly, Diane predicted that students would struggle with the structure and function of the cell membrane, cell transport, tonicity, and the application of knowledge. David admitted that he did not have expectations regarding student difficulties because he has not taught biology in over ten years. However, he predicted the students would struggle with vocabulary and the application of knowledge. After the students completed the final exam for the course at the end of the semester, in the third interview, he identified cell transport and tonicity as posing difficulties for the students. Since the computer modules were designed to address science concepts and skills that teachers indicated were difficult for students to learn, it is not surprising that many of the learning goals the teachers predicted would be difficult for their students to attain are the same learning goals identified as aligning with the computer modules.

Influences on learning goals development.

The teachers discussed aspects that played a role in developing their learning goals. Linda, Diane, and David considered the curricular expectations set out in the standards. Beyond referencing the standards, David did not identify any other factors that influenced the development of his learning goals. However, in addition to the standards, Linda developed learning goals based on information students would possibly encounter on standardized tests. However, she indicated the standards are too vague and the standardized tests lack rigor. In addition to the standards and standardized tests, she considered the academic prowess and needs of her students. For instance, Linda developed more rigorous learning goals for students who planned to pursue higher-level science courses, such as AP biology. Linda shared,

> I do not use the EOCT as my end goal in gifted and honors level classes, that's not my end goal, they have to do that, but that's one hoop just like the [standardized test] is one hoop. My goal for them is to be able to take this class and use it as a springboard for a higher-level science class that they're going to: AP, anatomy, micro, forensics, environmental. (I3, Lines 530-533)

Diane believed that the knowledge and skills required for her students to develop according to the standards and the standardized tests should align. Thus, when developing learning goals, she only attended to the standards, believing that if she covered the material in the standards, then the students will perform well on standardized tests. Although standardized tests lacked influence over her learning goals, she acknowledged that they determined the pacing of the curriculum. She shared,

> Well the standardized tests, theoretically, should be driven from state standards so as long as we're following our standards, then we should be covered on the end of course test . . . That being said, we do have to base pacing decisions on it because the end of course test is about three weeks before the end of the actual semester so there's a push to get all the material covered in time for the end of course test. So that makes a lot of our decisions based on, pacing wise, how long we spend on something. (I3, Lines 243-254)

Both Linda and Diane set expectations for their students based on their understanding of the vertical curriculum. For example, Linda only devoted a portion of a class period to covering cell organelles, explaining to her students that they should have learned the cell organelles and their functions in middle school. She allotted six of the 12 observed days in the cell unit to the topics of transport and tonicity. Furthermore, in discussing how the cell unit will progress in regards to student learning, Diane stated,

> . . . for the majority of them the cell organelles are familiar because they've learned it in life science, but they struggle with the cell membrane, like the details of it. So it takes a couple of days just to teach the structure of the cell membrane because it's unfamiliar to them. All they've really learned before is, like, what it does, but they don't understand why or how. (I1, Lines 28-32)

Communicating learning goals to students.

Although all of the teachers explained the alignment of their learning goals with the computer modules, none of the teachers communicated learning goals to their students during the implementation of the computer modules. Also, none of the teachers explicitly stated specific learning goals to their students. Furthermore, they did not involve their students in the development of learning goals or assess to determine whether or not their students held a shared understanding of the learning goals with them.

All of the teachers communicated learning goals to their students everyday through the notes, activities, labs, and study guides they required their students to engage in and complete. Linda and Diane employed similar methods to clarify learning goals to their students. They both utilized guided notes, meaning the students were given a packet of incomplete notes that they would fill in from the Powerpoint during the lecture. During the lecture portion of the lesson, Linda and Diane used attention focusing phrases to communicate the science concepts or skills that their students were expected to learn. In particular, Linda used phrases such as: "this is not all of the information you need", "this is what I expect you to be able to do", and " you need to know". For example, during a lecture on active transport, Linda stated,

> Let's start with the sodium/potassium pump. This is an animation that shows the sodium/potassium pump where sodium is pumped out and potassium is pumped in. That is not all you need to know though. You also need to know the actual shape change, which is in the picture that I gave you. It can only bind the sodium based on the shape, then with energy it closes and reopens on the other side. But the shape has changed and the sodium is released and now sodium can no longer bind, but potassium can bind and when it does it changes shape. (Linda, field notes, 10/24/13)

Also, on several occasions while using attention focusing phrases, Linda quantified the learning intentions. For example, in introducing passive and active transport, Linda stated,

> The two types of transport we are looking at today and tomorrow are passive and active. Passive transport does not require energy and we refer to that as following the concentration gradient. Diffusion is an example of that. The other type is active transport and just as the name implies, it does require energy to happen. You have to move against the concentration gradient. We are going to look at examples called pumps and endocytosis and exocytosis. We will talk on those on Thursday. Today we will talk about passive transport. (Linda, field notes, 10/22/13)

Similarly, Diane utilized attention focusing phrases such as: "it is your responsibility to know", "the main thing that I want you to know", " you need to understand", and "this is the big idea". For instance, Diane explained the structure of a phospholipid stating, "This is a detailed picture. You need to know that this is a phospholipid and label the head and that that is phosphate and hydrophilic and the tail is hydrophobic" (field notes, 10/16/13). Also, similar to Linda, Diane quantified the learning intentions. For example, while discussing diffusion, Diane noted,

> There are three factors that affect the rate of diffusion: temperature, pressure, and concentration. But what I want you to know is that the higher the temperature, the pressure, or the concentration, these things increase the rate of diffusion. So you need to know those three things and recognize the situation and apply that. (Diane, field notes, 10/21/13)

In addition to using attention focusing phrases and quantifying learning intentions, Linda clarified the learning goals related to cell structure and function through her assignment of a cell project in which the students drew a plant and an animal cell including the respective organelles. The student had to compare each organelle to an everyday person or thing based on the organelle's function. For example, students may compare mitochondria to a power plant. Although Linda only devoted a portion of a lesson to cell organelles, on four separate days, she persistently reminded her students that the cell project will provide them with the information they are responsible for learning in regards to cell organelles.

Also, Linda provided her students with several resources to help clarify learning goals. For example, the students completed a "plasma membrane and diffusion worksheet" and Linda explained to them that they will encounter those types of questions on the test. Furthermore, while discussing active transport, Linda suggested to her students to read certain pages from the textbook for clarification. Lastly, she provided her students with a study guide for the test within the first few days of the unit.

Diane also utilized other strategies to clarify learning goals besides attention focusing phrases and quantifying learning intentions. She commonly began each lesson by verbally asking a series of questions to the class that reviewed concepts from the previous day's lesson. Furthermore, for her college prep students, she provided them with flashcards with a cell organelle on one side and its function on the other side. Diane began several class periods having the students study the flashcards. Lastly, similar to Linda, Diane provided her students with a study guide for the cell test on the first day of the cell unit.

David clarified learning goals differently than Linda or Diane. He instructed his students to develop a chapter outline, telling his students to use the section headings as a guide: cell theory, organelles, cell membrane, diffusion and osmosis, active transport, endocytosis, and exocytosis. Also, David asked the students to read the chapter summary and informed them that about 80 percent of the information on a test is usually within the chapter summary. Furthermore, about half way through the cell unit, David provided the students with a study guide for the test. Lastly, David assigned the end of the chapter review questions that communicated science concepts students were responsible for learning.

Table 7

Influences on Learning Goals Development and Communicating Learning Goals to Students by Participant

	Influences on Learning Goal Development	Communicating Learning Goals to Students
Linda	-Standards -Standardized tests -Academic prowess and needs of students -Vertical curriculum	-Attention focusing phrases -Quantifying learning intentions -Cell project -Plasma membrane and diffusion worksheet -Study guide
Diane	-Standards -Vertical curriculum	-Attention focusing phrases -Quantifying learning intentions -Flashcards -Whole class verbal questioning -Study guide
David	-Standards	-Chapter outline -Chapter summary -End of chapter review questions -Study guide

Summary

In this section, I have described findings relating to how the three teacher participants in this study clarified learning goals. Using Wiliam's (2007) model as a framework, each of the subcategories of findings (identifying learning goals, finding alignment between the computer modules and the identified learning goals, predicting student difficulties with learning goals, discussing influences on the development of learning goals, and communicating learning goals to students) were considered separately from the others. One over-arching finding from this analysis is that clarifying learning goals was a process that was engaged in primarily in indirect ways by the teachers with little or no explicit emphasis on those goals.

Sharing Criteria for Success

Teachers engage in sharing criteria for success when they develop the criterion used to determine whether students attained the learning goals and then they communicate the criterion to their students. The criteria for success need to be connected to the learning goals. During each lesson Linda communicated learning goals to her students and shared the criteria for success in achieving them. For example, Linda engaged her students in a lab called "Basic unit of life – cell survey of types". During the lab, students prepared microscope slides of various cell types, and they practiced focusing a light microscope on low and high power and identified cell types and parts. In order to aid the students in determining when they have successfully focused a microscope slide, Linda showed the students pictures of the different cell types that they would be viewing under a microscope. She left the pictures projected on a screen enabling the students to compare their focused microscope slides to those projected on the screen. Furthermore, in order to communicate the criteria for success on the cell project discussed earlier, Linda provided her students with a rubric and shared high quality examples of projects from previous school years.

Linda also discussed the format of the cell unit test with her students on two separate occasions. On the first occasion, Linda explained the lab practical portion of the test, which was a new format of testing for the students. She stated,

> Next Wednesday on the test, there is no written portion. There is a lab practical with 15 scopes set up and I will ask you: what kind of cell is this?, what is the arrow pointing to?, what does this structure do in the cell? . . . You will not have to find your own cells, but you should have seen each of these cells . . . when I have it set up, you should be able to tell what you are looking at. (Linda, field notes, 10/21/13)

Then, while reviewing for the cell unit test, Linda discussed the test format with her students. She explained,

> Now, your test is tomorrow. It is multiple-choice and matching with a lab practical portion that is multiple-choice for you. So you need to make sure you are here and on time so we can get through. There will be 10 stations around the room and I will call you in groups of ten maybe 12 because there are 32 of you. You will take the test booklet to the counter. It is timed so you will have 30 seconds to do what is asked of you. You need to be focused and be paying attention. If you are in left field you will stay in left field and you will lose all those points. (Linda, field notes, 10/29/13)

Lastly, during the days in which the students completed the computer modules, Linda informed them that for the first modules, they needed to practice and become familiar with the system. However, for the last two modules, they will be graded of which 75 percent of the grade will be determined by the case summary.

Diane shared the criteria for success in regards to two assignments. First, Diane assigned her honors students the same cell project as Linda assigned to her gifted students, and she also provided them with a detailed rubric and shared high quality examples of projects from previous school years. Secondly, for both her CP and honors classes, Diane assigned the task of constructing a model of a cell membrane. She also provided a rubric for the model of a cell membrane. Diane did not communicate criteria for success during the implementation of the computer modules.

David shared the criteria for success in relation to the cell unit test. He reviewed the study guide with the students the day before the unit test. During the review lesson, the students asked David specific questions about what they needed to know and be able to do in order to be successful on the test and he answered them accordingly. Below is an excerpt from the classroom observation field notes in which students are asking about the knowledge they need to learn in regards to the scientists who contributed to the cell theory:

Student (S1): Do we have to know the scientists?

Teacher (T): Yes, but not all of them. (David goes through the list of scientists the students need to know)

S2: Do we need to know the year?

T: No.

Lastly, like Diane, David did not communicate criteria for success during the implementation of the computer modules. Below, Table 8 presents each teacher participant's methods of sharing criteria for success.

Table 8

Sharing Criteria for Success by Participant

	Sharing Criteria for Success
Linda	-Show pictures of focused microscope slides -Cell project rubric -High quality examples of finished cell projects -Discusses the format of the cell unit test -Discusses grading of the computer modules
Diane	-Cell project rubric -High quality examples of finished cell projects -Cell membrane model rubric
David	-Answering student questions about the information they need to know in order to be successful on the cell unit test

Eliciting Evidence of Learning

When teachers elicit evidence of learning, they attempt to make students' thinking visible in order to better understand how students are conceptualizing scientific concepts. Below, I will discuss two sections in relation to the teachers' actions involving eliciting evidence of learning: methods of eliciting evidence and quantity and quality of the elicited evidence of learning.

Methods of eliciting evidence.

Using a variety of methods, all of the teachers elicited evidence of learning through engaging in verbal conversations with students, collecting students' written work, and observing students. Linda asked her students questions during lecture portions of lessons. Although many of her questions pertained to the information the students were currently learning, Linda also occasionally asked questions relating to prior units. In the below excerpt from Linda's observation field notes on 10/17/13, she asked her students questions pertaining to the biochemistry unit completed before the start of the cell unit. For each question, several students call out answers in unison.

T: What are the four macromolecules?

S: Proteins, lipids, carbohydrates, and nucleic acids.

T: What is the building block for carbohydrates?

S: Monosaccharides.

T: What does mon mean?

S: One.

T: What are the building blocks for protein?

S: Amino acids.

T: What are the building blocks for nucleic acids?

S: Nucleotides.

T: Lipids are weird. Triglycerides are the most common lipid and those are the ones you eat, such as butter and oil. What are the building blocks for triglycerides?

S: Glycerol and fatty acid.

In addition to questioning students, Linda assigned and collected a variety of activities before administering the unit test: "Introduction to Microscope Lab," "Surface Area and Volume Worksheet Practice," "Basic Unit of Life – Cell Survey of Types Lab," and "Plasma Membrane and Diffusion Worksheet." During lectures and while engaged in class activities, students periodically asked Linda questions. Lastly, Linda observed students' work through the SABLE system while they were engaged with the computer modules.

Similar to Linda, Diane also asked her students questions during lecture portions of lessons, and her students periodically asked her questions during class. Diane frequently began class by asking her students a series of rapid questions reviewing the previous day's lesson. Furthermore, she consistently circulated throughout the classroom while students were engaged in activities, questioning individual students. For example, the students were instructed to construct a model of the cell membrane. Diane checked on each group of students and asked them to explain their models.

T: So what are these?

S1: Heads.

T: This is going to be what? The main part of the cell membrane is made of what?

S1: Heads and tails.

T: What do we call them?

S1: Phospholipids.

T: What part is the head? (The student shows her.) What's the head missing?

S1: The tail.

T: What is the tail made out of - it is made of something that doesn't like water.

S1: Lipid.

T: How many layers do you need?

S1: Three.

T: Not three, but two. (The teacher goes on to explain the phospholipid bilayer.)

T: What other things are in the cell membrane?

S1: Cholesterol.

T: What else?

S1: Proteins. (Diane, field notes, 10/29/13)

In addition to having discussions with her students, she assigned and collected several activities before administering the cell unit test: a color-coded worksheet comparing and contrasting prokaryotes to eukaryotes, a quiz on cell organelles and their functions, a model of the cell membrane, and a quiz on the parts and use of microscopes. Lastly, Diane used the SABLE system to observe students work while they were completing the computer modules.

Similar to Linda and Diane, David questioned his students during lecture portions of lessons, and they asked him questions during class. For example, during one class period, David instructed the students to read the chapter summary and to identify concepts that were unfamiliar to them. After allowing the students several minutes to complete the task, David called on individuals to share concepts that they learned from the summary. Below is an excerpt from the discussion.

[The teacher calls on another student to share something they learned from the readings.]

S1: Osmosis is the diffusion of water.

T: What does that mean – with the analogy here?

S1: Um, doesn't it have something to do with separating?

T: Not necessarily separating but what causes it to happen?

S1: I don't know.

T: If I had some – if I spray painted a piece of paper up here would [student C] know it if he didn't hear it or see it?

S2: Yes, he could smell it?

[The teacher indicates that the molecules move from high concentration to low concentration.]

T: How many smell molecules are by [student C]? None until I spray it. How many are up here? A lot. They eventually spread out and are evenly distributed across the room. Is there anytime when it goes from lower concentration to higher concentration?

S3: Active transport. (David, field notes, 10/21/13)

In addition to questioning his students, David also assigned and collected work from his students before the unit test, including chapter outlines and drawings of plant and animal cells that included the organelles and their functions. Lastly, he also used the SABLE system to monitor students' work while they completed the computer modules.

Quantity and quality of the elicited evidence of learning.

In order to provide the frequency with which each teacher elicited evidence of learning, I coded the classroom observation field notes for instances of eliciting evidence of learning. As opposed to quantifying the number of codes, I counted the number of lines of text devoted to eliciting evidence of learning for each teacher for each classroom observation. The number of lines of text representing eliciting evidence of learning would more accurately represent the amount of time teachers devoted to eliciting evidence of learning during class time than counting the number of codes.

As shown in Figure 9, the teachers were highly variable throughout the cell unit in the amount of time that they spent eliciting evidence of learning from their students. Interestingly, Linda and David devoted a large amount of time eliciting evidence of learning the day before they administered the cell unit test. Whereas, Diane devoted more time to eliciting evidence of learning in the beginning and middle of the unit and less time at the end of the unit. All of the teachers had fewer lines of text representing eliciting evidence of learning during the implementation of the computer modules. All of the teachers used the SABLE system to monitor students' work while they completed the computer modules. There were fewer verbalizations and fewer observations to record since the communications were occurring between the students and the computers and the teachers and the computers.

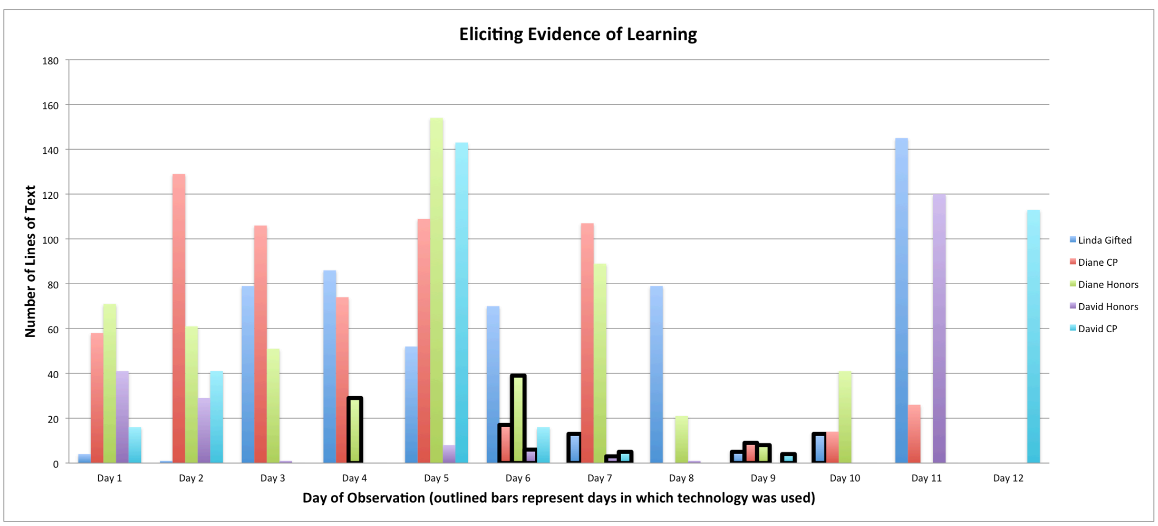

Figure 9. Number of lines of text representing eliciting evidence of learning by teacher and class period.

Figures 10 through 14 represent the types of questions each teacher verbally asked their students for each class period during the cell unit. Figure 15 represents the types of questions posed in each of the computer modules (see Appendix B for a full list of questions). The types of questions identified are action, attention focusing, comparison, measuring and counting, metacognition, problem posing, reasoning, and recall/factual. All of the teachers predominantly posed recall/factual questions. Just as before when considering the number of lines of text in classroom observation field notes devoted to eliciting evidence of learning, Linda and David asked more questions the day before the cell unit test than on any other day. On the other hand, Diane asked the most questions on day 5 for her honors class and on day 2 for her CP class. All of the teachers asked reasoning, comparison, and action questions although these types of questions were not frequent. Linda was the only teacher to ask measuring and counting questions, and Diane was the only teacher to ask problem-posing questions. With the exception of Diane's honors class during the osmosis module, none of the teachers asked questions during the implementation of the computer modules. During the osmosis module, Diane's students were forced to work in pairs because of a lack of computers. Although the SABLE system was functional, towards the end of the lesson, Diane walked around and asked questions to pairs of students about the computer module.

In contrast to the teachers' questions, the computer modules asked fewer recall/factual questions, opting instead to focus on reasoning questions. The diffusion module included 16 measuring and counting questions, asking students to interpret graphs, or identify where a measurement falls within a range of numbers. The modules did not ask attention focusing, comparison, or metacognitive questions.

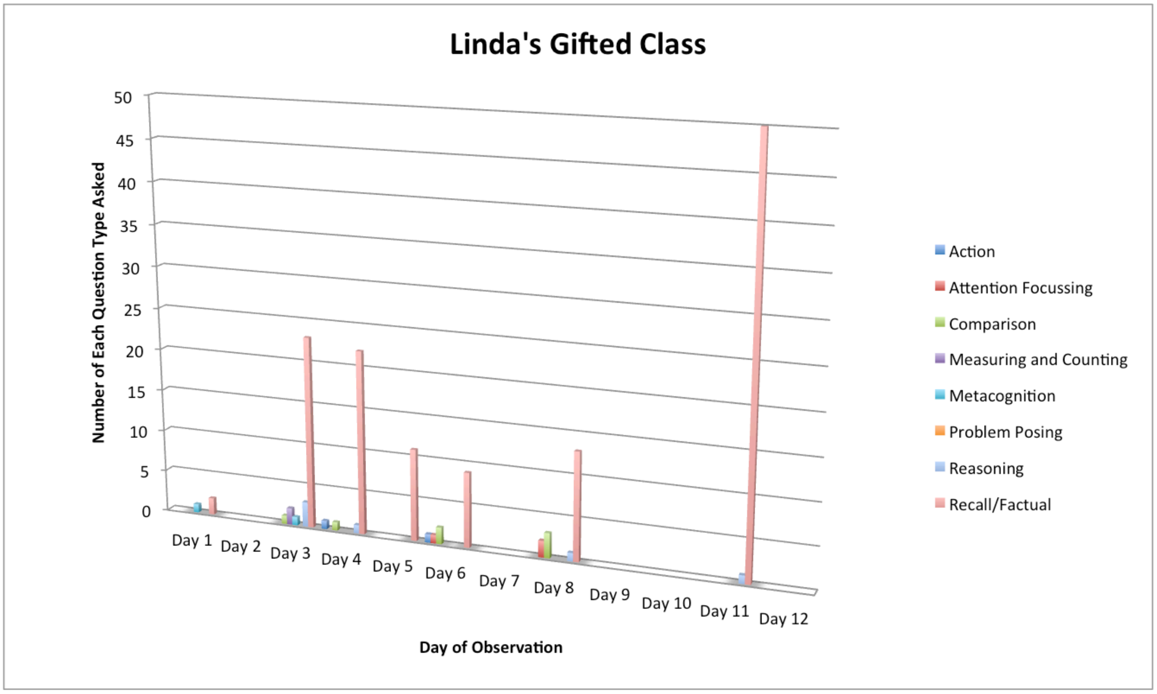

Figure 10. Types of questions asked during Linda's gifted biology class.

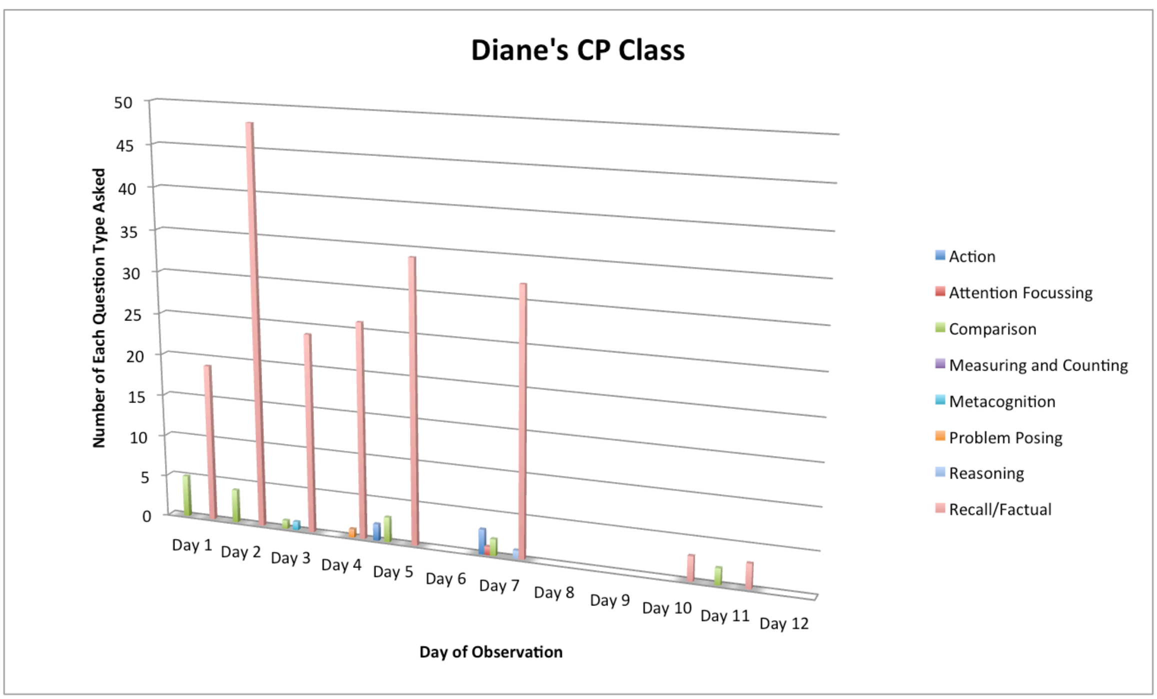

Figure 11. Types of questions asked during Diane's college prep biology class.

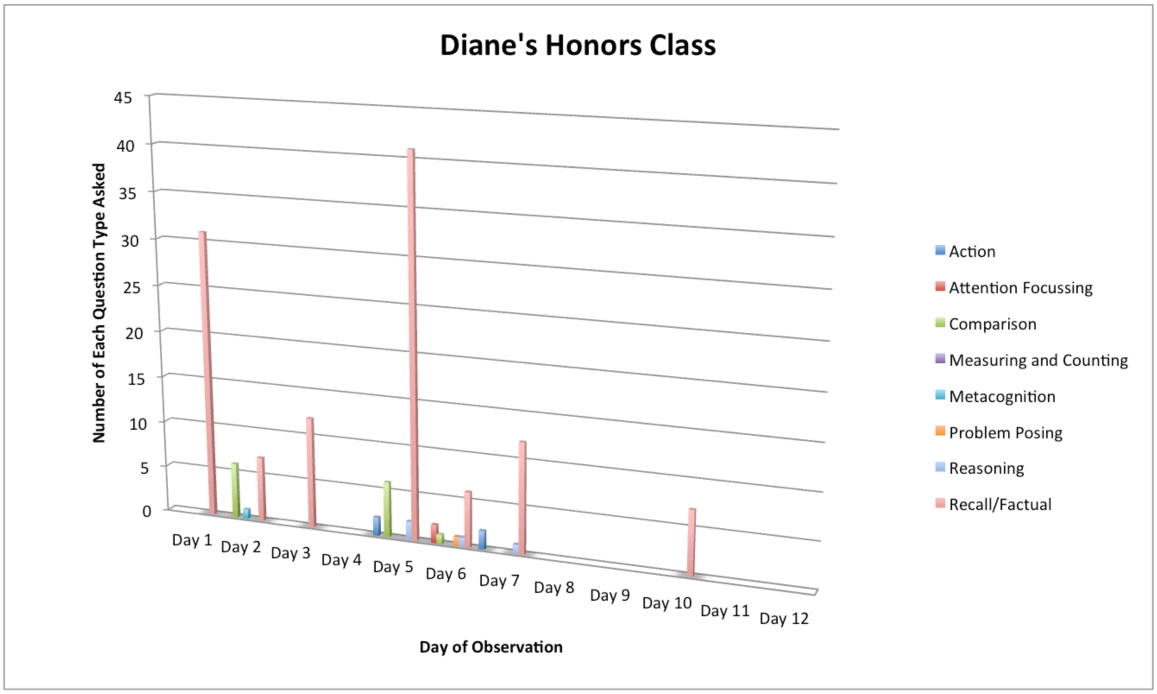

Figure 12. Types of questions asked during Diane's honors biology class.

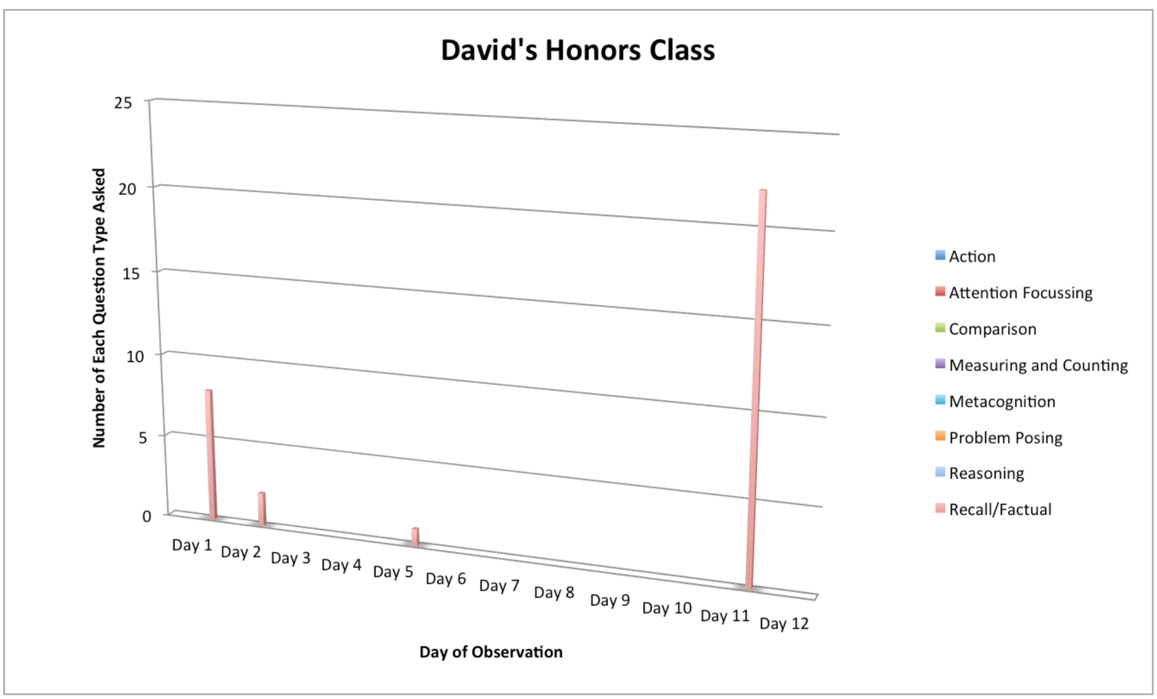

Figure 13. Types of questions asked during David's honors biology class.

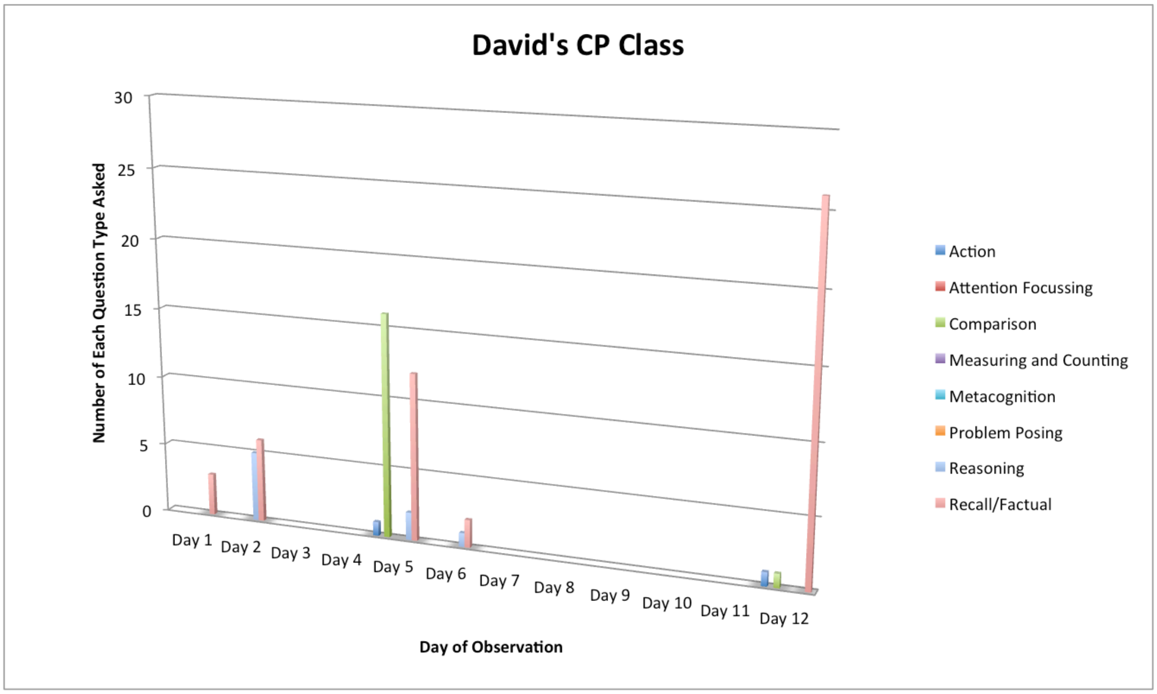

Figure 14. Types of questions asked during David's college prep biology class.

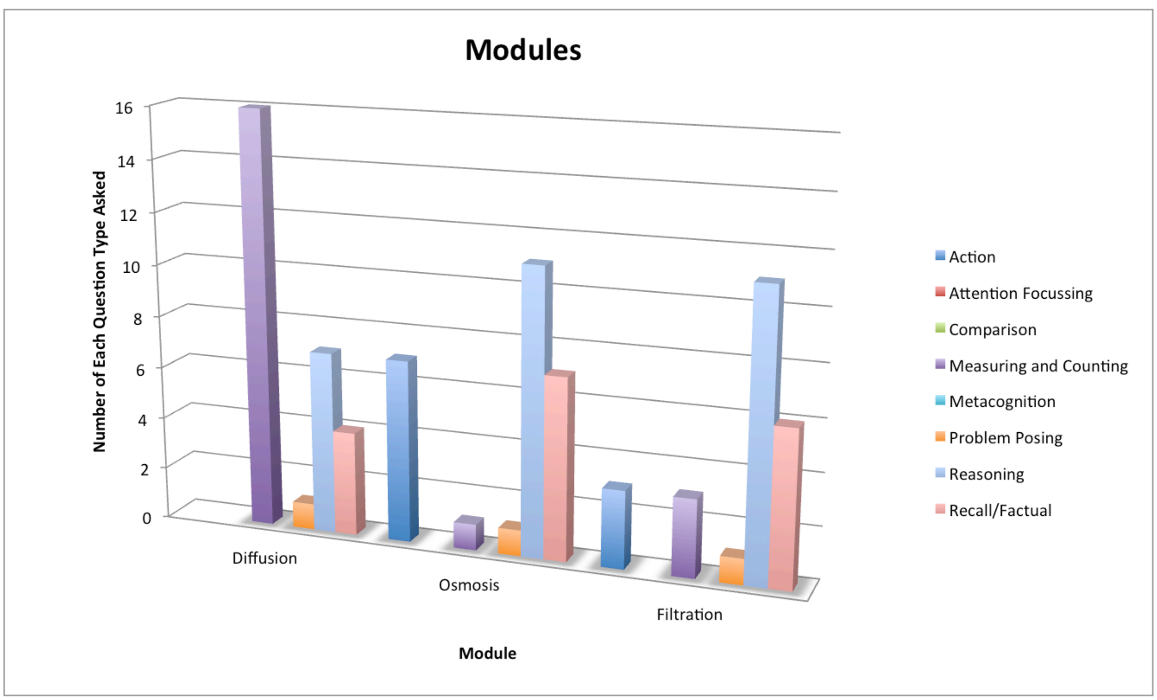

Figure 15. Types of questions asked for each computer module.

Providing Formative Feedback

After teachers elicit evidence of learning, they need to provide feedback that moves students forward in their learning. In this study, I did not collect student work with teacher comments, and therefore, I can only detail the verbal feedback that teachers provided to their students. In regards to written feedback, all of the teachers indicated during the interviews that there was a delay of at least several days from the time students submitted their work to the time their work was returned to them with written feedback. However, during the interviews, I did not discuss with the teachers the substance of the written feedback. For the three subheadings below that relate to providing verbal feedback, I will discuss: types and methods of feedback provided, individual students versus the whole class, and providing feedback during the computer modules.

Types and methods of feedback provided.

During class Linda verbally asked her students questions and provided feedback about whether or not they answered correctly. If the student answered the question correctly, she proceeded with the lesson. If the student did not answer the question correctly, she would call on another student, provide the correct answer herself, or ask the class to provide help. In the below excerpt from classroom observation field notes (10/18/13), when a student could not provide the correct answer, Linda asked the class to help the student. Asking the class to provide help communicated that the student's answer was not sufficient. When she called on a student who volunteered to help and she received his answer, she continued with the lesson, signifying that the second answer was acceptable.

T: Do bacterial cells have ribosomes? Yes, what do they do? [The teacher calls on a specific student.]

S1: Has something to do with proteins.

T: Who can help him? [Several students raise their hands and the teacher calls on one of them.]

S2: They assemble proteins. [The teacher continues on with the notes.]

Furthermore, Linda assigned worksheets for students to complete, and after allowing the students to work on the assignment for a certain amount of time, she provided the students with the correct answers. She either projected the worksheet with the answers on a screen, or she verbally said the answers.

When questioning students or providing students with correct answers, Linda also provided feedback about how one would arrive at the correct answer as evidenced by the below example in which students called out in unison.

T: First off, what microscope took this picture?

S: Electron.

T: How do we know that?

S: Because it is in black and white. (Linda, field notes, 10/17/13)

In the above example, Linda demonstrates how one would arrive at the correct answer by asking the class to explain their reasoning.

Similar to Linda, Diane also verbally asked students questions and provided them with feedback by communicating whether or not they answered questions correctly. Diane is especially similar to Linda in that she signified to students that they answered correctly by proceeding with the lesson and that they answered incorrectly by calling on another student, providing the answer herself, and/or stating that the answer was incorrect. For example, in the below excerpt, Diane asked a series of questions about prokaryotes and eukaryotes.

T: There are two different cell types: prokaryotes and?

S1: Eukaryotes.

T: [Student], what are plants?

S2: What do you mean?

T: Are they prokaryotes or eukaryotes?

S2: Prokaryotes.

T: No. They are eukaryotes. Student, what are protists?

S3: Prokaryotes.

T: No. What are they?

S3: Eukaryotes.

Not only did Diane provide feedback about whether or not students correctly answered questions asked verbally, but also, she constantly walked around and observed students as they worked on in-class assignments and provided them with feedback. For instance, Diane instructed her students to create a Venn diagram based on what they learned the previous day about prokaryotes and eukaryotes. Based on her observations of their work, she realized that the students were confused. The students were copying an unrelated picture from a Powerpoint slide instead of drawing a Venn diagram. Diane addressed the class, explaining how to draw and fill in a Venn diagram comparing and contrasting prokaryotes and eukaryotes. Lastly, Diane, similar to Linda, assigned written work to students, and after allowing a certain amount of time to complete the assignment, provided them with the correct answers. For example, in the above example with the Venn diagram, once the students completed the assignment, Diane projected on a screen a completed Venn diagram, allowing the students to compare their answers to her answers.

Similar to Linda and Diane, David also verbally asked students questions and provided them with feedback as to whether or not their answers were correct. He also employed similar methods by proceeding with the lesson when receiving correct answers and calling on another student or providing the correct answer himself when receiving incorrect answers. Different from Linda and Diane, David asked his students to justify their ideas when students disagreed about the correct answer. In the below excerpt from David's classroom observation field notes (10/25/13), he proceeded with his questions and when students disagreed about the correct answer, he encouraged them to justify their ideas and then, he provided the correct answer.

T: What is the smallest?

S1: The electron.

T: Next, [student]?

S2: Proton.

T: Next.

S3: Atom.

T: Next.

S4: Molecule.

T: Next, [student]?

S5: Is that right?

T: I don't know. What do you think?

S5: I think that cells are smaller than molecules.

S6: No, molecules are smaller than cells.

T: Why? How do you know?

S6: It's hard to explain.

T: Molecules are smaller than cells.

Similar to Linda and Diane, David also assigned written work. However, he did not verbally state the answers or project answers on a screen. Instead, he assigned the chapter review questions from the textbook and allowed the students to check their answers in the teacher's manual. The manual was placed at his desk and students could approach one at a time to review answers to questions they were struggling with.

Individual students versus the whole class.

During the classroom observations, I primarily captured verbal feedback, which was provided to the class as a whole. Therefore, the verbal feedback was not tailored to provide individual students with information regarding where they are in relation to the learning goals and how best to move their learning forward. The teachers usually interacted with the class as a whole. However, while the whole class was engaged in activities, each teacher interacted with students one on one.

During Linda's cell unit, she planned and enacted whole class instruction for each day I observed except for the days in which the students completed the computer modules (discussed in the next subheading) and completed two labs, one on microscope use and the other on cell types. I observed four instances in which Linda interacted with individual students during class, providing feedback that allowed them to continue progressing with the lesson. All of the one on one interactions were initiated by the student. For example, during a lab in which students viewed several different cell types under a microscope, a student approached Linda and said, "this slide doesn't have anything on it" (field notes, 10/21/13). Linda took the slide and went to a microscope with the student. She focused the microscope on low power and asked if the student could see the cells. When the student was able to see the cells, Linda indicated that they needed to use the fine adjustment to bring the cells into better focus. Linda provided feedback to the student that guided him/her through the process of focusing a microscope without completing the process for the student.

Although Diane also planned and enacted whole class instruction frequently, she created opportunities to interact with students one on one. For example, while lecturing, the students were responsible for completing guided notes. As the students filled out the guided notes, Diane walked around the classroom and checked on individual students' work. David was more variable in his type of instruction, frequently planning and implementing whole class instruction as well as small group and individual work. While the students worked individually or in small groups, David informed them that if they "get stuck" (field notes, 11/04/13), then he will help them. I observed one instance in which a student approached David and appeared to ask for help. I was unable to hear the conversation, but David and the student conversed for a few minutes while pointing to the textbook.

Providing feedback during the computer modules.

As stated previously, each of the teachers used the SABLE system to elicit evidence of learning. During the implementation of the computer modules, I observed occasions when Linda and Diane verbally provided feedback to their students based on the elicited evidence within the SABLE system; whereas, I did not observe any instances of David providing feedback. During the diffusion module, Linda interrupted the class and stated, "How are you supposed to treat her? The majority of you are not getting those questions correctly. Make sure you read all of the information" (field notes, 10/23/13). After the students were engaged with the filtration module for at least ten minutes, Linda stated to the whole class, "when you are doing countercurrent exchange, there are five regions, and it is ok to check more than one box" (field notes, 10/28/13).

Several students may have missed the question Linda referenced because the question does not indicate that more than one box can be checked. After all three computer modules had been completed, Linda discussed the simulations with her students and indicated what each case study was about and what treatment they should have administered.

During the implementation of the computer modules, Diane frequently checked the SABLE System and then, approached students or pairs of students to inform them that they had not progressed far enough along in the module and/or that their answers were insufficient. For example, she stated to a pair of students, “This, is what you want me to grade? You can’t redo it, but as you move forward, you may want to put a little more effort into it” (field notes, 10/31/13 CP). She said to another pair that when they provide good answers, "they need to be in complete sentences" (field notes, 10/31/13 CP). Also, after informing specific students that their work was unsatisfactory, she later re-examined their work and revisited them later in the class period. During the osmosis module, Diane used the Sable System, but she also walked around and questioned individual students herself. Below is an excerpt of some of the conversations that Diane had with her students during the osmosis module.

T: So what did you originally do?

S1: Hypotonic solution.

T: So now what should you do?

S1: Hypertonic solution.

T: Because that makes it?

S1: Shrink.

(Moving to another group of students)

T: What treatment did you use? What are you trying to do?

S2: The calf is having seizures.

T: Why?

S2: There is excess water.

T: Where do we want the water to go?

S2: Out.

T: How do we get the water out?

S2: Hypertonic.

T: There you go. (field notes, 10/22/13 Honors)

During the filtration module, Diane noticed that several students were missing the same question. She interrupted the students from working on the modules and stated that many of them were missing the same question. She continued, "Does diffusion move from high to low or low to high?" (field notes, 11/05/13 CP). The students indicated that diffusion moves from high to low concentration. Diane explained that on the question, the students were indicating that the molecules keep going from 90 molecules on one side of the membrane and 10 on the other to 60 molecules on one side of the membrane and 30 on the other and then stated, "But when it hits 60:60, what does it do? It stops because the whole big idea here is that in diffusion it evens out" (field notes, 11/05/13 CP).

Peer-assessment

Peer-assessment occurs when teachers encourage students to evaluate each other's ideas and work and to act as instructional peers, supporting each other in learning science concepts. None of the teachers planned instruction to include peers assessing each other's work or ideas. However, all of the teachers allowed their students to complete certain assignments in pairs or small groups. Although I did not ask the teachers to explain their reasoning behind allowing students to work together, I coded any instances of group work as peer-assessment because the students had the opportunity to act as instructional peers when in groups.

Linda allowed her students to work with partners during labs and was forced to pair her students during the diffusion module because of a technological issue that lessened the number of available computers. Also, she stated that she assigned her students seats based on the middle schools they attended. She explained,

> We have two feeder middle schools that are coming to us, [school X] and [school Y]. And sometimes [school X] teachers will have done this and [school Y] did not, or [school Y] will have done this and [school X] did not . . . What I have started doing this year is, I found more strengths with the kids, depending on the school, is, kind of, partner them up. So the way that I have them seated is never a whole [school Y] table or a whole [school X] table, it's a mixed bag. So I try to put a couple of [school Ys] with a couple of [school Xs] and then that way they can kind of inter-mix and mingle . . . So they do a lot of peer interaction . . . But if this person has had some exposure, they can talk about what they did in 7th grade, and then, this person has not so they've gotten it from a peer, and then I can talk about all of the different pieces that I have seen. (I3, Lines 399-412)

Diane allowed her students to work in groups to complete certain assignments such as constructing a cell model, using flashcards to quiz each other on the function of cell organelles, during lab investigations, and answering questions about tonicity. Also, she paired her students in both classes for the diffusion module because of a technological problem lessening the number of available computers. Although Diane did not originally plan to have students work in pairs on the diffusion module, she indicated that the experience was valuable. Diane noted,

> I liked when they did it collaboratively because I got to hear conversations about why are we doing this. I got to hear debate. I got to hear when they didn't agree. It's good for when they teach one another or try to make their point and in doing so, ascertain why this is right or wrong. You know like how, uh, the student who's right, the ability to like teach it to someone else, the student who's wrong, to be able to figure out where their error in thinking was collaboratively and for me, to hear that process go on was very valuable. (I3, Lines 148-155)

David allowed his students to work in groups to complete assignments from the textbook.

Self-assessment

Self-assessment occurs when teachers promote and support the development of self-reflection skills in their students. Students reflect on their learning and gain a better understanding of their progress towards learning goals and then they employ strategies to move their learning forward.

I rarely observed teachers explicitly engaging students in self-assessment. Linda and Diane allowed their students to rectify incorrect test questions and subsequently complete a re-assessment composed of the ten most frequently missed test questions. Allowing the students to correct their tests and then focusing on the ten most frequently missed questions, helped students identify areas in which they were unsuccessful with the content. Also, Diane engaged her students in self-assessment by having students separate a stack of flashcards on the function of cell organelles into one pile representing the organelles and function they know and one pile representing the organelles and functions they do not know. Although Diane did not specify the degree of certainty the students needed to have in order to place a card in the "know" pile, the flashcard activity drew students' attention to the number of organelles they were or were not familiar with. Lastly, as discussed in the providing formative feedback section, all of the teachers provided students with the correct answer to certain assignments. In providing students with the correct answer, teachers implicitly create opportunities for students to assess their level of understanding of the content.

Summary

The findings in this first section, teacher enactments of formative assessment, pertain to one research question: How do secondary biology teachers enact formative assessment during the cell unit? In order to examine the teachers' enactments of formative assessment, I used classroom observation field notes and interview data to identify instances in which they engaged in or discussed different aspects of Wiliam's (2007) five strategies for the effective implementation of formative assessment.

Linda, Diane, and David developed similar over-arching learning goals for their students, requesting that they relate science concepts to the real world and apply the knowledge that they are learning. Linda and Diane listed several learning goals in relation to the cell unit and predicted concepts that their students would struggle to comprehend. However, having not taught biology for over ten years, David struggled to articulate the learning goals for the cell unit and felt uncertain about the concepts that would pose difficulties for the students. All of the teachers identified the same learning goals as aligning between the computer modules and the cell unit: relate science concepts to the real world, apply knowledge, cell transport, and tonicity. All of the teachers used the science standards to guide the development of their learning goals, with Linda and Diane using their knowledge of the vertical curriculum. None of the teachers explicitly communicated the learning goals to their students or involved their students in the development process. Linda and Diane communicated the learning goals through using attention focusing phrases, quantifying learning intentions, and engaging their students in activities. David communicated the learning goals through having students construct a chapter outline, read the chapter summary from the textbook, and complete a study guide.

Linda shared the criteria for success each lesson, employing a variety of techniques such as providing rubrics, discussing testing formats and grading procedures, presenting examples of finished projects, and showing pictures of focused microscope slides. Diane shared the criteria for success for two assignments by providing a rubric and sharing examples of finished projects. David answered students' questions about the information that they needed to know in order to be successful on the cell unit test.

All of the teachers elicited evidence of learning from their students through engaging them in verbal discussions, collecting written work, and observing them during class activities. The teachers varied in the amount of time they spent eliciting evidence of learning during each lesson. Diane elicited evidence of learning more often during lessons towards the beginning and the middle of the cell unit. Linda and David both devoted the most time to eliciting evidence of learning the day before the cell unit test. All of the teachers elicited evidence of learning through using the SABLE system during the implementation of the computer modules. I coded fewer instances of eliciting evidence of learning on days in which the technology was used because both teachers and students were communicating with computers as opposed to each other. All of the teachers overwhelmingly asked their students questions requiring them to recall information. However, the computer modules focused more heavily on reasoning questions.

In this study, I only captured the verbal feedback that teachers provided to their students. In regards to written feedback, all of the teachers indicated that there was a delay of at least several days in providing written feedback to their students. Furthermore, all of the teachers provided verbal feedback to their students, indicating whether or not they answered questions correctly. Considering that the teachers were eliciting evidence of learning mainly through asking recall/factual questions and then, providing feedback as to whether or not those questions were answered correctly by students, the teachers were engaging in formative assessment that promoted the development of simple knowledge (McMillan, 2010). In addition, Linda and David primarily provided feedback to the whole class, and Diane provided feedback to both individual students and the whole class. While implementing the computer modules, Linda and Diane provided feedback to their students but David did not.

The teachers did not frequently engage their students in peer-assessment or self-assessment. The teachers did not request for the students to assess each other's ideas or work; however, the teachers occasionally instructed the students to work in pairs or small groups. In regards to self-assessment, all of the teachers provided the correct answers to certain assignments, allowing students to compare their answers to the correct answers. Linda and Diane required students to correct the test questions that they missed and then re-assessed the students on the ten most missed questions.

Teacher Views on Formative Assessment

In this section, I discuss the teachers' views on formative assessment, devoting a subheading to each participant: Linda, Diane, and David. The findings within this section were gleaned from the data analysis of the third interview. Relevant interview questions, a sample of which is presented in Table 9, aimed to elicit teachers' ideas about how they meet individual students' needs and the practicality of doing so, the frequency with which they managed and monitored student learning, and the ways in which they defined the term formative assessment. The last question of the last interview was the only occurrence during data collection in which I used the term formative assessment. I avoided the term formative assessment during data collection for two reasons. First, although my presence during classroom observations inevitably impacted the classroom environment, the less the teachers understood about my research aims, the less they tailored their lessons towards my research study. Secondly, the term formative assessment conjures up a variety of interpretations, and therefore, avoiding the term during interviews helped ensure that the participants and myself were discussing similar concepts.

The findings in this section relate to one research question: How do secondary biology teachers conceptualize formative assessment? Understanding teachers' views on formative assessment in conjunction with their enactments of formative assessment provides a context in which to explore the characteristics of the 3-D computer modules and the SABLE system that support and constrain teachers' formative assessment practices.

Table 9

Sample of the Interview Questions Related to Teachers' Views of Formative Assessment

Interview Questions
• How do you balance meeting the needs of most students versus meeting the needs of each student? • How practical do you believe it is to understand what each individual student understands about a specific learning goal at any point in time? • How often do you attend to managing and monitoring student progress? • What does formative assessment mean to you?

Linda

Linda described formative assessment as setting learning goals and then engaging in cycles of eliciting evidence of learning and providing feedback while working with her students to achieve learning goals. She defined formative assessment as a process of determining students' current level of knowledge, including identifying misconceptions. She explained that she elicited evidence of learning through questioning students and tending to students' questions followed by the provision of feedback to guide students towards achieving learning goals. Linda shared,

> . . . formative assessment, to me, means that I am literally forming their knowledge base, figuring out where they have misconceptions, background information that might not have been completely accurate, and then, molding it into the direction that I think they need to go, based on what my class is designed to prepare them for . . . That's what I'm doing, and I do that with questioning, and I do that with written response for each individual kid. (I3, Lines 578-590)

As evidenced by the above example, Linda viewed the purpose of formative assessment as determining students' current knowledge and then moving their learning forward to achieve learning goals.

Linda believed that she engaged in formative assessment "every day and . . . multiple times over the course of a class period" (I3, Line 545). Also, she believed that it is impractical for a teacher to have knowledge of every single student's level of conceptual knowledge at every single point in time. She explained, "I don't think that it's realistic for me to be able to think that every single kid sitting in my room for every single minute is going to get every single point that

I need them to do . . . you do the best you can, knowing what your end goal has to be" (I3, Lines 515-529).

Diane

Diane described the purpose of formative assessment as enabling her to understand what her students understand. She explained that formative assessments gave her insight into her students' learning and informed her instruction. In defining formative assessment, she stated,

> For me, it's all of the data that I collect throughout the course of the unit, um, it could take many forms, it could be performance based, it could be written, it could be lab based, it could be conversational, but it's anything that guides my instruction and gives me insight into students' learning. (I3, Lines 321-324)

Furthermore, Diane indicated that formative assessments are not graded and can be as valuable as summative assessments. She explained that she used the computer modules and the SABLE system as a formative assessment and did not plan to grade the students' work. She justified her decision and stated,

> I think formative assessment has just as much value as the graded and summative type things, and so, I don't think that [not grading the students' work on the computer modules] diminishes it. I don't think using it in real time without going back and doing it diminishes its value. If anything, I can always go back and look at student work later, but the value of this, that other things don't give me, is I have that feedback right away. I don’t have to wait for them to turn in an assignment . . . It's not going to do any good sitting on my desk. So I could go back and look at this information, but I do that all the

> time when they turn stuff into me . . . the thing that's lacking for students, is being able to look at it in real time, address it, and move on without having that delay.
>
> (I2, Lines 197-212)

Unlike Linda, Diane believed that it is practical to know what each of her students understands in regards to the standards at any given point in time. She explained, ". . . yeah, it's obtainable. We just have to do activities and seek out that information and not be content with just letting a few fail" (I3, Lines 223-224). On the other hand, Diane was similar to Linda in her belief that she engaged in formative assessment practices constantly throughout a class period and stated, "It's kind of a constant thing" (I3, Line 234).

David

David described formative assessment as a method to determine the information that he needs to teach his students in regards to the standards and to identify concepts that the students struggle to comprehend. He shared, "from a just real general standpoint, it is an assessment to determine what they know so you know what you need to teach . . . formative assessment is trying to find out what they don't learn very well or what they don't know" (I3, Lines 359-374). In regards to the frequency with which he engaged in formative assessment practices, David seemed to distinguish between formal and informal formative assessment. Regarding formal formative assessment, he indicated that he periodically assessed student progress, noting, "as the students get to certain points, just periodic checks, you know, to see where they are" (I3, Lines 46-47). On the other hand, he stated that he informally assessed his students "most minutes of every day" (I3, Line 280). Lastly, David shared Linda's belief that being aware of each student's level of knowledge at any given point in time was impractical because the practice is too time consuming and there are too many students, standards, and assessments. He explained,

> With the wide, wide range and number of concepts we're supposed to teach, um, it doesn't seem like it's a very practical use of time to get to every kid and find out what they know . . . And so trying to, trying to get a real good feel for what every kid really understands is, I'm not sure it's possible, but if it were, was possible, it would be incredibly time consuming and we have too many objectives, too many standards, too many goals, too many tests and quizzes to, um, to do that for 155 kids.
> (I3, Lines 259-268)

Summary

In order to make meaning of the findings in section two, teachers' views on formative assessment, I will situate each teacher within the key characteristics of formative assessment as described in the research literature. Also, I will draw on the findings in section one, teachers' enactments of formative assessment, to support the validity of my inferences.

Linda, Diane, and David demonstrated differing degrees of understanding that formative assessment is an iterative process that is seamless with instruction. Diane more frequently elicited evidence of learning and provided feedback to her students throughout each lesson with both the whole class and individual students. Linda described formative assessment as constant cycles of eliciting evidence and providing feedback. However, she engaged in these cycles primarily with the whole class and less frequently than Diane. David indicated that he formally formatively assessed his students periodically and informally formatively assessed them continuously. He elicited evidence of learning and provided feedback less frequently than Linda and Diane and almost solely interacted with his students as a whole class. None of the teachers discussed formative assessment as involving both teachers and students, and they described formative assessment as serving the purpose of providing teachers information about student learning. All of the teachers indicated that formative assessment involved gathering information about their students' level of knowledge and then, using that information to guide instruction. The teachers elicited evidence of learning of simple knowledge and provided feedback indicating whether or not students could answer questions correctly. Therefore, the teachers used formative assessment to promote the development of simple knowledge as opposed to the development of deep understanding.

Teacher Implementations of the Technology in Relation to Formative Assessment

In this section, I discuss the teachers' implementations of the computer modules and the SABLE system in relation to formative assessment. The findings within this section are divided into two subheadings: use of the computer modules and use of the SABLE system. The entire data set of classroom observation field notes and interview transcripts contributed to the findings within this section. Relevant interview questions, a sample of which is presented in Table 10, aimed to elicit teachers' ideas about ways in which the technology supported or hindered their abilities to manage and monitor student learning. The findings in this section relate to two research questions:

1. In what ways do the data from the SABLE system influence future instructional decisions within a cell unit?
2. How do 3-D computer modules involving cellular transport, coupled with a technology that allows real time monitoring of students' work, support or hinder teachers' formative assessment practices during the implementation of the cell unit?

Table 10

Sample of the Interview Questions Related to Teachers' Ideas About How the Technology Supported or Hindered their Formative Assessment Practices

Interview Questions
• How did the computer modules help you attain the learning goals that you set out for your students? The SABLE system? • What did the computer modules help you accomplish in terms of managing and monitoring student learning? The SABLE system? • How did you use the SABLE system? - For what purpose did you use the SABLE system? - What were you looking at within the SABLE system? - What were you learning about your students' understandings?

Use of the Computer Modules

The teachers used the computer modules in a variety of ways that highlighted aspects of the technology that potentially supported and hindered their ability to engage in formative assessment. There are three subheadings involving the use of the computer modules that relate to factors that support and hinder formative assessment: placement and use of the computer modules within the cell unit, characteristics inherent to the computer modules that enhance instruction, and problematic characteristics inherent to the computer modules.

Placement and use of the computer modules within the cell unit.

Each teacher implemented the computer modules at different times within the cell unit (see Tables 11, 12, 13, and 14). All of the teachers implemented the computer modules in the same order, starting with diffusion and then, progressing to osmosis and filtration. Linda implemented the computer modules towards the end of the cell unit, and out of 11 classroom observations, she implemented them on days seven, nine, and ten. On the instructional day between the diffusion and osmosis module, Linda stated that she purposely scheduled class time to discuss the diffusion module. During the last five minutes of class, she projected screenshots from the diffusion module and discussed the patient's symptoms and treatment options, explaining why the best course of treatment should have been to administer the three treatments in a specific order. Then, after completing the osmosis and filtration modules, Linda, once again, discussed all three of the computer modules during approximately the last five minutes of class time. She explained each patients' symptoms, diagnoses, and proper courses of treatment. Furthermore, Linda indicated that she placed the modules towards the end of the cell unit because she viewed them as relating to cell transport, which she planned instruction for at the end of the unit. Finally, she stated that she chose to implement the diffusion module first because it was the shortest of the three modules.

For Diane's CP class, out of 11 days, she implemented the computer modules towards the middle and end of the cell unit on days six, eight, and nine. On the instructional days that occurred after the implementation of the computer modules, Diane did not make any references to them. However, during an interview she explained that the modules highlighted that some of her students failed to understand recall/factual knowledge. She shared, "They don't get anything we're doing and I think that having them, seeing them struggle and seeing their inability to do it and just going through the motions and not stopping and thinking, is one reason we are doing these remediation centers today" (I2, Lines 229-231). Diane explained that based on the information she received from the SABLE system, she decided to differentiate instruction for the last instructional day before the test. Diane set up a series of progressive stations, or remediation centers, for students to work through. The first five stations dealt with previous classwork. If a student had no incomplete classwork, then they would begin at station six, working with the teacher through a demonstration on tonicity. Then, they progressed through stations seven and eight, completing a mock test and practicing focusing microscopes respectively.

For Diane's honors class, out of ten days, she implemented the computer modules on days four, six, and nine, spreading the modules throughout the cell unit. After completing the diffusion module, Diane briefly discussed it, explaining the patient's symptoms and diagnosis. Also, she discussed the three factors that affected the rate of diffusion that were discussed in the computer module: the concentration gradient, the diffusion distance, and the surface area. After completing the osmosis module, Diane discussed it with her students, explaining the patient's symptoms, diagnosis, and proper course of treatment. Then, she related the osmosis module to an activity in which the class soaked gummy bears in water and then added salt. During the activity, Diane and her students discussed the movement of water into and out of the gummy bears and related it to the movement of water into and out of the patient's brain cells in the osmosis module. Below is an excerpt from the discussion about the osmosis module and the gummy bear activity.

T: Yesterday, we encountered Clark. [Clark is the calf who was the patient in the osmosis module.] What was wrong with him?

S1: He was having seizures.

T: Why?

S2: Too much water was in his brain.

T: What solution did we give to bring down the swelling?

S3: Hypertonic.

T: Go get gummy bear petri dishes - get one per group of four. [The gummy bear had already been soaking in water.]

T: Look at the gummy bears. Those are like Clark's cells from yesterday. They were really big and swollen. So you guys decided to give him a hypertonic solution. So is more stuff in the gummy bears or in the salt? More stuff is in the salt, right? So what would happen if you pour salt in the petri dish?

S4: They would shrink.

Finally, Diane explained that she planned to implement the computer modules for both her CP and honors classes based on the availability of the computer labs.

David implemented the computer modules more towards the middle of the cell unit on days seven, eight, and nine of a 13 day unit. After implementing the computer modules, David did not make any references to the computer modules. However, he instructed his students to write a reflection on their experiences, asking them to write about the best part of their experiences with the computer modules and at least one aspect of their experiences that could have been better. Finally, David also indicated that he planned to utilize the computer modules based on the availability of the computer labs.

Table 11

Daily General Topics of Instruction – Linda's Gifted Biology

Day 1	Microscope parts and usage
Day 2	UGA pre-test; Microscope lab; Cell diversity notes
Day 3	Surface area and volume worksheet; Cell diversity notes; Prokaryotes and eukaryotes and Basic cell parts notes; Basic unit of life – Cell survey of types microscope lab
Day 4	Prokaryotes and eukaryotes and Basic cell parts notes; Basic unit of life – Cell survey of types microscope lab
Day 5	Basic unit of life – Cell survey of types microscope lab; Cell membrane and passive transport notes
Day 6	Basic unit of life – Cell survey of types microscope lab; Cell membrane and passive transport notes; Plasma membrane and diffusion worksheet
Day 7	Diffusion modules
Day 8	Cell membrane and passive transport notes; Plasma membrane and diffusion worksheet; Discuss diffusion module; active transport notes
Day 9	Osmosis module
Day 10	Filtration module
Day 11	Review for cell unit test

Table 12

Daily General Topics of Instruction – Diane's CP Biology

Day 1	Cell theory; Prokaryotes and eukaryotes; Cell parts
Day 2	Cell theory; Prokaryotes and eukaryotes; Cell parts
Day 3	Cell parts; Structure and function of the cell membrane
Day 4	Cell parts; Structure and function of the cell membrane
Day 5	Cell parts; Structure and function of the cell membrane; passive transport
Day 6	Diffusion modules
Day 7	Cell parts; Structure and function of the cell membrane; passive transport, active transport
Day 8	Osmosis module
Day 9	Filtration module
Day 10	Passive and active transport
Day 11	Review for the cell test

Table 13

Daily General Topics of Instruction – Diane's Honors Biology

Day 1	UGA pre-test; Cell parts; Cell theory; Prokaryotes and eukaryotes
Day 2	Cell parts; Prokaryotes and eukaryotes; Structure and function of the cell membrane
Day 3	Structure and function of the cell membrane; Passive transport
Day 4	Diffusion module
Day 5	Prokaryotes and eukaryotes; Structure and function of the cell membrane; Discussion of the diffusion module; Passive transport
Day 6	Osmosis module
Day 7	Discussion of the osmosis module; Passive transport; Active transport; Parts and usage of microscopes
Day 8	Usage of microscopes
Day 9	Filtration module
Day 10	Review for the cell unit test and the biochemistry remediation quiz

Table 14

Daily General Topics of Instruction – David's Honors and CP Biology

Day 1	Cell theory
Day 2	UGA pre-test; Chapter summary
Day 3	Chapter outlines
Day 4	Plant and animal cells; Prokaryotes and eukaryotes
Day 5*	Cell size in relation to atoms, electrons, molecules, and organelles
Day 6	Passive and active transport
Day 7	Diffusion module
Day 8	Osmosis module
Day 9	Filtration module
Day 10*	Chapter review questions
Day 11*	Chapter review questions
Day 12	UGA Post test
Day 13	Review study guide before the cell unit test tomorrow

* Days in which either the honors or the CP biology class was observed.

Characteristics inherent to the computer modules that enhance instruction.

The teachers explained ways in which the computer modules enhanced their instruction. For example, Linda discussed the ability to address multiple learning goals with each computer module, and shared,

> So by allowing me to hit, um, the role of the cell membrane and how it maintains homeostasis, it allows me to explain the impact of water in life processes really, really

> clearly, especially, um, using the movement across the membranes that they're seeing in all three situations, um, and then it allows me to investigate factors that affect the rate of cellular transport, if you change the concentration, change the size, all of those can happen in one laboratory experiment or in the three days that we're in there. Whereas I would have to design a completely separate lab that would take a whole period and then come back and analyze and then readdress so it's cutting down on the time I have to spend doing it. It's so much more directed. (I3, Lines 46-54)

Diane and David praised the visual aspects of the modules, explaining that the concepts involved in cellular transport are abstract. The computer modules allowed for students to visualize the normally unobservable phenomena, helping students to construct an understanding of cellular transport. Diane stated, "the visual aspect, they were able to visualize the animations of the particles moving and the cell transport, also, whereas, more traditionally, . . . you can't see the process" (I3, Lines 35-36). David shared,

> the thing that, that pops in my head first, you know, thinking about this is, ah, as we've given the final exam to the students, um, the, probably the thing that's come back has been hypotonic, hypertonic, and isotonic and, and there being a, um, a visual for them, you know, to refer to because they really struggle with it . . . I think that gave them something to, um, to, to put their, tie their knowledge to so that was a big, big plus. (I3, Lines 22-31).

The teachers credited the computer modules with enhancing their instruction and supporting student learning through connecting science concepts to real life. For example, Linda explained that her students referred back to the computer modules when preparing for the final exam. She stated,

> . . . even while we were reviewing for the final exam, those were the examples that they kept coming back to. "Ok, so, when we're looking at Anita and she had breathed in all that chlorine gas, where will we look at hypo and hyper?", I mean they're using that as their examples because now it's their hook, they remember it, it's their basis for comparison and it's not just words in a book and it's not just a picture, it is a real life scenario that they were able to interact with and solve on their own, and because they were able to problem solve while they were doing it, it stays with them longer.
> (I3, Lines 55-62)

Diane discussed the superiority of the computer modules over other computer activities because they were based on real life scenarios. She pointed out,

> . . . the animation on it is much better and much more involved and I think all the research is, like, using real life learning situations to help students make connections and so they all are like relatable and relevant where a lot of what's out there isn't. Um, so the technology itself is better. (I3, Lines 128-131)

David noted that the students became more engaged with the scientific concepts they were learning because of the real life scenarios depicted in the computer modules. He continued to state, " So that realistic part of it was very important that, um, reference, you know, I thought giving them a reference so they can apply new knowledge to was very, very important" (I3, Lines 36-38).

Lastly, Diane argued that the computer modules elicited richer information from the students than other activities, such as "webquests" (I3, Line 121). She noted that for the computer modules, "what makes this [the computer modules] different is they're not just going through the motions, it has that critical learning, critical thinking component" (I3, Lines 125-126).

Problematic characteristics inherent to the computer modules.

All of the teachers described a learning curve that the students experienced with the computer modules. For example, Linda explained that she planned to guide the students through the beginning of the computer modules. She stated, "So, at least for the first couple of them, I'm going to walk them through just to give them an example of what's happening, or at least partially through so they can know where to click and what to drag" (I3, Lines 340-342). In discussing a learning curve for using the computer modules, Diane stated, "I think there is a learning curve. I think they need to do one to get the hang of it . . . there's a learning curve and they're not quite sure what they are doing – just figuring it out and navigating through it" (I1, Lines 147-150). Also, David discussed the types of questions students asked as they worked through the modules, "Mostly it was, ah, the technical, ah, type questions, you know, 'how do I make the music turn off?', or, 'how do I get to the next step?', because they hadn't completed a chart or something like that, you know, it wouldn't let them go on" (I2, Lines 231-233).

Furthermore, the teachers explained that because of the learning curve, the students asked a large number of questions while working through the first module. In addition, the technology malfunctioned on occasion. When students encountered several technological problems, especially while learning how to navigate through the computer modules, the teachers became so busy addressing each problem that they did not have the opportunity to use the SABLE system or to tend to student learning. After a class period with an exceptionally large amount of technological issues, Diane lamented that the technology was particularly frustrating that day. While she had two students who cared enough to ask for help with conceptual understanding, she was unable to answer their questions because she was too busy helping other students manage technological problems (field notes, 11/04/13 CP). Also, in discussing the technology learning curve with the implementation of the first module, Linda stated, "Now I did not have as much time to do that part [check on their free-response questions]. I was kind of hoping I could tie it back at them a little bit more, but until they got more comfortable, that didn't happen as easily" (I2, Lines 202-204). Therefore, when the teachers were busy focusing on helping the students learn to navigate the computer modules and addressing technological issues, they were unable to use the SABLE system or attend to student learning.

Linda and Diane expressed frustration with the computer modules because users were unable to move forwards and backwards through the modules, which hindered student learning. For example, Diane explained that the computer modules prevented students from moving to a new section until they correctly answered the current section's multiple-choice questions. Some students only achieved a correct answer after multiple attempts. Diane argued that the students may lack a complete understanding of the material, and when they arrived at a future free-response question, "they would just get stuck" (I2, Line 95). In addition, Diane observed that students gained a more thorough understanding of the concepts as they progressed through a module and would benefit from the ability to amend earlier answers. Diane stated, ". . . some of the more motivated students need that opportunity to, like, go back and revisit the concepts" (I2, Lines 97-98).

Linda shared that sometimes students failed to complete the computer modules during the allotted class time. Although she appreciated that the students could access the computer modules from home, both her and the students were frustrated with the fact that they were unable to resume the modules. Instead, the students were forced to start from the beginning. Given that each module requires at least forty-five minutes to complete, both Linda and her students were frustrated with having to click through the entire module each time they loaded it.

In order to deal with technological issues, Linda stressed the need for a teacher's manual for the computer modules that detailed each section, provided instructions on how to fix common technological errors, and enabled short-cuts through the program. For example, Linda explained that with the correct keystrokes, frozen sections of the module could be skipped. While this allowed for students to continue working, it also resulted in them missing important concepts and struggling to answer subsequent questions. If teachers had a manual that adequately described each section of the modules, then they could step in and walk students through the skipped areas. Students would be able to continue working through the module and answering questions as if nothing had happened, diminishing the impact of technological errors on instruction. Furthermore, Linda was only aware of the keystroke fix because of her close relationship with the software developers. She pointed out that other teachers would need that information as well. Finally, if the software allowed the users to access different sections without having to work through the entire module and a teacher's manual explained how to access this feature, then Linda could have class discussions about the modules without needing to click through the entire module. She envisioned an electronic manual that would enhance her ability to engage in meaningful classroom discussions by allowing her to quickly jump to any section of a module with one click. Linda shared,

> But if I have to click through the whole thing to get to what I want, that takes time and I don't always have time for that, so having that clickable teacher guide, you know, even if you don't put it on paper. If you have the teacher guide where here's the first part and here's what they need to see, then you can open up the third part and here's what you

should see, and I could jump from one to the next. For me, that would do two things: it would let me work with the kids who run into glitches, and then, if I'm reviewing in class, like you saw me, talking about the modules and going over what you should have seen, I like to take hypersnap pictures from that and stick it up there so they know exactly what I'm talking about, and maybe have the whole class problem solve through this one. (I3, Lines, 254-263)

Use of the SABLE System

The teachers utilized the SABLE system in various ways that elucidated factors that possibly supported and hindered their ability to engage in formative assessment. There are four subheadings involving the use of the SABLE system that relate to aspects of the technology that support and hinder formative assessment: use of the SABLE system in relation to instruction, aspects used within the SABLE system, characteristics inherent to the SABLE system that support the facilitation of gathering and processing student data, and characteristics inherent to the SABLE system that hinder the facilitation of gathering and processing student data.

Use of the SABLE system in relation to instruction.

All of the teachers used the SABLE system to elicit evidence of student learning while the students were engaging with the computer modules. However, only Linda planned to analyze the students' completed work within the SABLE system in order to assign a letter grade. Diane and David noted time constraints with evaluating students' work outside of the class period in which they completed the modules. Diane explained that although the data in the SABLE system was useful, she did not have the time to further evaluate beyond the initial analysis during instruction on the computer modules. She shared,

> So I'm not saying I won't go back ever, [laughs], um, it's useful, what's there, and we talked about maybe going back to review again before the end of course test and help them retain it, and I know I can disaggregate this by skill up here, but for the time being [laughs] in the immediacy of this unit where I have got to test by tomorrow and I'm the last one to do it, I just, um, have found it more useful to grade their written assignments and give them back where they can have the feedback on them, um, and talk through these. And I think it's very useful. (I2, Lines 190-197)

David noted that he did not have time to analyze the data in the SABLE system beyond the class time in which the students completed the computer modules, stating that further analysis of the data would not be an efficient use of his time. He stated, "With this particular situation because time is so tight, I doubt if I go in and do much analysis on it . . . And so to spend a, a huge percentage of time on that, is not, ah, the most efficient way for me to help the kids get what they need to get I don't think" (I2, Lines 135-152).

Aspects used within the SABLE system.

All of the teachers used the standard SABLE interface, shown in Figure 7 in chapter three, that presented them with color-coded information about student progress through each module. However, none of the teachers utilized the analysis tool that grouped questions by scientific practices, as shown in Figure 8 in chapter 3, such as making predictions, constructing a hypothesis, and analyzing data. Linda used the rubric tool to assist her in providing feedback and grading the modules. The rubric tool provides an exemplar answer and suggests how to allocate points for the free-response questions. Linda shared, " I would copy the exemplar answer and stick it in there so that they [the students] could see exactly what could have been looked for . . . I copied the, um, rubric up here to put in there so he [a student] could see where the points were for that" (I2, Lines 166-178).

Characteristics inherent to the SABLE system that supported the facilitation of gathering and processing student data.

When recalling the use of the modules last year and the lack of access to the SABLE system, Linda and Diane discussed feeling removed from the instruction. Linda explained that while the students worked through the computer modules, she was unsure about their progress. Linda lamented, "The delay that we had last year between, they did it [the computer modules], but I couldn't really see what their responses were. I could not see what they were doing. I kind of had to make some guesstimations about where they were" (I1, Lines 305-307). Diane expressed her frustration in not being able to access the students' answers last year, stating, "Last year when we did these modules, we never got any feedback so there wasn't much accountability for them [the students], but more importantly, we didn't know what they had learned" (I1, Lines 114-116). While implementing the computer modules, Linda and Diane felt that the SABLE system allowed them to be more involved in the process of teaching and learning, and utilizing an iPad to access the SABLE system created even stronger feelings of connectedness for Diane. She explained,

> I can't remember the exact question because [within the computer modules], like it [the SABLE system] showed me instantly that none of them got that, but it enabled me to like see instantly, especially with the iPad, like walking around the room, um, it allowed me to address misconceptions easier and kind of be more involved in the process because I see what they're doing and what they're getting, then I'm able to address it. Like in the classroom yesterday, because I knew whether they had saved Clark or not or what they

had done, I was able to, like follow up with that more readily, I guess. It's been really good. Yeah. It's been very good. (I1, Lines 123-130)

All of the teachers used the SABLE system to elicit the same two types of evidence of student learning. First, the teachers indicated that they examined the data in the SABLE system to determine students' strengths and weaknesses as evidenced by the scientific concepts involved in the questions students answered correctly or incorrectly. Linda noted, ". . . I can see those spots where they're having difficulty and maybe misunderstanding that needs to go and be clarified" (I2, Lines 200-201). Diane shared, ". . . the first thing I liked was the immediacy that which I could see like where their deficits were . . . several of them were having trouble with a particular question . . . that asks. . . what's the effect of a shallow concentration gradient" (I2, Lines 45-56). David stated, "Well, in looking at the, um, the columns and the rows in that spreadsheet, it let's me identify places where they struggle, you know, what they don't quite get" (I2, Lines 159-160).

Secondly, the teachers determined whether or not the students were putting forth adequate effort and providing enough detail on the free-response questions. Linda stated, "I sort of spot checked some of their answers, and I was seeing a lot of the kids that were giving much more detail, um, supporting what they had to say, going back and pulling information from the manual to be able to see what they needed to see" (I2, Lines 71-74). Diane explained that the free-response questions provided her with information about students' levels of effort in completing the computer modules. She stated,

> With CP [college prep], I was able to use it also for discipline (laughs), not discipline but for classroom management, because a lot of these kids were just going through the

> motions and they weren't writing anything. And they were writing, um, "she's sick, get over it" . . . So I was able to go and, um, address that. (I2, Lines 82-85)

In comparison, David identified student effort by examining each student's row of data. David shared, "the rows were helpful [within the SABLE system] to see that I had kids that weren't even trying" (I3, Lines 73-74). Students who incorrectly answered all or a majority of the questions indicated to David that they were not putting forth effort in completing the computer modules.

In addition to identifying students' strengths and weakness and whether or not they were providing detail and putting forth effort, Linda and Diane utilized the data in the SABLE system to determine whether or not to provide feedback to individual students or the whole class. In deciding whether to approach individual students or address the whole class, Linda said,

> . . . the nicest thing about it is that I can address those misconceptions that they [the students] might have or issues or questions immediately when I see that heat map [color-coding within the SABLE system], anything that comes up yellow or red, I can go right to the kid and remind, or if I see a whole column, then I can stop the class and do a little quick re-teaching. (I3, Lines 42-45)

In relation to providing feedback, Diane stated, ". . . [SABLE] helped me meet the learning goals by allowing me immediate intervention because I was able to like stop and correct misconceptions both as a whole group and individuals immediately" (I3, Lines 60-62).

In addition to the aforementioned uses of the data in the SABLE system, Diane also discussed analyzing the students' pace throughout the computer modules. For example, Diane approached students who had not completed as many questions as other students, sometimes asking them if they needed help, other times noticing they were off-task, and still other times simply observing the students' work without saying anything to the student. In relation to analyzing the students' pacing throughout the computer modules within the SABLE system, she shared,

> and then it [the SABLE system] also let me see, as far as pacing goes in my CP class, you know, a lot of kids were just stuck way back at early questions and it turned out they weren't able to go in and like gather the data on Clarke and so they were just stuck floating around out there. (I2, Lines 85-88)

All of the teachers stressed the speed at which they could use the SABLE system to elicit evidence of learning, provide feedback, and modify their instruction based on student needs. Linda explained, ". . . the nicest part about it [the SABLE system] is that I can get that [student data] immediately when they're in there [completing the computer modules] . . . I can see what's going on" (I3, Lines 39-41). In regards to the immediacy of eliciting evidence, providing feedback, and modifying instruction, Diane stated, "I liked it [the SABLE system] because it helped me, like, in real time, address the issues instead of having to go back the next day and do it . . . I was able to see who's struggling and address it there" (I2, Lines 114-116; 190). Furthermore, David described how the SABLE system helped him manage and monitor student learning and shared,

> Well for me, it was when you look at that spreadsheet, ah, view and you could go down the line or down the column and look at, ah, a bunch of greens or reds or yellows and you can see, you know, where their strengths and their weaknesses, that was, to me, that was very, very useful because it let me see that 80% of the class was not getting one question right or 80% of the class was getting a particular question right. (I3, Lines 62-66)

Also, Linda and Diane indicated that if they implemented the computer modules without SABLE, they would lack the ability to elicit evidence of student learning, provide feedback, or modify their instruction based on students' needs without creating some form of written assignment to complement the modules. Even if they created a written assignment, the immediacy with which they could elicit evidence, provide feedback, and modify their instruction would be lost.

The teachers indicated that using the SABLE system with an iPad allowed them to elicit evidence of learning, provide feedback, and modify instruction more efficiently than with a personal computer. They indicated that the iPad allowed for them to be mobile so they could interact directly with students and did not have to move back and forth from individual students to a personal computer. Linda explained,

> But the mobility was nice because then I could walk right up to a kid and kind of hover over their shoulder and give them a little piece of information, and then, keep walking around and hover over another kid - sometimes good things - sometimes things that needed to be corrected. If I saw a particularly good answer or a kid that was going particularly quickly and everything was green, then that was a good indication of, ok, you know what's going on, you're not just getting lucky doing that. So it was nice to be able to walk around with more freedom with the IPAD than with the computer.
> (I2, Lines 312-319)

In describing the benefits of using an iPad to access the SABLE system, Diane noted,

> It was much better to use it with the iPad because it gave me the freedom to move around and then approach people, like with the data in front of me, show them their answers. It just made me more, um, available to the students. Sometimes you have to choose

> between am I'm going to go look at SABLE or am I going to go interact with the kids. (I2, Lines 255-259)

Furthermore, David shared his views on using the iPad to access the SABLE system and stated,

> Yeah, it would be much eas- I think it would be a hundred times better because you could carry it around with you and you could, you could show the kids, you know, poss – potentially things, but you, um, especially when they wrote the short answers, you could take the iPad around and, and show them, you know, "this is where you said something you shouldn't have said", or "this is a great job", you know, "describing that", and, "I like what you wrote right here", or whatever. But to have that and to be able to show it to them right away, which would be easy with an iPad, it would be difficult with a laptop, um, I think would be very helpful, very useful. (I2, Lines 214-221)

The previous year when the teachers implemented the computer modules, the SABLE system was still in development and therefore, not in use. In order for the teachers to hold students accountable for participating in and completing the modules, they needed to develop a worksheet to go along with the modules. Diane indicated that the SABLE system held students accountable, allowing her to observe student answers and address either the class or specific individuals when they needed to improve their responses to questions. She stated,

> And it helped me keep them on task too at that lower level where they're not as highly motivated – helped me keep them focused for them to understand, that they were, it, kind of, gave it a depth of accountability that a lot of times I think they don't have on – when they're doing, like computer modules. (I2, Lines 116-119)

She continued to explain that she believed that being able to hold students accountable for their answers elicited richer evidence of student learning. She described,

> . . . they were not giving me full sentences. They were, just kind of, giving me half way answers. Although they were correct, they weren't really thought out. So I was able to stop instruction when I realized that and let them know I could see them. Then you could see, if you like compare the data to when I stopped instruction and addressed the whole class and said, "I need well thought out answers, I'm reading your answers", and then they knew that they were kind of accountable for the information, they started writing more. And there's like a sharp, if you were to pull all of this data, you could see, like, sentence fragments here . . . once I addressed it, they were able to write me, like, more well thought out answers. (I2, Lines 64-72)

Characteristics inherent to the SABLE system that hindered the facilitation of gathering and processing student data.

Linda explained that with the current placement of free-response questions clustered at the end of the computer modules, her ability to provide feedback in real time and communicate to students what is expected of them was restricted. Linda suggested spreading out the free-response questions within the modules and adding an automated grading component to the SABLE system for the first few free-response questions. Having a few free-response questions earlier in the modules and having the SABLE system assess them for quality (i.e. looking for key words or length of response), would enable her to more quickly identify problem areas with each student and address them. Describing the automated grading component, she stated,

> What kind of answer would be an acceptable kind of thing, you know, when they're doing that [answering free-response questions]? Um, that one might look for a few key words or a particular length of something that's there . . . I just want a little bit of it at the beginning so they can get an idea of what their answers need to look like, how much

more, um, detail they might want to put, how much more explanation they would require and not try to be so short in their answers . . . just for a formative kind of thing as they're moving through the case . . . But have a little bit more of the formative, um, short answer, kind of, thing that is scored for them or letting me see as they're going along, "ok, yeah, they got that, they understand that really needed to have this, this, and this before they can move along. (I3, Lines 137-156)

Linda and David criticized the presentation of the SABLE system data because the interface did not display all of the students' answers and the accompanying questions on the same screen. Instead, they were required to scroll vertically and horizontally, making it difficult to determine which student and question were represented by each answer box. Linda stated, "And I know the screen's going to be a little bit too small to see all of the kids on one screen, but even if I only had to scroll, you know, half way" (I2, Lines 35-36). Furthermore, David shared, "it [the SABLE system interface] could have been maybe reduced, ah, I didn't like the fact that I couldn't see the whole page . . . That was a little bit of an issue" (I3, Lines 67-68).

All of the teachers mentioned that even though the SABLE system recorded whether students answered multiple-choice questions correctly, determining why students missed questions proved arduous. The teachers believed students missed questions for a variety of reasons, such as struggling to navigate through the modules, lacking understanding of science concepts, having difficulty with reading comprehension, and being distracted with the gaming aspect of the modules. Linda shared,

. . . if you just tried to answer four times in a row and you never got it right and it shows up red, does that really mean that you didn't understand it? Or were you just trying to get through it quickly because you knew we only had fifty-five minutes? (I3, Lines 355-358)

Diane explained the difficulty she experienced with differentiating between students who did not understand the science content versus students struggling to navigate through the computer modules,

> . . . it seems the students struggled more, um, they really had a difficult time, like, gathering the data and like just navigating the system itself, and I think, um, that those students, they inhibit their learning a little bit because of their frustration, just like, knowing what to do and working through the system itself. And then, I don't know if they don't actually, if the material is frustrating them or if the system is frustrating them. Are they shutting down because they don't get the biology of it or are they shutting down because they can't figure out how to upload the data inside the frame and where to go next . . . (I3, Lines 98-105)

In attempting to determine why students answered questions incorrectly, David indicated,

> . . . it was hard at times to, to differentiate between the struggles they were having with concepts verses the struggles they were having with reading comprehension for example. There were some kids that whenever they read some of the instructions or some of the, um, and I think that speaks to education in general, ah, when they read the instructions or they read the prompts that were in the program, they, some of them didn't get it. (I3, Lines 47-52)

Discussion of the Findings

The findings in section three, teacher implementations of the technology in relation to formative assessment, relate to two research questions:

1. In what ways do the data from the SABLE system influence future instructional decisions within a cell unit?

2. How do 3-D computer modules involving cellular transport, coupled with a technology that allows real time monitoring of students' work, support or hinder teachers' formative assessment practices during the implementation of a cell unit?

The ways in which the data generated in the SABLE system influenced future instructional decisions within the cell unit were different for each teacher. There were three primary contextual factors that impacted the ways in which the data generated in the SABLE system influenced the teachers' future instructional decisions: the placement of the computer modules within the cell unit, teacher familiarity with the technology, and teacher confidence with the content being taught.

Linda implemented the modules during the end of the cell unit, leaving one day to review before the cell unit test. Because Linda utilized the modules at the end of the cell unit, she was unable to utilize the student data within the SABLE system before administering the cell unit test. Therefore, the data in the SABLE system did not have major impacts on her future instruction. However, in Diane's honors biology class, the students completed the modules on diffusion and osmosis towards the beginning of the cell unit. Scheduling the modules earlier in the cell unit allowed Diane to connect the science concepts in the computer modules to the concepts involved in other class activities, such as the demonstration on the movement of water into and out of gummy bears. Furthermore, although she implemented the computer modules towards the end of the cell unit in her CP class, she interpreted the data within the SABLE system as indicating that her CP students possessed widely varying levels of understanding in regards to the concepts in the cell unit. Therefore, during the lesson before the cell unit test, she differentiated instruction in order to better meet the needs of each student within her class as opposed to meeting the needs of a subset of her students.

On the other hand, David's placement of the computer modules did not influence how he used the data within the SABLE system to inform future instruction. Although he implemented the computer modules towards the middle and end of the cell unit, he did not make any references to the computer modules during future lessons. During the interviews, he stressed his unfamiliarity with the content because he had not taught biology in over ten years. Also, unlike Linda and Diane, he was implementing the computer modules for the first time during the 2013/2014 school year.

Several themes emerged from the data that informed the over-arching research question: How do 3-D computer modules involving cellular transport, coupled with a technology that allows real time monitoring of students' work, support or hinder teachers' formative assessment practices during the implementation of a cell unit? The teachers were able to enact their normal formative assessment practices while implementing the 3-D computer modules and the SABLE system. All of the teachers described alignment between the computer modules and the learning goals of the cell unit. The teachers elicited evidence of learning and provided feedback that promoted student development of simple knowledge. The teachers used the SABLE system to determine whether or not students answered questions correctly, provided detailed answers for the free-response questions, and progressed through the modules at a similar pace to their peers. Although the modules elicited evidence of student learning, which was stored in the SABLE system, none of the teachers conducted an in-depth analysis of the data in order to gain better insight into how the students understood the science concepts. Furthermore, the teachers did not engage the students in peer or self-assessment while implementing the computer modules.

In addition to enacting their normal formative assessment practices, the computer modules and the SABLE system allowed the teachers to extend beyond their normal enactments of formative assessment. The SABLE system allowed the teachers to possess greater and more efficient processing power while engaging in formative assessment practices. When enacting formative assessment, teachers need to elicit evidence of learning from students and then, process large sums of student data in order to determine what and how each student understands science concepts. Then, teachers need to make informed instructional decisions as to how best to support further student learning.

First, the computer modules elicited richer evidence of student learning than the three teacher participants. The computer modules primarily posed reasoning questions, whereas the teachers primarily asked recall/factual questions. Second, when eliciting evidence of learning on-the-fly, teachers need to mentally process large sums of data in the moment. Also, teachers elicit evidence of learning through collecting written work and can conduct a more in-depth analysis over a school day, overnight, or over the course of a few days before making informed instructional decisions. The SABLE system supported teachers' formative assessment practices because it provided a constantly morphing, color-coded visual that reflected student answers and pace. Because the SABLE system provided a quick visual of student learning, teachers could divert processing power away from eliciting, organizing, and storing evidence of student learning. Instead, they could devote more processing power to interpreting and using the information gathered in the SABLE system to make informed instructional decisions.

Third, each of the teachers, during instruction without technology, engaged in cycles of eliciting information from their students, providing feedback, and modifying their instruction. Sometimes, these cycles occurred quickly when teachers asked the class or specific students recall/factual questions, and depending on students' answers, either re-explained a concept or proceeded with further instruction. During these questioning episodes, teachers only received information from the few students who they called on or who volunteered to answer. In order to gain information from the entire class, the teachers needed to assign work, collect it, and review it. In these circumstances, the cycles of eliciting information, providing feedback, and modifying instruction lasted approximately one week. The SABLE system supported teachers' formative assessment practices because it allowed teachers to complete these cycles with all of their students rapidly and frequently during a single class period.

Fourth, the teachers lacked direction in their normal approach to making decisions about interacting with the class as a whole or with specific individuals during the process of teaching and learning. Most instruction involved whole class interactions, with students occasionally working on activities individually or in small groups. Diane was the only teacher who consistently approached individual students to elicit evidence of learning. However, the SABLE system allowed all three of the teachers to make more informed and directed decisions about addressing student learning with individual students versus the whole class. The teachers indicated that the SABLE system clearly and quickly indicated through the color-coded pattern whether the class as a whole was struggling with specific concepts or just a few individuals. Furthermore, the iPad allowed the teachers to more easily address struggles that individual students were experiencing because the teacher became mobile and could approach a student, show them where they are struggling, and discuss why and how to improve.

In addition to increasing processing power, the computer modules and the SABLE system enhanced teachers' formative assessment practices because students' experiences with the computer modules provided a space for teachers and students to engage in further discussion involving cellular transport. When the students worked through the modules, they were able to build, to some degree, conceptual understanding of scientific concepts related to cellular transport. The real-life scenarios provided the students with a foundation upon which to build their understanding of cellular transport and to develop a vocabulary associated with cellular transport. This foundation and vocabulary allowed for future discussions involving cellular transport to occur in class as students continued to refine and modify their understanding of the concepts. These class conversations further allowed teachers to gain insight into students' knowledge and to continue cycles of eliciting evidence and providing feedback.

Sometimes the implementation of computer lessons can remove teachers from the process of teaching and learning. Linda and Diane indicated that last year, when they implemented the computer modules without the SABLE system, they had no knowledge of how the students were performing. The coupling of the SABLE system with the computer modules reconnected teachers to the process of teaching and learning, allowing the teachers to engage in formative assessment. Furthermore, the use of the iPad created a stronger connection to the process of teaching and learning for the teachers.

In addition to the ways in which the computer modules and the SABLE system supported the teachers' enactments of formative assessment, there were several ways in which the technology constrained the teachers' formative assessment practices. On one hand, the computer modules and the SABLE system increased the teachers' processing power in relation to formative assessment. On the other hand, certain aspects of the technology restricted teachers' processing power. First, the computer modules and the SABLE system supported teachers in eliciting evidence of learning, providing feedback, and modifying instruction. However, when the technology posed several technological problems in one class period, teachers were too busy addressing these issues and could no longer engage in formative assessment. Adding to the distraction of the teachers, students encountered a learning curve with the first module. Thus, when technological problems occurred in conjunction with the implementation of the first module, little, if any, formative assessment occurred.

Second, although the teachers believed that the modules and the SABLE system elicited richer data about student learning compared to other activities they assigned, the teachers cited potential factors that caused confusion regarding the reasons students struggled with the concepts involved in the computer modules. All of the teachers indicated that their students experienced a learning curve with the first computer module. Also, all of the teachers indicated that some of the students may have felt rushed to complete the modules within the given time frame, and some students may have been distracted with the gaming component of the modules as opposed to learning about the science concepts. Diane and David, who taught college prep students, also indicated that their students struggled with reading comprehension and many of them did not understand what the free-response questions were asking. Therefore, the teachers were not always certain as to whether or not the students missed questions because they lacked an understanding of the science concepts, because they experienced difficulty navigating the technology, or because they struggled with reading comprehension.

Third, although the SABLE system provided a color-coded visual displaying student data, the teachers needed to scroll down columns and across rows in order to visualize all of the data for one student or one question. All of the teachers indicated that scrolling in order to visualize all of the data while maintaining which box represented which question or student proved difficult.

Fourth, Linda pointed out that she could not process the data for the free-response questions in real-time partly because the questions were clustered towards the end of the modules. Furthermore, the SABLE system lacked a grading component for the free-response questions. Lastly, Linda and Diane noted that the immediacy with which they could elicit evidence, provide feedback, and modify instruction would be lost without the SABLE system.

Although the technology created a shared context in which teachers and students could discuss abstract concepts, an inherent characteristic of the computer modules restricted these conversations. The computer modules only allowed teachers and students to move forward throughout the program. In addition, although students could access the computer modules from home, they could not resume their place within the modules and instead had to work through the entire module again. Neither the teachers nor the students could skip around the modules moving from one section to the next forwards and backwards. Therefore, when teachers conversed with their students about the concepts involved with the computer modules, they could not easily show the visuals within the computer modules.

CHAPTER 5

DISCUSSION AND IMPLICATIONS

Summary of the Study and Discussion

This study examined how 3-D computer modules and the SABLE system supported and constrained teachers' formative assessment practices. In order to explore teachers' formative assessment practices while using technology, I examined three teachers' implementations of the cell unit in which they utilized the 3-D computer modules and the SABLE system. For the teacher participants, I observed a combined total of five introductory biology classes, which included CP, honors, and gifted students. I conducted classroom observations, recording a written record of the instructional verbalizations between teachers and students during the implementations of the cell unit for each of the five classes. I conducted three interviews with each teacher to elicit their ideas and thoughts on formative assessment and the use of the computer modules and the SABLE system in relation to their formative assessment practices.

Several major themes emerged from the analysis of the data generated within this study in regards to teachers' formative assessment practices with and without the use of 3-D computer modules and the SABLE system. The first theme relates to the processing entities involved in formative assessment practices with and without the use of the 3-D computer modules and the SABLE system. First, while teachers support students in attaining pre-determined learning goals, teachers are the sole processing entity during their enactments of formative assessment when they lack the support of instructional technology. They are responsible for eliciting evidence of learning from their students; gathering, organizing, and storing student data;

interpreting student data; and acting on the gathered student data in order to support further student learning. Although students participate in the process of formative assessment, I did not investigate their role because this study focused solely on teachers and their formative assessment practices. During cycles of formative assessment, the teachers elicited evidence of learning at the recall/factual level and provided feedback, communicating whether or not students correctly answered questions. Thus, the teachers engaged in cycles of formative assessment that promoted student development of simple knowledge. Furthermore, when teachers engaged in verbal cycles of formative assessment, they elicited information from a subset of students and completed multiple cycles in one class period. However, in order to elicit evidence of learning from each individual student, teachers needed to collect written work. Teachers were only able to approximately complete one cycle of formative assessment per week in regards to assigning, collecting, analyzing, and returning students' written work.

Secondly, when teachers implemented the 3-D modules and the SABLE system, they were no longer the sole processing entities while conducting formative assessment. The computer modules assumed the responsibility of eliciting evidence of learning from the students, and the SABLE system gathered, organized, and stored the elicited evidence. Furthermore, the computer modules, through posing reasoning questions, and the SABLE system, through holding students accountable for their answers, elicited richer data from the students than teachers did during their normal formative assessment practices. Although richer data was elicited, the teachers did not analyze the richer student data. Instead, they paid attention to whether or not students correctly answered questions, which promoted the development of simple knowledge.

In addition to gathering, organizing, and storing elicited evidence of student learning, the SABLE system began to interpret the gathered student data by presenting a color-coded visual of students' answers. The color-coded visual provided information about the number of student attempts to correctly answer multiple-choice questions. The teachers indicated that the color-coded visual enabled them to quickly identify individual and whole class trends in student understanding. The standard SABLE system interface allowed teachers to efficiently make informed decisions about whether to address the whole class or approach individual students about concepts that they were struggling to understand. Because the computer modules and the SABLE system elicited, gathered, organized, and stored evidence of student learning, teachers were able to engage in multiple cycles of formative assessment with each student in a class period.

Although several characteristics of the computer modules and the SABLE system supported teachers' formative assessment practices, inherent characteristics to the technology also interfered with teachers' abilities to engage in formative assessment. For example, many of the open-ended response questions were clustered towards the end of the modules, and the SABLE system lacked an automated grading component for the open-ended response questions. Therefore, the teachers received students' answers to the open-ended response questions towards the end of the class period and lacked the necessary time to analyze them in real time. Furthermore, in order to visualize all of the data for one question or one student within the SABLE system, teachers were required to scroll down columns and across rows, slowing their ability to interpret student data. In addition, the teachers struggled to make interpretations about why students incorrectly answered questions identifying several possibilities such as, students lacked an understanding of the science concepts, students experienced difficulty navigating the technology, or students struggled with reading comprehension. Also, when the technology malfunctioned, especially in combination with students who were experiencing a learning curve while interacting with the first computer module, then teachers were unable to examine the student data within the SABLE system and the formative assessment process stopped.

The second theme involves teacher connectivity to the process of teaching and learning. Linda and Diane explained that during the previous school year, 2012-2013, when they implemented the computer modules without the SABLE system, they felt disconnected from the process of teaching and learning. Unless they developed a worksheet to accompany the computer modules, they were unaware of the students' levels of knowledge in relation to the science concepts discussed in the computer modules. Even with an accompanying worksheet, their ability to provide feedback and modify instruction was delayed. During the current school year, 2013-2014, with the implementation of both the computer modules and the SABLE system, they felt connected to the process of teaching and learning because they could visualize the students' answers, allowing them to provide feedback and modify instruction in real time. Furthermore, using the SABLE system with the iPad created stronger connections between the teachers and the process of teaching and learning. With the iPad, they were able to approach individual students and show them where they are struggling and then, discuss why and how to improve.

The third theme involves the creation of new contexts in which teachers and students could have discussions about the science concepts that they were learning through the use of the computer modules. Without the computer modules, teachers possessed information that they wanted their students to learn and provided instruction on abstract concepts, which are usually presented as disconnected from each other and the real world. Students lacked a foundation upon which to build understanding of new science concepts and struggled to construct knowledge. However, when students interacted with the 3-D computer modules, they were provided with visual representations of abstract concepts that were presented in connection with each other and the real world. After interacting with the computer modules, the teachers and students existed within a shared context in which they could have meaningful discussions about the scientific concepts in which they were learning. However, these meaningful discussions were restricted because the teachers and the students could not easily interact with the computer modules together. When discussing concepts involved in the computer modules, teachers were unable to show the visuals within the computer modules without working through the entire module, which would not necessarily be efficient from an instructional perspective.

Implications

In this study, I identified several characteristics of the computer modules and the SABLE system that supported and constrained teachers' formative assessment practices. This study has several implications for the future development of instructional technology. Instructional technologies that support the formative assessment process need to aid teachers in eliciting, gathering, interpreting, and acting on evidence of student learning. Instructional technology cannot replace the nuanced abilities of teachers to interpret and act on evidence of student learning. Therefore, instructional technology will be most beneficial in perfecting methods of eliciting, gathering, organizing, and storing student data. The types of information elicited and the ways in which the data is organized can support or constrain teachers' abilities to effectively interpret and act on evidence of student learning. Thus, instructional technologies need to elicit rich data, which can be organized and presented in an easy to read interface.

Instructional technology such as the version of the computer modules that lacked the ability to collect and store students' answers severely restricted teachers' formative assessment practices and disconnected the teachers from the process of teaching and learning. Thus, when instructional technology developers design new programs, they need to build tools that enable teachers to access student data. More importantly, teachers need to access student data in real time in order to provide immediate feedback and complete multiple cycles of formative assessment in one class period with each student. Furthermore, instructional technologies that allow the monitoring of student work need to run on hand held devices so that teachers can more easily work with individual students.

Developers of instructional technology as well as teacher educators need to consider how the implementation of instructional technology can complement effective pedagogies. For example, the computer modules restricted users from skipping from one section to the next, preventing teachers from capitalizing on meaningful conversations with students after they worked through the computer modules. Furthermore, teacher educators need to support teachers in determining effective instructional practices while using instructional technologies.

The research literature is unclear as to whether instructional technologies catalyze changes in pedagogy (Hawkridge, 1990; Philip & Garcia, 2013) or provide additional resources that support their existing pedagogies (Haass, Seeber, & Weininger, 2001). Instructional technologies have a complex interaction with pedagogy. Within this study the computer modules and the SABLE system acted as a catalyst and enhanced teachers' formative assessment practices. The teachers were able to elicit and gather evidence of student learning, make interpretations of the elicited evidence, and then, modify instruction accordingly for each student in real time. However, the instructional technologies also supported teachers' enactments of their existing pedagogies because although the computer modules and the SABLE system elicited richer evidence of student learning, the teachers still enacted formative assessment practices that promoted the development of simple knowledge. Therefore, although instructional technologies have the potential to enhance teachers' formative assessment practices, the technology alone is not sufficient to improve teacher practices.

Directions for Future Research

This study examined how the use of 3-D computer modules and the SABLE system supported and constrained three teachers' formative assessment practices during the implementation of the cell unit. In order to have a more complete understanding of the ways in which the instructional technologies can support the formative assessment process, more teachers in a variety of contexts need to be studied. Furthermore, as teachers gain more experience with the technologies, factors that support and constrain their formative assessment practices will change as evidenced by the changing barriers to the integration of technology over time (Ertmer, 1999).

In order to better understand how instructional technologies can support teachers' formative assessment practices, more research needs to be conducted on effective pedagogies that are enacted with instructional technology. For example, does the order in which the computer modules are implemented or the placement of the computer modules within the cell unit impact student learning? Would student learning be further supported by the opportunity to work with peers on the computer modules or evaluate peers' treatment decisions?

The connection between teachers' implementations of instruction that is conducted with instructional technology and their formative assessment practices has been the central focus of this research. This study's importance arises from the fact that the teaching of science entirely within a technological environment will soon become the norm across the United States and across the developed world. As has been seen by the early years of the "computers in schools" movement; the rush to adopt technology is often moved ahead of understanding of whether that technology offers a benefit to the teachers and learners who will use it. Regardless of the technology that is available for teaching, it seems clear (Philip & Garcia, 2013) that good teachers and their good teaching will be needed through many future iterations of these instructional technologies. If this is the case, understanding the use of fundamental pedagogies, such as formative assessment and how it impacts learners' development of knowledge, will always be important. It is hoped that this study will be a first effort to continue building that understanding.

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APPENDIX A

INTERVIEW PROTOCOL

Interview 1

1. What are the main concepts that you want your students to learn in the cell unit? What are the big ideas?

2. What are your expectations for how the unit will progress in terms of student learning? What do you think students will struggle with in terms of their learning during this unit?

3. Where within the unit do you plan to use the 3-D computer modules? What are the reasons for placing the modules where you have placed them?

4. How will you monitor the progression of student learning throughout the cell unit?

5. How do you think the SABLE system will help you during the cell unit? Or the computer modules? How will the SABLE system help you with your teaching? How will the computer modules help you teach the concepts that you want the students to learn?

Interview 2

1. Ask the teacher to pull up one of her classes' SABLE artifacts for one of the case studies and show us the data. These questions are in regard to when the teacher used the SABLE system while the students were completing the modules during class.

    Have her explain how she used the system.

    For what purpose?

    What was she looking at?

    What was she learning about her students' understandings?

2. Did you use or do you plan to use the data that was generated by the SABLE system other than during the teaching of the computer modules? If so, how? If not, why?

3. Did the knowledge you gained from the SABLE system impact your instruction? If so, how? If not, why? (Was the knowledge not useful or did you not have time, etc?)

4. Tell me about using the IPAD vs the laptop to look at SABLE. Where did the IPAD come from?

5. Tell me about the types of questions that the students were asking? Were they mostly technological or content based? Tell me about the content-based questions that the students were asking.

Interview 3

1. How did the computer modules help you attain the learning goals that you set out for your students?

2. What did the computer modules help you accomplish in terms of managing and monitoring student learning? (so you have learning goals that you set out for your students in the unit – how did the modules help you identify where your students were in terms of achieving those learning goals and then also, how did the modules help you identify the next instructional steps to take to help the students achieve the learning goals you set out)?

3. Same two questions above, but about SABLE.

4. Do you recall any questions or types of questions from the modules that were useful in gauging depth of student understanding and explain why?

5. You have shared many ways in which the modules and the SABLE system have supported you in managing and monitoring student learning. Are there any characteristics of the modules or SABLE that hindered your normal ability to manage and monitor student learning?

6. Are there any characteristics that could be added to the modules and the SABLE system to more fully support you in managing and monitoring student learning?

7. Your Honors students worked in collaborative groups for the diffusion module. Would you have them work in collaborative groups next time you use the modules? Why or why not? What are the positives and negatives of having the students work individually? Work in groups?

8. Would you ever use the modules as more of a demonstration where you would walk the students through some or all of the case study? What are the positives and negatives of using this teaching strategy?

9. I want to understand how you go about managing and monitoring student learning during the cell unit. You already shared with me a variety of strategies you use to accomplish this such as questioning, observing, and giving quizzes. Can you walk me through how you go about managing and monitoring student learning during the cell unit from the initial stages of planning to the end of the unit when the students take the unit test?

10. How do you balance getting information from the class as a whole versus from individual students about their current conceptual understandings about a specific topic?

11. How do you balance meeting the needs of most students versus meeting the needs of each student?

12. How practical do you believe it is to understand what each individual student understands about a specific learning goal at any point in time?

13. How often do you attend to the managing and monitoring of student progress?

14. What drives your decisions behind what you expect your students to know and be able to do?

15. What role do standardized tests play in your decisions involving managing and monitoring student learning?

16. How do you go about figuring out why your students do not understand something?

17. What role do students play in the managing and monitoring of their own learning? Of their peers' learning?

18. In education there is a lot of jargon that can mean different things to different people. I believe formative assessment is something that may mean something different to teachers versus administrators versus policymakers. What does formative assessment mean to you?

APPENDIX B

3-D COMPUTER MODULE QUESTIONS

Diffusion Module Questions

1. What is air? Air is a mixture of gases including oxygen, nitrogen, and carbon dioxide.

Choose the correct percentages below.

	0.04%	21%	78%
Oxygen			
Carbon dioxide			
Nitrogen			
Other gases	0.96%		

2. What effect does the concentration difference have on the rate of diffusion of oxygen? (In the computer simulation, there is a data table to the left of this question.)

a. Decreasing the concentration difference increases the rate of diffusion.

b. Changing the concentration difference has little effect on the rate of diffusion.

c. Increasing the concentration difference increases the rate of diffusion.

3. What effect does the diffusion distance have on the rate of diffusion of oxygen?

a. Increasing the diffusion distance decreases the rate of diffusion.

b. Changing the diffusion distance has little effect on the rate of diffusion.

c. Increasing the diffusion distance increases the rate of diffusion.

(In the computer simulation, there is a data table to the left of this question.)

4. When compared to normal, what effect would a shallow concentration gradient have on the rate of diffusion? (In the computer simulation, there is a graph to the left of this question.)

a. Slower

b. No effect

c. Faster

5. What effect does the surface area on the rate of diffusion of oxygen?

(In the computer simulation, there is a data table to the left of this question.)

a. Decreasing the surface area increases the rate of diffusion.

b. Changing the surface area has little effect on the rate of diffusion.

c. Decreasing the surface area decreases the rate of diffusion.

6. Compare the Admission data to the Normal Range and select whether the arterial oxygen level is low, normal, or high.

7. From what you learned in the diffusion manual, what factors could be responsible for the patient's low arterial oxygen?

8. Now compare the concentration difference to determine whether it is low, normal, or high.

9. Then, the students compare each the diffusion distance and the surface area to determine if they are low, normal or high.

10. Do the data you have collected support your hypothesis as to why your patient has hypoxemia? Explain why.

11. Choose the order in which you want administer the treatment options. (Diuretic by injection, Oxygen by nasal prongs, Corticosteroids by nebulizer)

12. Explain why you ranked the treatments this way.

13. Now compare the concentration difference to determine whether it is low, normal, or high.

14. Then, the students compare each the diffusion distance and the surface area to determine if they are low, normal or high.

15. Then, the students compare the arterial blood oxygen level to determine whether it is low, normal, or high.

16. This treatment has increased your patient's arterial blood oxygen. Why? (The students answer this question based on the data that they collected)

17. Now compare the concentration difference to determine whether it is low, normal, or high.

18. Then, the students compare both the diffusion distance and the surface area to determine if they are low, normal or high.

19. Then, the students compare the arterial blood oxygen level to determine whether it is low, normal, or high.

20. This treatment has increased your patient's arterial blood oxygen. Why? (The students answer this question based on the data that they collected)

21. Now compare the concentration difference to determine whether it is low, normal, or high.

22. Then, the students compare both the diffusion distance and the surface area to determine if they are low, normal or high.

23. Then, the students compare the arterial blood oxygen level to determine whether it is low, normal, or high.

24. This treatment has increased you patient's arterial blood oxygen. Why? (The students answer this question based on the data that they collected)

25. Patient's history.

26. Patient's symptoms.

27. Diagnosis.

28. How concentration difference, diffusion distance, and surface area were affected by the treatments?

Osmosis Module Questions

1. Experiment Station

Create a concentration gradient to make oxygen molecules diffuse across the membrane and into the cell.

Outside the cell: 0 30

Inside the cell: 0 30

2. What happens to the concentration of free water molecules if you add salt to a solution? (Increase or Decrease)

3. Predict which way the free water molecules will diffuse? (Out of a cell, Into a cell, or No net diffusion)

4. Predict what would happen to red blood cells if they were placed in:

A) Hypertonic solution (shrink, swell, or stay the same)

B) Isotonic solution (shrink, swell, or stay the same)

C) Hypotonic solution (shrink, swell, or stay the same)

(They are given a picture and a caption that indicates the number of solute molecules and number of free water modules inside and outside of the cell.)

5. In the image, is the blood hypertonic, isotonic or hypotonic compared to the matrix of the brain? (hypertonic, isotonic, or hypotonic) (They show a picture of the brain matrix and the blood vessel showing sodium ions and free water molecules.)

6. Yes, the blood is hypotonic compared to the matrix of the brain. Now, which way will free water molecules move? (from blood to matrix, or from matrix to blood)

7. What will happen to the pressure in the brain if water moves into it from the blood? (increase, decrease, or stay the same)

8. Upload your data below and interpret

Matrix

Sodium (low, normal, high)

Pressure (low, normal, high)

Blood

Sodium (low, normal, high)

Pressure (low, normal, high

Neurons

Firing rate (low, normal, high)

9. Which describes the net free water movement between the blood vessel and the matrix? (into vessel, in equilibrium, out of vessel)

10. Using the sodium data you collected and what you learned from the Seizure Manual, why are the free water molecules diffusing out of the vessel?

11. Why is the pressure in the matrix high?

12. The following list is not in the correct order. The first three events are numbered correctly. Using numbers 4 through 8, label the remaining events in the order that led to Clark's seizures.

___ Net movement of free water into the matrix

_2_ Loss of sodium ions due to diarrhea

_1_ Normal Blood and Matrix Sodium concentrations

___ Abnormal neuron firing rate

___ Increased matrix pressure

___ Seizures

___ Low Blood Sodium Concentration

_3_ Excessive intake of water

13. Choose a diagnosis from these two options:

(Cerebral edema, epilepsy)

14. Explain your decision.

15. Interpret each as higher, lower, or equal to normal blood Na+ concentration.

Isotonic saline (lower, equal, or higher)

Hypotonic saline (lower, equal, or higher)

Hypertonic saline (lower, equal, or higher)

16. Now rank these 3 saline solutions based on free water concentration:

Isotonic saline (lowest, middle, or highest)

Hypotonic saline (lowest, middle, or highest)

Hypertonic saline (lowest, middle, or highest)

17. Based on the data collected and what you have learned about osmosis and the three treatment options, rank the treatments from most effective to least effective.

Isotonic saline (least effective, ….., most effective)

Hypotonic saline (least effective, ….., most effective)

Hypertonic saline (least effective, ….., most effective)

18. You have chosen Hypertonic/Hypotonic Saline. Predict the effects of your treatment on the following:

Blood sodium concentration (decrease, no change, or increase)

Brain matrix pressure (decrease, no change, or increase)

Neuron Firing rate (decrease, no change, or increase)

Net free water movement (into vessel, in equilibrium, or out of vessel)

19. Justify your answer regarding net free water movement.

20. The following list is not in the correct order. Starting with seizures, use numbers 3 through 7 to identify the sequence of events showing how hypertonic saline re-established equilibrium and stopped the seizes in Clark's brain.

___ net movement of free water into vessel

_2_ administer hypertonic saline

___ increase in blood sodium concentration

___ decrease in neuron firing rate

___ decrease in matrix pressure

_1_ seizures

___ seizures stopped

21. Based on what you have learned, summarize the relationship between solute concentrations on opposite sides of a semi-permeable membrane and the direction of movement of free water molecules.

22-26) Case Summary: Now that Clark is ready to go home, you need to write a case summary for the owner. As you write your Case Summary, cover each of the topics in order. You will have an opportunity to review and edit your Summary before submitting the final version.

22. Patient summary.

23. Initial laboratory findings.

24. Treatment goals.

25. How osmosis was involved in causing Clark's seizures?

26. How osmosis was used to stop Clark's seizures?

27. You have chosen Hypertonic/Hypotonic Saline. Predict the effects of your treatment on the following:

Blood sodium concentration (decrease, no change, or increase)

Brain matrix pressure (decrease, no change, or increase)

Neuron Firing rate (decrease, no change, or increase)

Net free water movement (into vessel, in equilibrium, or out of vessel)

Filtration Module Questions

1. Upload and interpret results. For each solute the students indicate whether the solute concentration is low, normal, or high.

Solutes	Normal range	Anthony's level
Urea	10-16 mg/dL	187 mg/dL
Potassium	3-5.5 mmol/L	9.6 mmol/L
Albumin	2.5-3.5 gm/dL	3.2 gm/dL

2. Based on Anthony's history, symptoms and the diagnostic test results, select your final diagnosis. (liver failure, kidney failure, heart failure)

3. Justify your decision below.

4. What needs to change so that only the yellow solutes diffuse across the membrane?

5. What do you predict concentrations will be at 15 seconds? (60/60, 90/30, 30/90). (The students are shown a graphic that indicates at 0 seconds the solute concentration is 120/0, after 5 seconds, the concentration is 90/30, after 10 seconds, the concentration is 60/60.

6. Explain your answer.

7. Adjust the pore size to filter urea and potassium, but not albumin.

8. Upload and interpret data. For each solute the students indicate whether the solute concentration indicates whether you met your goal.

Solutes	Normal range	Before	After dialysis
Urea	10-26 mg/dL	90 mg/dL	45
Potassium	3-5.5 mmol/L	9.6 mmol/L	6.0
Albumin	2.5-3.5 gm.dL	3.2 gm/dL	3.2
Body Mass	180 lbs	185 lbs	183

9. Upload and interpret data. For each solute the students indicate whether the solute concentration indicate whether you met your goal.

Solutes	Normal range	Before	After dialysis
Urea	10-26 mg/dL	90 mg/dL	25
Potassium	3-5.5 mmol/L	9.6 mmol/L	4.5
Albumin	2.5-3.5 gm/dL	3.2 gm/dL	3.2
Body Mass	180 lbs	185 lbs	180

10. (Parallel flow) Then, the simulation graphs the data collected showing the filter regions on the x-axis and the concentration of solutes on the y-axis. The red line indicates urea concentration in the blood and the blue line indicates the urea concentration in dialysate. In which regions of the filter is there a concentration gradient between the blood and dialysate? (Region I, Region II, Region III, Region IV, Region V) The students check all that apply.

11. Now choose which way urea is diffusing by selecting the appropriate arrow icon.

Blood	In this column, arrows point to the left, right, and both ways)	Dialysate
90		0
68		22
45		45
45		45
45		45

12. With parallel flow, diffusion of urea occurred at regions I and II but not at regions III, IV, or V because . . .

a. Urea was too big to go through the pores in regions III, IV, and V.

b. There was no concentration gradient for urea in regions III, IV, or V.

c. There was no urea in the blood in regions III, IV, and V.

d. The pore size was too small in regions III, IV, and V.

13. (Countercurrent flow) Then, the simulation graphs the data collected showing the filter regions on the x-axis and the concentration of solutes on the y-axis. The red line indicates urea concentration in the blood and the blue line indicates the urea concentration in dialysate. In which regions of the filter is there a concentration gradient between the blood and dialysate? (Region I, Region II, Region III, Region IV, Region V) The students check all that apply.

14. Now choose which way urea is diffusing by selecting the appropriate arrow icon.

Blood	In this column, arrows point to the left, right, and both ways)	Dialysate
90		64
74		48
58		32
42		16
26		0

15. With countercurrent flow, diffusion occurred in all regions of the filter. Explain why.

16. As you've determined, urea diffused in all regions of the filter during countercurrent flow. Using what you know about the sizes of urea and potassium, what would potassium do during countercurrent flow?

a. Diffuse in all regions of the filter. (Graph shown from previous screen on parallel and countercurrent flow)

b. Diffuse until equilibrium is reached in regions III, IV and V. (Graph shown from previous screen on parallel and countercurrent flow)

17. Explain your answer.

18. At the end of countercurrent flow, Anthony's mass had decreased to reach his goal. What happened during dialysis to cause the decrease in Anthony's mass?

19. Why did albumin never diffuse into the dialysate? (A graph shows the concentrations of albumin in the blood and the dialysate in all five regions of the filter.)

20-24) Case summary:

20. Patient summary.

21. Treatment goals.

22. How diffusion was involved in reaching goals?

23. How body mass is returned to normal?

24. Why countercurrent flow was better than parallel flow?