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https://doi.org/10.7275/5992226.0 https://scholarworks.umass.edu/dissertations_2/187

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A NOVEL APPROACH TO USING PERSONAL RESPONSE SYSTEMS AND DIAGRAMS TO FOSTER STUDENT ENGAGEMENT IN LARGE LECTURE: CASE STUDY OF INSTRUCTION FOR MODEL-BASED REASONING IN BIOLOGY

A Dissertation Presented

by

JOHANNA M. FITZGERALD

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

DOCTOR OF EDUCATION

September 2014

College of Education

Mathematics, Science and Learning Technologies

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Approved as to style and content by:

_____
John J. Clement, Chair

_____
Randall W. Phillis, Member

_____
Florence Sullivan, Member

_____
Christine B. McCormick, Dean
College of Education

DEDICATION

To my husband and my four children, all beautiful and intelligent and strong people who inspire me every day to be a better person:

John Christopher Fitzgerald

Aileen Maisy Fitzgerald
Carra Louise Fitzgerald
Maeve Clancy Fitzgerald
John Paul Eugene Fitzgerald

To my Fairy Godmother for all her love and support over the years, she is the most giving person I have ever had the privilege to know:

Ruth Pratt

ACKNOWLEDGMENTS

Thank you to my committee: Randall Phillis, Florence Sullivan, and my advisor, John Clement. Especially, Randall Phillis for providing such a rich, fun, and exciting research topic as well as years of support, encouragement, and funding. And John Clement whose patience and guidance every step of the way as well as intellectual discussions and meticulous attention to detail have been a precious gift. This has been an adventure in thinking both inside and outside the box with thanks to the insightful, creative and practical input of all my committee members.

I would also like to thank those who helped me in various ways throughout this journey, from childcare to editing to advice: my husband John C. Fitzgerald; my dear friends, Nicole Bruno, Stacy Senflug, Jenny Potee, and Stephanie Parker; my in-laws Dorothy and Paul Fitzgerald, my father, Jay Pikiell, and my mother, Christine Heard, and my siblings; my colleagues, Norman Price and Zane Barlow. Thank you to Susan Bronstein for many years of encouragement, guidance (at home, work and school), and graduate funding. And a very special thanks to my fairy godparents, Ruth and Leonard Pratt, for all they have done over the years to help me reach this goal.

Finally, I would like to thank all my family and friends for their constant encouragement and support over the years as I studied, read and wrote.

This material is based upon work supported by the U.S. National Science Foundation under Grant DUE-0512725, R. Phillis, Co-PI and N. Stillings, Co-PI; and Grant DRL-1222709, J. Clement, PI. Any opinions, findings, conclusions or recommendations expressed in this work are those of the author and do not necessarily reflect the views of the National Science Foundation.

ABSTRACT

A NOVEL APPROACH TO USING PERSONAL RESPONSE SYSTEMS AND DIAGRAMS TO FOSTER STUDENT ENGAGEMENT IN LARGE LECTURE: CASE STUDY OF INSTRUCTION FOR MODEL-BASED REASONING IN BIOLOGY

SEPTEMBER 2014

JOHANNA M. FITZGERALD, B.S., UNIVERSITY OF MASSACHUSETTS AMHERST

M.S., UNIVERSITY OF MASSACHUSETTS AMHERST

Ed.D. UNIVERSITY OF MASSACHUSETTS AMHERST

Directed by: Professor Emeritus John J. Clement

At UMass Amherst a method of personal response system (clickers) use in large lecture biology called Guided Application of Model-based Reasoning (GAMBR) has been designed to give students experiences in reasoning like expert biologists: In large lecture biology many instructors appear to use clickers mainly as a quizzing and attendance tool. Less well documented and examined are uses of clickers to facilitate cognitive engagement in learning scientific models and skills. In GAMBR, clicker questions ask students to apply and perturb biological models; this is designed to engage them in model-based reasoning. In an attempt to understand such a course, an exploratory case study of GAMBR was conducted to examine and describe three main components: clicker questions design, the hierarchical organization of the course, and student utterances during class-wide discussions. Field notes and course materials served as the primary basis for case study descriptions of hierarchical organization, clicker questions, and for open coding to generate new categories of student talk. A taxonomy of types of student utterances was identified, including utterances that suggested student engagement with the models. An important subset of the latter type suggested model-based reasoning.

Results indicated that 89% of utterances during class-wide discussions following clicker questions suggested engagement with the model, and within those 33% suggested reasoning with the model. Two major types of diagrams were used with clicker questions. Model representation diagrams presented a partial model. Data diagrams presented data related to the model. Other questions had no accompanying diagram. Student talk that suggested engagement in model-based reasoning occurred at a higher frequency when clicker questions were accompanied by a diagram and especially with a model-representation diagram. A hypothesized model of six nested levels of processes in the instructional approach and hypotheses on why GAMBR produced a high percentage of model talk and model-based reasoning talk were generated, grounded in the case study observations of clicker question and course structure. It is suggested that GAMBR contains interesting alternatives to the more commonly used approach of peer instruction in large lecture biology courses using clickers, especially for those interested in promoting scientific reasoning.

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CHAPTER 1

INTRODUCTION

Purpose of Study

The purpose of this study was to examine and describe three of the main components of a large lecture introductory biology course being taught at the University of Massachusetts Amherst: 1) personal response system (a.k.a. clicker) question design, 2) student talk in class-wide discussions, and 3) the course structure design, including instructional phases. This course is taught using an educational approach the instructor calls Guided Application of Model-Based Reasoning in Biology with unusually ambitious learning goals and a novel form of personal response system (clicker question) implementation.

Rationale for Study

Electronic clickers are becoming common tools for supporting student learning in large lecture halls, yet the literature on the development and implementation of questions specifically designed for biology is limited (Kay & LaSage, 2009). In addition, though the literature supports the use of external representations (Gilbert, 2007) and mental modeling (Clement, 2000) in science education, little can be found relating these to clickers use.

Case Study Setting

Imagine a large lecture class filled with students talking, gesturing, and drawing as they reason with models of biological processes, as they learn not only content but

scientific reasoning and process skills. In contrast to taking endless notes and memorizing facts, students are actively debating and mentally testing hypotheses about the biological models, animating the model in their minds to envision the impacts that changes would have on the functionality of the system. Instead of testing students' ability to regurgitate isolated details about seemingly unrelated systems, assessment questions focus on testing the students' ability to choose, use, or revise biological models. The questions are embedded with the key vocabulary and concepts, thereby testing students' content knowledge indirectly.

At the University of Massachusetts Amherst clickers have been used for over 10 years with the goal of generating just such a classroom through an innovative way of thinking about and practicing large introductory biology education. The Guided Application of Model-Based Reasoning in Biology (GAMBR) instructional approach includes specific classroom activities and an expanded set of learning goals that center on learning to reason with biological models like an expert biologist. The approach involves an innovative use of causal diagrams of biological systems in conjunction with clicker-questions that may support internal visualization, potentially expanding clicker use beyond a basic "active-learning" tool to a mental modeling facilitator.

Literature on undergraduate science education has called for instruction methods that promote problem solving skills, critical thinking, and meaningful learning for a diversity of students (Boyer Commission on Educating Undergraduates in the Research University, 1998; Handelsman et al., 2004, 2007; National Research Council, 1999, 2003, 2007; Project Kaleidoscope, 2006), and for clicker questions and approaches that result in "cognitive" engagement (Beatty et al., 2006a, 2006b; Cooper et al., 2006; van Dijk, van

den Berg, & van Keulen, 2001). In addition, the use of internal and external visualizations and model-based instructional approaches to promote the development of correct mental models has been encouraged (Clement, 2000; Gilbert, 2007; Gobert, 2000; Ramirez & Clement, 2008).

Overview of Project

This project examined the clicker questions, student talk, and instructional phases and their relationships, within the unusually ambitious model-based reasoning goals of the GAMBR approach, with special focus on the associated diagrams used with clicker-questions. Qualitative and quantitative research methods were applied to explore and describe the above aspects of the GAMBR approach as well as patterns among these aspects. In the final chapter, the findings are used to develop a hypothesized model of the effect of multiple layers of instructional strategies on student talk in class-wide discussions, and to generate recommendations for instructional practices that may be applicable to other large lecture instructors using or looking to use clickers. The findings may be especially of interest to those instructors seeking to integrate inquiry/process/reasoning-related learning goals into large lectures and to those interested in model-based learning.

CHAPTER 2

REVIEW OF SOME KEY IMPACTS AND ISSUES IN THE EFFECTIVE USE OF CLICKERS IN LARGE-LECTURE BIOLOGY COURSES

This chapter reviews the key benefits and issues in the use of clickers in large lecture halls discussed in clicker-related literature, focusing on biology courses and related fields to provide background and relevance for conducting a case study on the Guided Application of Model-Based Reasoning (GAMBR) instructional approach.

Introduction

The use of clickers has increased rapidly in higher education over the past decade, with numerous colleges and universities currently integrating them (Abrahamson, 2006). However, making the successful transition from traditional lecture to using clickers can be difficult due to the challenge of creating and adapting effective questions and classroom discourse and overall course integration (Feldman & Capobianco, 2003). There now exists a substantial body of literature presenting research and information on the benefits of using clickers in large lecture courses; two main areas of clicker literature examined were: (1) effects of clickers on classroom behaviors and (2) clicker question design and implementation. Literature related directly to biology instruction was the main focus, but related fields were also included to provide a thorough investigation. The chapter ends with a discussion of gaps in the research related to large lecture biology education.

Impacts of Clickers on Classroom Behaviors in Large Lecture Halls

Clicker use in large lecture halls has been demonstrated to have positive impacts on many aspects of students' behaviors in the classroom, including attendance, participation, attention, interaction, discussion, formative assessment, and learning.

Attendance

When clickers are used as a tool to account for students' presence in class, attendance numbers increase (Burnstein & Lederman, 2001; Cain et al., 2009; Caldwell, 2007; El-Rady, 2006; Greer & Heaney, 2004; Preszler, Dawe, Shuster, & Shuster, 2007). However, Greer and Heaney and Barnett (2006) found that when grades were attached to clicker use in attempt to boost attendance, students developed negative attitudes toward clickers. Caldwell (2007) observed that students would bring several clicker units to class to click for friends, something difficult to monitor effectively in large lecture halls.

Participation

When compared to non-clicker classrooms, clicker use has been correlated with higher participation rates in classroom activities (Bullock et al., 2002; Caldwell, 2007; Draper & Brown, 2004; Greer & Heaney, 2004; Jones, Connolly, Gear, & Read, 2001; Mula & Kavanagh, 2009; Siau, Sheng, & Nah, 2006; Stuart, Brown, & Draper, 2004; Uhari, Renko, & Soini, 2003; van Dijk et al., 2001). Jones et al. reported that student participation increased when clickers are used for case studies. Bullock et al. found that participation increased when grades were impacted by students' success on clicker questions. Cheating was, however, again an issue of concern raised by Barnett (2006).

Kay and LaSage (2009) recommend that clickers should be used to provide an "inherent learning incentive" that motivates students to attend and participate, rather than attaching it to student grades.

Attention

Several studies show clicker use is associated with increased student attention during class (Bergtrom, 2006; Burnstein & Lederman, 2001; Caldwell, 2007; d'Inverno, Davis, & White, 2003; Draper & Brown, 2004; Elliott, 2003; Jackson, Ganger, Bridge, & Ginsburg, 2005; Jones et al., 2001; Latessa & Mouw, 2005; Siau et al., 2006; Slain, Abate, Hidges, Stamatakis, & Wolak, 2004). However, Kay and LaSage (2009) note that no direct link has been made between increased attentions associated with clicker use and learning performance. However, there is evidence that students have difficulty paying attention for longer than 20 minutes during a class session (d'Inverno et al., 2003; Jackson et al., 2005) and Kay and LaSage hypothesize that presenting clicker- questions every 20 minutes during a lesson could enable students to concentrate throughout the entire lesson by "requiring students to shift their attention and actively participate in the learning process" (p. 8).

Interaction

Frequent and constructive student interactions were reported to occur with clicker use in many studies (Beatty, 2004; Bergtrom, 2006; Caldwell, 2007; Elliott, 2003; Freeman, Bell, Comerton-Forder, Pickering, & Blayney, 2007; Kennedy, Cutts, & Draper, 2006; Sharma, Khachan, Chan, & O'Byrne, 2005; Siau et al., 2006; Slain et al.,

2004; Stuart et al., 2004; Trees & Jackson, 2007). Positive student interactions were measured in several ways: articulation of student thinking (Beatty, 2004), number of probing questions and enhanced focus on student needs (Beatty, 2004; Siau et al., 2006), useful peer-to-peer discussions (Bergtrom, 2006; Caldwell, 2007; Kennedy et al., 2006), and active learning (Elliott, 2003; Kennedy et al., 2006; Slain et al., 2004; Stuart et al., 2004). Student interactions, however, likely vary greatly depending on the design and implementation of clicker questions, yet no studies were found comparing student interactions under different clicker environments (always clicker versus traditional or comparisons of slight modifications of clicker use).

Discussion

Students report being more engaged in concepts and discussions when clickers are used (Bergtrom, 2006; Preszler et al., 2007; Simpson & Oliver, 2007). However, studies have raised concerns about the effectiveness of classroom discussions following clicker questions. For example, Nicol and Boyle (2003) found that some students dominated groups discussions, leaving others feeling rushed to accept an answer they did not completely understand, resulting in many students preferring to think about questions themselves prior to working on them with their peers. d'Inverno et al. (2003) suggests that clicker class discussion approaches be applied in small classes rather than in large classes. Other problems with group and class discussions surrounding clicker questions have been reported, such as different students' viewpoints increasing confusion (Nicol & Boyle, 2003; Reay, Bao, Li, Warnakulasooriya, & Baugh, 2005), feelings of distraction (Draper & Brown, 2004), and intimidation and anxiety (Nicol & Boyle, 2003). Kay and

LaSage (2009) call for more research about creating effective group and class discussions that are "focused, non-threatening, and efficient" (p. 9).

Formative Assessment

Asking and answering questions can help students to fill gaps in their understanding and focus attention on important components of the material being presented (Otero & Graesser, 2001). Feedback can help scaffold learning, provide motivation, and reinforce information (Sales, 1988). Freeman et al. (2007) suggests that the formative assessment that students receive from clickers provides a motivation to study by acting as a warning to students of how much preparation they need before class and exams. Many studies show that clickers provide effective formative assessment for both students and instructors (Beatty, 2004; Bergtrom, 2006; Brewer, 2004; Bullock et al., 2002; Caldwell, 2007; Draper & Brown, 2004; Dufresne & Gerace, 2004; Elliott, 2003; Greer & Heaney, 2004; Hatch, Jensen, & Moore, 2005; Jackson et al., 2005; Siau et al, 2006; Simpson & Oliver, 2007; Stuart et al., 2004). However, Abrahamson (2006) suggests that an instructor's skill at immediately addressing student problems and misconceptions significantly impacts the success of clickers as a formative assessment tool.

Learning

Though there is evidence that clickers motivate students and increase all around satisfaction, evidence varies on the success of clickers in learning outcomes (Judson & Sawada, 2002). Successful learning outcomes are likely greatly dependent on the

question design and format of use. For example, studies using clickers in conjunction with active learning strategies appear to be more consistently successful (Caldwell, 2007; Duncan, 2005; Freeman et al., 2007; Judson & Sawada, 2002).

Generating Clicker Questions and Lessons

Information about how to structure clicker use varies between studies, based on the implementation goals and field of study. Further, a lack of direct comparisons between clicker approaches makes it difficult to determine which question design and implementation formats are most effective and why (Kay & LaSage, 2009). This may make designing one's own questions or selecting which ones to use from an existing question bank and implementing them a daunting task for instructors considering using clickers in their classroom. In addition, there are common concerns about decreased content coverage compared to traditional lecture format (Beatty, 2004; Beatty et al., 2006b; Burnstein & Lederman, 2006; Caldwell, 2007; d'Inverno et al., 2003; Burton, 2006; Cutts, 2006; Draper & Brown, 2004; Fagan, Crouch, & Mazur, 2002; Freeman et al., 2007; Hatch et al., 2005; Sharma et al., 2005; Siau et al., 2006; Slain et al., 2004; Steinert & Snell, 1999; Stuart et al., 2004).

Question Banks

There are an ever-increasing number of ready-made question sets (for examples see: A2L Library, 2008; Chemistry Concept Tests, 2008; Cornell Mathematics Database, 2008; Mazur, 1997). Caldwell (2007) found that the majority of clicker question collections were based in Physics. There are several online, open access sources to

biology clicker questions covering various topics and ranging in difficulty, for examples see Science Education Initiative, University of Colorado (n.d.) that provide an extensive setup of course curricula including clicker questions. These include introductory molecular and cellular biology materials and Study Blue, University of Washington (2014) that again provide course materials including clicker questions. In addition, several textbooks now provide clicker questions for life science classes.

However, many clicker questions remain focused on assessing student knowledge of taught information and are different from those described by Beatty et al. (2006a, 2006b) who uses them to help drive instruction rather than break up lecture with periods of active engagement. One key exception in biology is the use of clickers to support case study teaching approaches, and some example case studies with clicker questions can be found at the National Center for Case Study Teaching in Science (2014) website.

Despite the increasing number of existing clicker questions available to instructors, it is important to keep in mind Beatty et al.'s (2006a) comment that it is difficult to use preexisting questions if you do not understand the goals and logic behind their design. Walvoord and Hoefnagel (2011) reiterate this stating, "Many publications provide tips, guidelines, and best practices [for clicker question design], but there is no substitute for practice and experience when it comes to writing questions that promote and assess higher order learning" (p. 183).

Question Design

The process of generating effective clicker questions is challenging and time consuming (Allen & Tanner, 2005; Boyle, 2006), and there is a need for more information about question preparation strategies (Kay & LaSage, 2009). Dangel and Wang (2008) calls question design one of the "biggest challenge[s]" in effectively implementing student response systems (p. 101). Various recommendations have been made to face this challenge, such as the importance of having clear pedagogical goals (Beatty, 2004; Beatty et al., 2006a; Caldwell, 2007; Poulis, Massen, Robens, & Gilbert, 1998) and carefully planning out lessons (Allen & Tanner, 2005; Beatty, 2004; Beatty et al., 2006b; Caldwell, 2007; McCabe, 2006; Poulis et al., 1998). Woods and Chui (2003) provide suggestions about possible question types, but the recommendations are very board, and not specific to biology.

Walvoord and Marielle (2011) provide ideas on how to convert old questions into clicker questions, as well as how to write new ones using Crowe, Dirks, and Wenderoth's (2008) Blooming Biology Tool, which helps to rate questions for knowledge, comprehension, application, analysis, synthesis, and evaluation. They, as well as others (Beatty et al., 2006a; Skinner, 2009), point out that it is important to identify the goal of the questions before attempting to use or design them. And they list several possible goals, including fact/concept check, apply course material in a novel situation, peer instruction, promote discussion among students, and collect student opinions. They mention that Skinner encourages that questions should be designed not only to address content goals but process goals, as well as metacognitve goals. Further, they provide a list of online websites that aim to support development of multiple-choice questions.

Beatty et al. (2006a) discuss in detail how to develop clicker questions meant to "target the development of cognitive skills, analysis, and problem solving ability, and productive student metacognition about physics, learning, and thinking" (p. 31). Their 2006 article on question design provides four makeovers of physics problems as examples of how a typical summative multiple choice assessment item could be transformed into a successful clicker question. *Audience Response Systems in Higher Education: Applications and Cases* (Banks, 2006) contains an array of case studies discussing question design and implementation, but they are not specific to biology. Additional recommendations on clicker use embedded in the literature include spontaneous question use (Stuart et al., 1998), continual refinement (McCabe, 2006), and development of distinct question types for different subject topics (Kay & LaSage, 2009).

Instructional Approaches

Many of the studies reporting successful impacts on student behaviors (e.g., increased attendance and participation) do not provide in-depth details on the question design and implementation. However, Peer Instruction[1] (PI) was mentioned frequently in the literature. Question Driven Instruction (QDI) was also a prominent instructional method, though there were no studies where QDI was used in biology[2]. I will discuss QDI here, though, because it is one of the more well known innovative approaches to clicker use and was the bases for the Guided Application of Model-Based Reasoning instructional approach on which this case study was conducted.

[1] For a discussion of PI, see Crouch and Mazur, 2001 and Mazur, 1997; for examples of studies using PI specific to biology, see Argamberuster, Patel, Johnson, and Weiss, 2009; Brewer, 2004; Crossgrove and Curran, 2008; Knight and Wood, 2005; Preszler et al., 2007; Suchman, Uchiyama, Smith, and Bender, 2006.

[2] For a discussion of QDI, see Beatty et al., 2006b.

Peer Instruction (PI)

PI involves posting a clicker question to which students respond individually, and then, if a majority of the students answer incorrectly, reposting the question and allowing for peer-discussion (Mazur, 1997). During peer-discussion, students' talk with their peers about the clicker question in either pre-assigned or self-created groups. The lecture remains a main part of instruction in classrooms where PI is used, and the clicker questions are aimed at checking and correcting student understanding of specific concepts. Class discussion (if present) appears to be aimed at fielding clarification questions. PI appeared frequently in the clicker literature as the method of clicker implementation used in large lecture biology and physics courses.

Question Driven Instruction

As stated above, QDI did not appear in the clicker literature as an approach used in large lecture biology courses. QDI involves an instructional cycle of clicker question, peer-discussion, displaying of class-histogram, class discussion, mini-lecture, and finally a new question (Beatty et al., 2006b). Clicker questions are the core-learning component of QDI classrooms, driving the direction of instruction by informing the instructor of what the students need support in and allowing him/her to re-arrange and generate questions on the fly in response (termed *agile teaching* by Beatty et al., 2006b, p. 4). Lecture time is vastly decreased and used to introduce and sum up concepts applied in the clicker questions (Beatty et al., 2006b). In addition to checking for student understanding, QDI questions aim to engage students in problem solving and discussion. The success of QDI in physics is well documented, and Beatty et al. provide detailed recommendations

about how to implement the cycle and design questions (e.g., average number of questions per class, average time per question, pre-class preparation).

Clicker Use in Large-Lecture Biology Courses

Both QDI and PI were developed originally for use in physics, and the literature on question design and application for biology, though present, is more limited than physics (Caldwell, 2007). Studies of clickers being used to apply methods, such as PI, in biology and biology-related courses reliably reported improved motivation and consistent or improved performance on content-based assessments (for examples of use with PI, see Argambruster et al., 2009; Brewer, 2004; Crossgrove & Curran, 2008; Knight & Wood, 2005; Preszler et al., 2007; Suchman, Uchiyama, Smith, & Bender, 2006). Other variations of clicker use were also presented in biology literature, such as Team-Based-Learning (Carmichael, 2009) and case studies (Brickman, 2005; Herreid, 2006). However, much of the literature on clicker use in biology courses focused on reporting successful impacts on students and contained only a brief statement of the instructional method used, with few or no examples of questions and details about implementation.

The barriers that most instructors face/fear in facilitating discussions in large lectures and approaches for overcoming them are presented. However, question design is not addressed. The studies reporting on large lecture biology clicker use tend to measure effectiveness of increased motivation and success on content-based assessments. Changes in students' scientific skills (e.g., reasoning, creativity, articulation) nor overall understanding of the process of science were not assessed in any of the biology articles found. Knight, Wise, and Southard (2013) also focuses on student discussions and

approaches to increasing student talk around their reason behind an answer versus focusing on only the answer.

Use of clickers with case study teaching has been increasing and as stated above, examples of clicker questions that can be used with case studies are presented on the National Center for Case Study Teaching in Science (2014). It is important to note that there were non-clicker-based approaches to large lecture biology education that reported success at impacting the way students think about biology as a whole. Problem-Based Learning (PBL) has become popular in medical education (Donham, Schmieg, & Allen, 2001; Shipman & Duch, 2001), though this has been implemented with clickers as well. Cooper, Hanmer, & Cerbin (2006) describe the use of Problem-Solving Modules, in which teams of students work in iterative cycles to generate phylogenetic trees based on information provided by the instructors at set intervals. Random samples of group work is collected, projected for the class to see, and critiqued by the instructor at each interval. Another example, though again not reported to be widely used, is Workshop Biology (Udovic, Morris, Dickman, Postlethwait, & Wetherwax, 2002). In this approach, a science-as-inquiry theme is integrated throughout the curriculum and beyond biological content, the goals of Workshop Biology include discussion making and an appreciation for science.

However, Segura (2013) used a mixed methods approach to investigate differences between clicker-based classes and traditional classes to examine academic performance, affective learning, student intellectual stimulation, revised learning indicator, and connected classroom climate, and revealed no significant difference among these variables. Further, the main benefits perceived by participants in the study were

faster quizzes and immediate feedback, and drawbacks included limited question formats and the inability to review questions/answers. This study supports the need to expand the existing literature on innovative clicker uses if the hope is to have the technology support more advanced learning.

Summary and Concluding Remarks on Clicker Literature as it Relates to Large-Lecture Biology Education

Existing clicker question banks are not necessarily optimal for more ambitious objectives because they have been designed specifically to support particular approaches to clicker use that aim for traditional learning goals (Beatty et al., 2006b). While the literature on clicker use now spans many fields (Kay & LaSage, 2009), a majority of the literature presents information on the impacts of clicker use, but neither specific suggestions for clicker question design nor how to use them to foster or expand classroom learning tends to be addressed. The literature put forth by the Scientific Reasoning Research Institute (SRRI) at the University of Massachusetts Amherst (the literature associated with QDI) is an exception in that it discusses approaches to question design and implementation aimed at engaging students in higher-order metacognitive learning in great detail. However, this body of literature is based in physics education, and though it states it is applicable to other subjects, examples of clear models on how to do so were not found for biology. Walvoord and Marielle (2011) provide ideas for clicker question design for biology based in Blooms Taxonomy, but the literature is otherwise limited. Thus, I found though there are many existing biology clicker questions available on the web and via textbooks, support is limited for instructors starting out with clickers

in biology to design or adapt their own questions, especially if their goals extend beyond increase attendance, participation, and checking for understanding of lectured material.

Perhaps as a result of this lack of support, I found the bulk of the literature on using clickers to reform biology courses remains focused on increasing student motivation and performance on traditional, content-based assessments (for examples, see Arambruster et al., 2009; Brewer, 2004; Crossgrove & Curran, 2008; Knight & Wood, 2005; Preszler et al., 2007; Suchman, 2006). As stated above, there are few ideas about using clickers to change the way students think about biology and assess alternative learning goals, such as scientific reasoning. However, there are appeals for clicker questions and approaches that result in cognitive engagement (Beatty et al., 2006a, 2006b; Cooper, 2006; van Dijk et al., 2001). Though some clicker questions may be aiming and achieving higher cognitive engagement, they do not seem to be impacting the learning goals or content structure, with perhaps a few exceptions, such as using clickers with case studies.

Existing literature, not directly related to the use of clickers, provides insight into how questions can be designed and used to support learning and instruction beyond traditional learning goals. Meltzer (2006) states that instruction should focus on understanding student comprehension to identify knowledge gaps, potential building blocks, and further, it should push students to reason with the information to better their understanding. Sense-making activities, such as interpreting data, making predictions, and explaining phenomena to help students develop a deeper understanding of content knowledge, are called for by both Perkins (1998) and Chi, de Leuw, Chiu, & LaVancher. (1994). Dangel and Wang (2008) suggest that the goal should be to create questions that

"address deep learning and include response options that provide diagnostic information about students' thinking and reasoning" (p. 102).

Thus, though clickers have been shown to be an effective tool for enhancing the classroom environment through increasing positive student behaviors, the ability of the technology on its own to truly change the learning goals of large lecture biology courses is limited. This is because there is a gap between the theoretical potential of question design for optimal and deeply cognitive student learning and the available guidelines for how to design and implement such questions for use with clickers in large lecture biology courses.

I believe this gap is present partly because biology education has not historically been approached as a problem solving science in the classroom; memorization of vocabulary and concepts has been the primary focus, thus limiting most existing clicker question banks to fact checking, content driven learning tools. However, as with all sciences, scientific models in biology are the result of, and driving force behind, scientific inquiry (for relevant research, see e.g., Cartier, 2000; Cartier, Rudolph, & Stewart, 2002; Gobert, 2000; Gobert, Snyder, & Houghton, 2002; Lawson et al., 2000; Michael et al., 2002; Modell, 2000; Raghavan, Sartoris, & Glaser, 1998). Model- and inquiry-based educational approaches have been developed and tested, but a majority of previous research has focused on k-12 education. Thereby, the approaches are inherently designed for small classrooms, requiring interactions that would be difficult to achieve in large lecture halls (for examples, see Buckley, 2000; Raghavan, Sartoris, & Zimmerman, 2002; Tsai & Chang, 2005). There are several challenges to the implementation of such instructional methods (for more, see Smith et al., 2005).

By making reasoning with scientific models the core-learning objective in a large lecture biology course and using clicker questions as tools to get students to actively master the biological concepts, students can engage in scientific investigation rather than memorize relatively isolated facts. As a result, students may begin to think of biology as an active body of theory that continues to evolve and that they can contribute to. A case study of the GAMBR instructional approach presents the opportunity to explore a model of clicker-based instruction that embraces such advanced learning objectives in a large lecture biology setting. Such exploratory research could reveal patterns in student behaviors, instructional modes, and clicker questions with theoretical and/or instructional implications, ultimately, providing support for further research into using clickers to engage students not only in content but in scientific modeling and inquiry in large lecture biology courses.

CHAPTER 3

REVIEW OF SOME KEY ISSUES IN THE EFFECTIVE USE OF STATIC DIAGRAMS IN SCIENCE TEACHING

This chapter reviews key issues in the effective use of diagrams in science teaching and related fields to provide background and relevance for focusing on the diagrams used in the Guided Application of Model-Based Reasoning (GAMBR) instructional approach.

Introduction

Research on mental modeling has revealed the important role of both internal and external visualizations (Gilbert, 2007) and cognitive research on how students process information has lead to various theories about how external representations can best support the generation and correction of internal visualizations (for example, duel-coding theory [Clark & Paivio 1991]; cognitive load theory [Sweller & Chandler, 1994]; generative theory [Wittrock 1974, 1989]; multimedia learning theory [Mayer, Bove, Bryman, Mars, & Tapangco,1996]). In keeping with what is known about active learning and constructivist theory, research has shown that students need to be actively engaged with these visual aids to optimize their impact (Chan & Black, 2006; Eysink, Dijkstra, & Kuper, 2002; Mayer, 2002; Mayer & Moreno, 2002). The drive of design effective media-based instruction is becoming more prominent as the role of internal and external visualizations in learning science becomes more apparent (Gilbert, 2007). Many interactive animations and simulations have been developed; unfortunately, the use of such technologies in large lecture halls is limited by the fact that most classrooms are not

equipped with the necessary technology or seating configuration for students to interact in work groups with computer-based models/simulations.

For this reason, it seems prudent to examine innovative teaching methods that use non-computerized visual representations in large lecture halls. To explore this idea, research on the use of static diagrams in science instruction was reviewed, with some reference to the use of diagram drawing, animations, and simulations as a way to build a perspective for looking at the effective use of static diagrams. Some relevant studies on math and computer science education were examined to make the review more complete.

Research on Static Diagrams

Diagrams facilitate the reorganization of information and make implicit information explicit, revealing interactions that are not obvious in text (Hayes, 1978; Larkin & Simon, 1987). Diagrams can decrease cognitive load by holding information, freeing up space in the working memory. Research on static diagrams can be broken down into two large categories: diagram drawing and use of provided diagrams. Researchers have also examined the use of diagrams by scientists and novices to help establish guidelines for the use of diagrams in science education.

Diagram Drawing: Learning Benefits and Instructional Techniques

Drawing diagrams is a commonly recommended problem solving strategy. Educational research has focused on how the use of diagram drawing improves student problem solving skills, memory, and transfer and provides products for teacher assessment.

Studies show that there are many educational advantages of engaging students in diagram drawing activities. Students tend to use diagrams when they experience high cognitive load, such as when working on challenging problems (Corter & Zahner, 2007). However, this strategy is not always successful because students do not necessarily have enough diagramming skills to generate and apply a useful representation of the problem (Diezmann 1995, 2002; van Essen & Hamaker, 1990). Instructional methods that demonstrate and engage students in proper diagramming can increase use of the strategy for problem solving (Diezmann 1995, 2002; Uesaka, Manalo, & Ichikawa, 2007). Diagramming can also have broader uses as learning tools to increase understanding and retention of material (Gobert & Clement, 1999). This effect can be deepened by cyclical diagram drawing tasks where students draw, analyze, and revise, resulting in the building of robust mental models and providing an effective method for teachers to assess students' mental models (Gobert, 2000). Thus, there is some evidence that diagram drawing can support the generation of mental models resulting in better learning expressed in problem solving ability and understanding.

Provided Static Diagrams: Learning Benefits and Instructional Techniques

Investigations of the role of provided static diagrams in problem solving and learning have also been conducted. Various studies have shown that presenting diagrams and text versus text alone can increase retention and understanding. Other conditions for effective diagram use have also been suggested.

Studies looking at the use of presented static diagrams suggest that diagrams are useful learning and problem solving tools. Under particular conditions (appropriate text,

test, and learners), explanative illustrations (ones that help students visualize the scientific process) were shown to enhance learning (Mayer & Gallini, 1990). In the same way, they help in problem solving by setting up the initial base for the information and facilitate mental animation (Bauer & Johnson-Laird, 1993; Hegarty, 1992). The diagram helps one to mentally organize the information in the text correctly and efficiently, and the text helps one to use the diagram by providing information that extends beyond the diagram's limits. Combining diagrams and text can help students retain and transfer scientific information (Mayer, 1993; Mayer et al., 1996; Mayer, Steinhoff, Bower, & Mars, 1995). These findings could be explained by a theory presented by Novak (1995) that when text and diagram are presented together, the learner needs to connect/integrate the diagram and text mentally. This required process of integration forces the student to actively engage in the material.

Presenting students both text and diagram may also help because it provides them with multiple representations of the same material, increasing the available knowledge they have about the topic to work with (Schultz & Waters, 2000). By increasing the ways in which information is presented to students, we can increase their exposure to the information and their flexibility with the material (Schultz & Waters, 2000). Students learn better via different pathways and by increasing the available modes of information (Schultz & Waters, 2000). A wider variety students with different learning styles can have an equal chance at learning the material. In the later discussions of animations and simulations, it is important to consider that though the representation modes are often compared for effectiveness, it is also important to consider the advantages of using them in conjunction with each other.

Similarly, it could be that working with a static diagram to solve problems improves learning because students need to mentally animate the model, which facilitates the generation, correction, and retention of a mental model (Gilbert, 2007). Therefore, it might be advantageous to incorporate problem solving into use of representational diagrams in education because it not only helps the students build an initial mental model; it facilitates the correction of errors in that model by requiring the students to test the model through mental animation to solve the problem. It should be cautioned, however, that students might mentally animate the model incorrectly while engaging in these activities even when using a diagram.

Difficulties with Static Diagram Use

Despite the apparent benefits of including diagrams in educational materials, research has also revealed several issues students encounter when attempting to use or interpret diagrams.

Studies have also revealed issues with using diagrams for educational purposes, such as issues around transfer and expertise and prior knowledge. Students have trouble understanding the difference between a scientific model and a representation of that model (Cartier et al., 2002), connecting and using different diagrammatic representations (Kindfield, 1994), and understanding the relationship between diagrams and the scientific models they represent (Cartier et al., 2002). Also the student's success with diagrams is highly dependent on the level of the student and the complexity of the diagram. More novice students have difficulty working with complex diagrams, and more expert students reap little to no benefit from simpler diagrams (Butcher, 2006). Even specific

instruction on diagram use can fail to result in successful problem solving (Thomas, Ratcliffe, & Thomasson, 2004).

Guidelines for Static Diagram Use

Sets of guidelines for diagram use generated by Kindfield (1994) and Kozma, Chin, Russell, and Marx (2000) were also looked at. Both sets suggest that students do something with the diagrams (e.g., practice diagram-dependent reasoning and use diagrams as tools to run and analyze experiments). Butcher (2006) recommends that diagrams should be designed specifically for the level of the students intended to use them. However, the use of diagrams has been mostly superficial, playing a passive role in the learning process (Gobert, 2000). Similarly, Mayer's 1993 study of textbook diagrams resulted in the conclusion that the potential power of graphics was not being utilized to its fullest. Thomas et al. (2004) recommend designing an effective instructional method for teaching students how to use diagrams for problem solving. Studies of diagram use in the classroom setting suggest that there are specific actions of the instructor and students that make diagram use more effective (Marquez, Izquierdo, & Espinet, 2006; Useaka et al., 2007) that might help to develop more specific instructional guidelines for developing effective diagram use in students.

Use of Static Diagram Compared to Computerized Visualization Tools

Overall, the research on the use of animations and computer simulations versus static diagrams reveals a common trend. Tversky, Morrison, and Betrancourt (2002) conducted a review of studies comparing animations to static diagrams. They concluded

that in studies where animations were found to be more effective than static diagrams, students were actively interacting with the animation. However, they point out that these same studies consistently failed to test the diagrams under the same interactive learning conditions. Studies comparing the use of simulations and static diagrams by Lowe (1999) and Chan and Black (2006) support this trend. Similarly, in studies reviewed where animations and diagrams were compared without the advantages of interactivity on behalf of the animation, no learning differences were found (Hegarty, Naravana & Freitas, 2002; Mayer et al., 2005; Mayer, 1993; Narayanan & Hegarty, 2000).

Research suggests that not only should animations be interactive but also that the interactions need to be specific in order for the animations to outperform static diagram use (Eysink et al., 2001, 2002). Narayanan and Hegarty (2000) and Hegarty et al. (2002) developed five stages of comprehension on which they felt multimedia design should be based and without which they found diagrams to outperform animations as learning tools because the animations did not engage students in ways that promoted learning. Similarly, Mayer (2002) developed a set of guidelines for the use and design of multimedia that included an interactivity principle, which stated that students should have some control over the media.

Computer simulation studies comparing simulations to diagrams have similar issues as animation research. For example, White (1993) found that classes that used a simulation out-performed classes that used static diagrams. However, the structure of the instruction in the classrooms varied; the class that used the simulation was run in an inquiry-based style, while the other class experienced a more traditional approach. Steinberg's (2000) comparison of simulations and diagrams showed no difference

between the two methods on post-tests, which they attributed to lack of active engagement with the simulation. However, observations of the students suggested that individuals who did actively engage with the simulation considered more complex problems. Lowe (1999) observed that not only was interactivity key but what the students were interacting with, stating that simulations have to be carefully designed to engage students with the important aspects of the program, to prevent them from spending time focusing on less relevant components. This was similar to Eysink et al. (2001, 2002) conclusions about animation use. Pea, De Corte, Linn, Mandl, and Verschaffel (1992) made the point that both the internal and external learning conditions are important for the successful use of simulations, stating that the goal of computer tools is to enhance students' sense-making capabilities and learning conversations and that both the simulation and the learning conditions under which it is used are important to consider when designing and testing.

Based on the literature reviewed, there are many factors that play into successful educational media, including the learning environment. Tversky et al. (2002) suggested that the main benefit of animations over diagrams is their interactivity. I suggest that the nature of interactivity with which the tools are engaging students impacts the potential benefit they may have.

I feel that more research needs to be focused on how media are being incorporated into the dynamics of the classroom rather than on just the impacts of visual aids used in sterile environments. In this way, instructors in classrooms with and without access to computers could be able to better use external visualizations to support students' internal visualization, thus enhancing students learning experience.

Concluding Remarks

Research has indicated that active engagement with material promotes effective absorption and integration of the material by the students. This is thought to be part of the advantage of using diagrams in conjunction with text to facilitate learning; students are required to integrate the text and diagram and, thereby, actively engage the material (Mayer, 2002). However, the introduction of the computer into science education has created many alternatives to the static diagrammatic representations of old. These new options have raised questions about the effectiveness of static diagrams as learning tools, mainly: Are they equal in educational power to more advanced technologies, such as animations and simulations?

Research comparing computerized visualization tools and diagrams has had mixed results, which depends mostly on the design of the experiments used to test them. While these tools are supposed to be more engaging and interesting because they are dynamic, students can be more passive in their interaction with them, resulting in information not being retained by the students (Lowe, 1999). Guidelines for effective design and use of media share the common themes that are recommended for diagrams: encouraging and requiring active engagement with the material.

The current research on both diagramming and supplied diagrams has influenced the development of educational technology, which has sought to further enhance their benefits. Yet, the protocols do not require participants to interact with a comparable static image or set of images in the same way that the computer simulation or animation does. Though this might seem the point, which is that it is hoped such visualization tools will have the potential to support student engagement better than static diagrams, as stated

previously, there are some educational environments in which computerized representation tools cannot be easily applied (e.g., large lecture halls). Guidelines for science education suggest the integration of tools that allow students to build images and models, indicating that the external and internal construction of one's own visualizations can play an important role in learning, as can components that engage students in interacting with the media (Gilbert, 2007). There appears to be a gap in the understanding of the potential role of static diagrams in constructivist-based learning environments, and it seems, therefore, important to revisit the roll of static diagrams in classrooms as they change from transmissionist-type teaching spaces. Static diagrams can, and are, used in a more constructivist manner in some classrooms; examining such uses of static diagrams that more closely mirror the interactivity students engage in during the use of an interactive animation or simulation might help to facilitate learning in non-computerized learning settings.

Kozma (1994) called for a change in multimedia research focus from "Do media influence learning?" to "In what ways can we use the capabilities of media to influence learning for particular students, tasks, and situations?" and stated that in doing so "we will both advance the development of our field and contribute to the restructuring of schools and the improvement of education and training" (p. 7). I concur with this approach and feel that more research needs to be focused on how media are being incorporated into the dynamics of the classroom rather than just on the qualities of visual aids used in a sterile environment.

Summary of Visual Aid Literature Review as it Relates to Large Lecture Biology Courses

The use of diagrams in science education has been shown to support learning in several ways. Diagrams facilitate the reorganization of information and make implicit information explicit, revealing interactions that are not obvious in text (Hayes, 1978; Larkin & Simon, 1987). Diagrams can decrease cognitive load by holding information, thus, freeing up working memory (Bauer & Johnson-Laird, 1993). Under particular conditions (appropriate text, test, and learners), explanative illustrations (ones that help students visualize the scientific process) enhance learning (Mayer & Gallini, 1990). Combining diagrams and text can help students retain and transfer scientific information (Mayer, 1993; Mayer et al., 1996; Mayer et al., 1995). Presenting students diagrams in conjunction with text provides multiple representations of the same material, increasing the available knowledge, exposure and flexibility of the topic, and supports visual learners.

Beyond traditional learning goals, there is increased focus on the students' mental models in science education research (Clement, 2000), which the use of diagrams may support. Scientific reasoning is a cognitive process that involves internal visualizations, including mental simulations and animations; external visualizations, such as diagrams and computer simulations can support internal visualizations (Gilbert, 2007). In addition, presenting diagrams may enhance the development of correct student mental models by representing the scientific model information in a way that it is hoped students will mentally organize it (Gilbert, 2007). Diagrams can also help set up the initial base for information in problem solving and facilitate mental animation (Bauer & Johnson-Laird, 1993; Hegarty, 1992).

Sets of guidelines for diagram use in science education have been generated by Kindfield (1994) and Kozma, Chin, Russell, and Marx (2000). In addition, Marx (2000) suggests that students do something with the diagrams (e.g., practice diagram-dependent reasoning, use diagrams as tools to run and analyze experiments). However, the use of diagrams has been mostly superficial, playing a passive role in the learning process (Gobert, 2000). Thomas et al. (2004) recommend designing an effective instructional method for teaching students how to use diagrams for problem solving. Studies of diagram use in the classroom setting suggest that there are specific actions of the instructor and students that make diagram use more effective (Marquez et al., 2006; Useaka et al., 2007).

Research on computerized tools has found that student interactivity with the external representation is the key factor for increased learning outcomes over diagram use (Chan & Black, 2006; Hegarty, et al., 2005; Hegarty et al., 2002; Lowe; 1999; Mayer, 1993, 2001; Narayanan & Hegarty, 2000; Steinberg; 2000; Tversky et al., 2002; for simulations, White, 1993). Research suggests that not only should students interact with representations but that the interactions need to be specific (Eysink et al., 2001, 2002).

However, there is a gap in the literature with regard to the use of external visualizations in large lecture courses, especially in an interactive setting, making research aiming to provide guidelines and/or theoretical models for the use of diagrams in conjunction with PRS questions a needed endeavor. The GAMBR approach uses diagrams in conjunction with the PRS questions to support instruction. Preliminary research on the use of diagrams in the GAMBR approach suggests that students are interacting with the diagrams in ways that support learning (see Chapter 5). A more in-

depth exploration of GAMBR could lead to theories and instructional implications for the use of diagrams in large lecture biology courses to support instruction and learning.

CHAPTER 4

GUIDED APPLICATION OF MODEL-BASED REASONING: DESCRIPTION AND OVERVIEW OF PREVIOUS LITERATURE AND RESEARCH

This chapter gives an initial description of Guided Application of Model-Based Reasoning in Biology (GAMBR) and summarizes pervious literature and initial research that has been conducted on this instructional approach to provide further rationale for using it as a case study subject.

Introduction

Many of the existing model-based instructional approaches for biology were developed for k-12 (for examples see Buckley, 2000; Raghavan et al., 1998; Tsai & Chang, 2005). GAMBR differs from these curricula in that it is geared for undergraduates in large-lecture classrooms and uses clickers as an integral part of the classroom structure.

GAMBR was derived as part of a project to reform the lecture portion of the introductory biology course at the University of Massachusetts Amherst. It began as an attempt to implement the use of clickers and was originally modeled after Question Driven Instruction (QDI). Over the years, GAMBR has become its own method of large lecture biology instruction that goes beyond just having students use clickers in the format of QDI.

The primary instructor received a grant from the National Science Foundation (NSF) for the assessment and development of clicker questions based on the GAMBR approach. The proposal for this grant describes some of the key aspects of GAMBR that

make it different from other large lecture biology courses, including topical learning cycles, closely linked formative and summative assessments, and model-based reasoning learning objectives. A pre-/post-test suggested that students generate more hypotheses about the impacts of a drug on a novel model at the beginning versus at the end of the semester. Preliminary analysis suggests that the hypotheses students presented at the end of the semester tended to include more model components further down the causal chain from the mechanism that the drug is reported to act on in the question prompt. Preliminary research in the form of a Likert survey on the use of diagrams in the classroom suggest that students engage with the diagrams in ways suggestive of mental modeling.

This chapter describes some major features of the course that have been defined by the instructor, summarizes the descriptions of GAMBR provided in the grant proposal and the previous research on hypotheses generation and diagram use. The final discussion provides support for this approach as a case study based on gaps in the current large lecture biology literature.

GAMBR in Biology Instructional Approach

GAMBR in biology is a way of thinking about and implementing biology instruction developed to improve the instruction of the lecture portion of introductory biology at the University of Massachusetts Amherst where the lecture sizes range from 200 to 480, providing instruction for more than 1000 students per semester. GAMBR is an instructional approach by which students are asked to focus their learning by reasoning with well-established scientific models. In the GAMBR approach, the students

"learn" about natural processes by reasoning with the model: actively using the concepts, vocabulary, and in many cases diagrammatic representation of the model to understand how the parts of the model work collectively to achieve their biological goal. The teaching method was originally based in the QDI format[3] , where the problems are centered on scientific-models.

The overall objectives of the instructional approach are: 1) to get students to reason with biological models like expert scientists and 2) to develop runnable mental models of key accepted scientific models of biological processes. These goals include both content knowledge and process skills. The content learning goals are similar to most introductory biology classes, with the main difference being that students are not tested on content directly but rather indirectly through answering problems that require them to know the vocabulary to reason correctly about the problem. The process skills have been labeled as: model choosing, model using, and model modifying or elaborating by the instructors/developers.

Course Learning Objectives

This section provides a detailed look at the different learning objectives for the course. The course is broken down into 6 units, which reflect the broad content learning objectives taught.

- Signal Transduction
- Gene Expression Control
- Protein Structure, Enzyme Function and Energetics

[3] See UMPERG website for more information: http://umperg.physics.umass.edu/

- Photosynthesis
- Genetics
- Cancer

Each unit has a particular set of learning objectives that is associated with it. These are posted on the course website in the form of questions the students should be thinking about during the unit. These content goals are consistent with most undergraduate introductory biology courses. See Figure 4-1 for a sample set of unit questions.

Control of Gene Expression – Objectives

What makes different cell types different?

* Do different cells have different sets of genes?
* What is a gene expression "pattern"?
* How can DNA microarrays be used to assay gene expression?

How is the genome organized?

* How many genes are in the human genome?
* How many chromosomes are in the human genome?
* How do these numbers compare to other organisms?
* How many genes are on each chromosome?
* How "big" are genes?
* How "big" is a whole chromosome?
* How much space is between genes? -What is in that space?

What is the structure of a gene?

* What is the transcribed region?
* What is the promoter, or regulatory region?
* What are the parts of a promoter? e.g. What is the TATA box? What is an enhancer?
* What is the coding sequence?
* What are introns and exons?

How are genes expressed?

* Which molecules are produced during gene expression...and in what order?
* What are the enzymes required for gene expression?
* What is the difference between transcription and translation?

How does transcription work and how is it regulated?

* What is the basic structure of DNA?
* What is the basic structure of RNA? How does it differ from DNA?
* What does RNA polymerase do? How?
* What are transcription factors, and how do they influence gene expression?
* What is chromatin? How can chromatin structure affect gene expression?

How is the expression of multiple genes coordinated?

* How are genes with related functions organized in prokaryotes?
* How are genes with related functions organized in eukaryotes?
* How can signals from outside the cell activate sets of genes?
* What is imprinting? How is DNA methylation involved?

Figure 4-1: Learning objectives associated with unit control of gene expression.

Model-based Reasoning Learning Objectives

The instructor and his research team have categorized the model-based reasoning skills focused on in the course as the following: model choosing, model using, and model modifying through elaborating and revising. These are shown in Figure 4-2 below.

Model-Based Reasoning Learning Objectives

The lead instructor and his research team as have categorized the MBR skills focused on in the course as the following: model choosing, model using, and model modifying through elaborating and revising.

Model Choosing

Invoke appropriate models
Apply appropriate level of detail
Understand implied or underlying models/principles

Model Using

Map observations onto model components
Story problem mapping
Apply model logic to predict and explain
Proper use terminology in context of model
Recognize / confront misconceptions of basic principles

Model Modification (Elaborating and Revising)

Identify mismatches between model predictions and observation.
Use data to support/reject model revisions.
Invoke plausible revisions/extensions to models.
Determine when explanations are
Confirmed / plausible / busted.
Designing experiments to provide data addressing model revisions.
Resolve/understand ambiguity.
Evaluate quality of evidence.

Figure 4-2: Model-based reasoning learning objectives.

Question Driven Instruction: A Stepping-stone for GAMBR

With the goal of restructuring the introductory biology course through the implementation of clickers, the instructor, Professor Randall Phillis, looked to a successful method of clicker instruction being used in large lecture courses in the UMass Amherst Physics department: Question Driven Instruction (QDI). The basic structure of classroom activities in GAMBR mirrors that of QDI, and I will therefore briefly discuss it.

QDI is a teaching method that was developed by the UMass Amherst Physics Education Research Group (UMPERG) as a pedagogical approach to using classroom response systems (CRSs) in 1993 (Beatty et al., 2006b). A cyclical teaching approach that centers on having students actively solving physics problems, QDI was founded on constructivist beliefs in which knowledge is constructed by an individual's attempts to use his/her existing knowledge to make sense of new experiences and that a significant portion of an individual's knowledge is constructed in response to interactions with others. QDI has been shown to be an effective classroom strategy for generating a constructivist-learning environment in large lecture physics courses where students construct their understanding of physics through working on in-class problems, talking to peers and the instructor as they do so (Dufresne, Gerace, Leonard, Mestre & Wenk, 1996).

QDI revolves around a question cycle involving the students and instructor. In brief, the professor uses a personal response system to pose a question to the class, the students work in small groups to answer it, their answers are submitted via clickers, a histogram of the class responses is displayed, a class-wide discussion ensues, and when a

satisfactory degree of closure is reached, the next question is posted. The question cycle is central to the class structure, with an average of 3 questions being discussed per class. The instructor designs and delivers the questions based on the formative assessment provided by students' responses to the clicker questions and the class-wide discussion. Students are expected to enter class familiar with terms and concepts via pre-class reading assignments (Beatty et al., 2006b).

UMPERG describes the methodology and benefits of QDI at length[4]. The success of QDI is highly dependent on the development and implementation of effective clicker questions. Beatty et al. (2006a) present traditional physics questions and describe the process of transforming them into quality clicker questions for physics. The article provides insight into the construction of clicker questions that will incorporate content, process, and metaprocess goals and states that, though the example questions are for physics, the generative process is presented as cross-curriculum (Beatty et al., 2006a). Beatty et al. (2006b) provide a very detailed description of QDI implementation.

Physics Versus Biology Models

The physics models used in QDI are mathematical formulas used to predict the outcome of interactions between objects and energy, and most importantly, they are concrete, meaning that they are not subject to creative change. The skills in the clicker questions applied in physics are determining which model to use to solve a given problem and which specific variables to include in the formula. In biology, models are conceptual representations of biological systems; they are complex, varying, and constantly evolving

[4] Visit UMPERG website for more information: http://umperg.physics.umass.edu/

as new information is rapidly being discovered and the systems are better understood through biological research. There is also a layering of models, where the components of larger models can be broken down into models themselves, and these models' components can than be farther dissected into models (e.g., the models of the Krebs cycle and electron transport chain are embedded in the model of metabolism). The clicker questions that are used in GAMBR attempt to reflect the fluidity of biological systems and encourage students to think about possible changes and modifications that could occur in a model, be they manmade affects or natural mutations.

Visual Aids in GAMBR

Examining the notes of classroom observations from the fall 2006 semester revealed that in addition to the clicker questions, there were hundreds of different graphics used by the instructor to support student learning. The graphics included, but were not limited to: handouts, parts of clicker questions, drawings on the board, and images in PowerPoint presentations.

There is a long list of graphics that are used by the instructor once or twice to help illustrate a point. These include things as simple as computerized slides of people with particular diseases. There are other graphics that are meant to help students visualize scientific models or specific components of them as they are being explained. These include animations of biological processes, such as protein synthesis; diagrams of molecules, such as ATP; and diagrams from the textbook illustrating the steps in biological processes, such as DNA synthesis. These types of graphics are projected onto

two large TV screens and two projection screens at the front of the class via computer and document cameras.

There are also diagrams the professor draws on the board to help students understand or think about the scientific models they are working with. They include prediction tools, like Punnett squares and genetic keys.

Lastly, there are graphics that the professor has the students work with extensively during class and on quizzes and exams. These are diagrams that are handed out in conjunction with or directly integrated into the formative (clicker) and summative (quiz and exam) assessment problems. They include diagrams of signal transduction pathways and electrophoresis gels (examples of course diagrams are shown in Chapter 8). While all the graphics likely play an integral part in the building of the students' mental models, the clicker question-related diagrams were the graphics chosen for exploration because they appeared to be the ones most closely linked to the GAMBR approach, as they are embedded in the problems meant to engage the students in model-based reasoning.

Overview of Existing Literature and Research on GAMBR

As demonstrated in Chapter 2, there is a gap in the literature related to the use of clickers for question design and implementation in large lecture biology instruction. To provide rationale for using GAMBR as a case study for clicker use in large lecture biology courses, the existing publications and preliminary research about GAMBR are summarized here.

The proposal for the NSF grant awarded to Professor Phillis and Neil Stillings (2004) describes the MRB approach focusing on the alignment of formative and summative assessments. In addition, an article we are currently working to publish presents data on student attendance and engagement (Barlow et al., pending). Preliminary research has also been conducted on hypotheses generation (Barlow & Fitzgerald, 2011) and diagram use (see Chapter 5).

NSF Grant: CCLI-ASA-Area 1: New Development Proposal: Assessment of GAMBR in Biology

The NSF grant proposal begins with a description of the introductory biology course as a general picture of the course (large lecture biology course for majors) and a definition of what model-based reasoning in biology means—similar to the one provided above. It is important to note that the course had evolved in some ways between the writing of the grant and the time of this study so a more detailed and current description of the course (in Chapter 6) was developed as the first step toward answering the research questions (stated in Chapter 5). The information about the course provided in this chapter represents what was known and/or said of the course prior to the study.

The proposal describes the typical daily classroom cycle and the semester's topical learning cycle as follows:

Classroom Learning Cycle

There are several elements to the classroom learning cycle:

1. Prior to each class, students visit the course website to answer a pre-class quiz that checks their basic understanding.

2. During the class meeting, the instructor poses a graded series of 2-5 questions that require model-based reasoning. The questions, which are in multiple-choice format, are projected on a large screen at the front of the lecture hall. Groups of three or four students discuss the questions. Students commit to and submit their personal answers via hand-held wireless transmitters to a central computer, which displays a histogram of the students' choices on the screen. Students receive immediate formative feedback on their progress in model-based reasoning.

3. Following small-group discussion, the instructor leads a whole-class discussion in which groups explain their reasons for choosing various answers. The instructor wraps up the discussion by reflectively elaborating and repairing lines of student reasoning and summarizing the critical properties of the model that have been illustrated.

After class, the instructor posts on the website the day's GAMBR problems with remarks that remind students of the lessons learned about models and about scientific inquiry. (Phillis & Stillings, 2004, p. 3)

Topical Learning Cycle

The topical learning cycle has several elements in addition to those of the classroom cycle:

1. Web-based class preparation materials and in-class instructor comments frame GAMBR formative learning episodes in terms of the major questions being addressed.

2. Sequences of GAMBR problems are often couched as extended inquiries into research questions, such as therapeutic cloning. These problem sequences move well beyond textbook presentation.

3. An GAMBR-oriented quiz is administered each week, providing a comprehensive formative assessment of the week's models.
(Phillis & Stillings, 2004, p. 3)

In addition, the proposal discusses the close integration and alignment of the formative and summative assessments in the course and portability of GAMBR instruction in general. The next section then discusses the differences between the type of multiple choice questions used in GAMBR and the more recall-type multiple-choice

questions traditionally asked in biology. In this section, several recall and GAMBR questions are presented as well as the benefits to the later versus the pervious. The rich biological context (or scientific model) in which the GAMBR questions are embedded is also provided.

Ultimately, the proposal presents a case and methodology for researching the use of multiple-choice questions to foster and assess model-based reasoning in hopes of developing a question bank.

In the course of collecting data for this grant, it was determined by the Principle Investigators that merely generating a bank of pre-designed questions would not allow future instructors to implement the GAMBR approach. The implementation of GAMBR questions is so intimately connected to the design of the questions, that to truly apply the instructional methods successfully, instructors must either design their own questions and question sets or have a deep understanding of the learning goals of each question and the scientific model they play on.

One intention of this case study is to provide a more detailed description of the course content, components, and the large-scale instructional practices so others might be able to attempt to implement the GAMBR approach.

SABER Poster:
Effect of GAMBR Instructional Approach on Hypothesis Generation

Barlow and Fitzgerald (2011) presented a poster on the impact of GAMBR instruction on student hypotheses (number and content) at the first annual Society for the Advancement of Biology Education Research (SABER) conference. In the fall of 2008, 700 students were given identical pre-/post-tests, on the first and last day of the semester;

both the model and the topic, synaptic transmission, were not covered during the semester. The test presented a novel model that related to the effect of a drug neural synapse and asked students to write as many hypotheses as possible for the drug's mechanism of action. Analysis of the data suggests that the GAMBR approach supports students in generating hypothesis,reflected in a statistically significant increase in the number of hypotheses generated pre to post semester. Further, preliminary analyses of the data suggest that the increase in hypothesis generation is related to a better perception of causal logic in biological systems demonstrated by students creating more hypotheses dealing with the functionality of components further down or up stream of the components mentioned in the problem. Further, the researchers noted a perceived increase in content knowledge present in the vocabulary used in the wording of the hypotheses. In summary, analyses of the data led to the following preliminary conclusions:

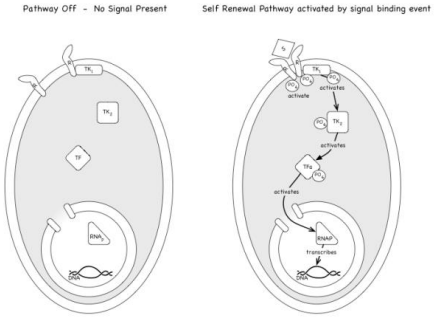
> Overall our initial data suggests that GAMBR classroom instruction increases student willingness/ ability to generate a wider range of hypotheses to explain an observation and to state those hypotheses in a more expert manner. Additionally, the increase in number of hypotheses is not non-specific, but rather reflects an increased appreciation of the relationships between components in the model, and an increase ability to explain outcomes using process based logic. (Barlow & Fitzgerald, 2011, p. 1)

Preliminary Research on Diagram Use: Classroom Observations and Student Survey

As stated above, diagrams were often associated with clicker questions in the GAMBR approach. The students are expected to use the diagram while they reason with the model to respond to the clicker question. The diagrams used in the course in association with clicker questions depict either biological models, such as signaling

pathways, or observable data (image of electrophoresis gel). Figure 4-3 shows examples of each diagram type and an associated clicker question.

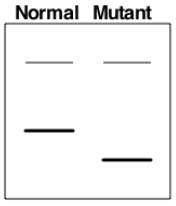
Example of a Signal Transduction Pathway Diagram and an Associated Clicker Question



Which of the following would create a positive feedback cycle that would make signaling permanent?

TK1 activates a phosphatase that targets TFa
TK1 inhibits a phosphatase that targets TK2.
TFa activates a gene that encodes an inhibitor of receptor mediated endocytosis
TFa activates a gene that encodes a kinase that targets TFa.

Example of Electrophoresis Gel Diagram and an Associated Clicker Question



The gel above shows RNA from a normal gene and a mutant copy of the gene. Which of the following could account for these results? (PICK ALL THAT APPLY)

The gel above shows RNA from a normal gene and a mutant copy of the gene. Which of the following could account for these results? (Pick all that apply)
1. The mutation disrupted the TATA box.
2. The mutation blocked the binding of DNA bending transcription factors.
3. The mutation prevented the removal of introns.
4. The mutation caused an exon to be removed along with the normal introns.
5. The mutation disrupted the normal termination signal and prevented hairpin

Figure 4-3: Example diagrams and clicker questions.

Survey on Student Diagram Use

A Likert survey (see Table 4-1) was used to explore the role of diagrams in GAMBR to determine if further study was warranted. It is important to note that the survey was not tested for reliability and validity and was taken on a volunteer basis. However, it was reviewed for face validity by an educational expert prior to distribution.

Table 4-1: Results of Likert survey on diagram use.

Question	Mean	Median	Mode	SD
1. The diagrams used in the class helped me to understand the course material.	4	4	4	1
2. I used the diagrams as tools to solve problems in class and on quizzes and exams.	4	5	5	1
3. I used diagrams differently in this class than I have in previous biology classes.	4	4	5	1
4. I animate the diagrams using gestures when I am trying to explain my understanding to fellow students.	3	3	3	1
5. I drew/wrote on the diagrams while using them to solving problems.	4	4	5	1
6. I used diagrams in this class more often than I did in previous biology classes.	4	4	5	1
7. I modified the diagrams that were handed out in class to fit my own needs in understanding the material	3	3	3	1
8. I drew diagrams on my own to help me understand the biological concepts covered in class more frequently than I did prior to this class	2	2	1	1
9. The diagrams confused my understanding of the biological system because they were incomplete representations.	3	3	3	1
10. The diagrams used in class helped me to build mental models of the biological systems they represented	4	4	4	1
11. The diagrams helped me to run mental models of the biological systems they represent.	4	3	3	1

The Likert scale was 1-5, where 1 was strongly disagree and 5 was strongly agree. Note that there have been no significances done on this data. The survey also included the open response question: "Please share any general comments you have about the use of diagrams in this class."

It is important to note that the data were not meant as evidence that the use of diagrams is important and/or why. It was meant only to examine whether or not further considerations about the use of diagrams might be valuable. Because the instructor's focus in the class is problem-solving, the diagrams were incorporated into the class as parts of problems, not as a learning devices in and of themselves. That is to say that prior focus in GAMBR instruction by the instructor or previous researchers has not focused on the visual components of the clicker questions. By collecting information on the students' perceived use of the diagrams during problem-solving, strategies that enhance their educational benefit could be identified and expanded. Ultimately this might improve the GAMBR method and provide ideas for diagram-related teaching practices that are transferable to large lecture instruction in general.

The Diagram Use Likert survey was aimed at gathering information about students' ideas regarding their use of diagrams in this class. It was posted on the class website and 120 students took the survey on a voluntary basis. The basic statistical results are displayed in Table 4-1; however, the results of the survey should be read with discretion as the students who participated in it were not randomly selected. The sample is, therefore, likely biased toward students who wanted to express their positive or negative opinions about the use of diagrams in the classroom. Also, there were approximately 480 students in the class, so it could be quite possible that the opinions, positive or negative, expressed about the use of diagrams are not shared by a majority of the class. In actuality, the fact that only 120 students participated, could be an indication that a majority of the students did not view the use of diagrams as an important component of the course and, therefore, did not bother to participate in the survey. In

addition, remember that there was no validity and reliability testing on the survey instrument, which also limits its ability to offer any statistically significant information. That said, the main goal in administering the survey was to see if it was worth exploring the use of diagrams in the course further, that is, exploring if any students found them important and might be using them in ways that could facilitate mental modeling.

Likert

Analysis of the survey data suggested some interesting aspects of diagram use in the course. A majority of the students tended to agree with the statements, "I use the diagrams to solve problems in the course" and "The diagrams help me understand the material (Questions 1 and 2). They also tended to agree with the statement, "The diagrams help me build mental models of the biological systems," and in slightly fewer cases, "They help me run mental models" (Questions 10 and 11). These responses suggest that the diagrams are supporting many students in the generation of and use of mental models, which concurs with the findings of Schnotz and Bannert (2002). Questions 4, 5, and 7 were meant to address more specifically whether students use the diagrams in ways that are associated with building or running mental models based on the strategies defined by Stephens and Clement (2007) derived from expert think-aloud protocols as well as research done on gestures by Roth (in press). The results of Questions 4 and 7 are not as clear-cut because they averaged a neutral rating of 3, which corresponds to "Sometimes." The responses to Question 5, however, provide a slightly stronger indication that students are using the diagrams to support problem solving.

Question 9, which also averaged a 3, making it difficult to interrupt, could indicate that some students find the diagrams to be helpful, and some find them to be confusing.

Lastly, Problems 6 and 8 were aimed at determining if the students perceived diagram use in this course as different from previous biology classes. The students tended to agree with Question 6, suggesting that they used diagrams more often in this course. However, the results of Question 8 suggest that this did not appear to transfer to an increase in independent diagramming by the students.

A more relevant question, that perhaps should have been asked, is: "Did the use of diagrams in this class help students understand the biological systems better than the use of diagrams in previous classes?" Some of the comments on the open response portion of the survey indicate that many students would have agreed with this statement, yet it would still be difficult to discern if the student understanding is better because of the use of diagrams or because their content knowledge it increasing.

Student Answers to Open Response Survey Question

The open response question about diagram use in the course was: "Please share any general comments you have about the use of diagrams in this class.' There were 55 responses to this question. It is highly likely that the students who chose to complete this portion of the survey are those who felt strongly about the use of diagrams in the class. This concept is supported in that most of the comments collected were positive or negative, rather than neutral. Thirty-three of the responses indicated that the students perceived the use of diagrams in the class as helpful, 12 contained negative comments about the diagrams and or class, and 10 were positive but did not address the diagrams

specifically. This could suggest that a majority of the students that took the survey found the use of diagrams helpful. Regardless, the answers to this question were encouraging to me, in that they suggested that some students found the use of diagrams beneficial to their learning and provided a little insight into why that might be. The negative comments were also helpful because they helped the author think about some of the potential drawbacks to the use of diagrams in this instructional approach.

Several students mentioned that they were visual learners, and therefore the diagrams were helpful. This further supports the idea that a majority of the students that participated in the survey may be those that enjoyed the use of diagrams in the class. Examples of these comments are:

> "They were very helpful since I am a visual learner."

> I think the diagrams in this class are a really great way for visual learners to understand the concepts of the class, as opposed to just mindless memorizing of vocabulary. I also like how the diagrams are supplied during the exams because we can still use them as a reference when figuring out problems.

> Very cooool. They are good for helping us understand material because, I know myself and many others are "visual learners" and we can take notes on them!! I like when there are faces drawn on them, and the "Simpsons" and fun stuff like that. It makes the class seem less stressful… and less serious, but we still learn!

Some comments were very insightful, providing feedback about why the student thought the diagrams were important to the class. For example:

> I think the use of diagrams is a key part of this course and should be utilized more in other courses. Using diagrams and then having mutations and structures added or subtracted to the diagrams in problems or in class really makes the student...at least for me...understand the concept, process, and ideas so that you can apply them and understand changes that may occur. Without the use of diagrams I sometimes find myself memorizing information out of lecture notes and the book,

but not understanding the general process or understanding how the system changes if changes are applied. “

Both the diagrams and the analogies make complicated systems very easy for me to learn. For example, Professor Phillis explained enzyme saturation by having us imagine the entire class throwing pencils at him, and every pencil that he caught (impossible to catch every one) was a substrate converted to an enzyme. This is something that I will remember in a few years, not just that day. The diagrams work the same way because I form a mental picture that I can remember and MANIPULATE. It is like a machine that I can turn on (like the one where: last kinetochore attaches...so sister chromatids separate)

Despite some confusion, I did enjoy using diagrams in class. It was like solving puzzles. It was very fun looking at an ideal system and trying to visualize how that system would change if another factor, like a mutant gene, were present. Some were difficult to read or understand, however, Professor Phillis did a good job trying to simplify some very complex processes. After looking to the textbook to understand what some parts of the diagram meant, they were very useful to have.

The diagrams are very useful in helping understand and I think it is necessary to leave them unfinished because it can go multiple ways so it gives us the ability to fill it on with the multiple finishes.

I believe that this was a commonly used mechanism in teaching any kind of science course; however, Professor Phillis managed utilize this tool in a way that the students can actually understand.

Other comments provided suggestions on how the use of diagrams could be improved,

for example:

In general, I believe the diagrams and how they are presented to be VERY useful and for the most part understandable. However, it would be _great_ to periodically translate what the current diagram being looked at is in the big picture. i.e., "Ok, so we have diagram X ... remember that this system is related to <insert previous system learned about> by <...>, and both are part of <... larger system>" etc... lots of times I can put that together in my head, but I've heard lots of complaints from people in lecture wishing that were done more often so they could get a better grasp as to what we're talking about.

The majority of the negative comments reflected students' dislike with having to use information in class rather than just memorize facts, such as:

> Next semester please explain how things go step by step rather than handing out a diagram and having us interpret them.

> I like the CLICKER problems, some of the time. They do help in knowing what kind of problems he is going to ask on a quiz or exam. However, I do not like those type of problems. I find them really ambiguous some of the time, and I am used to having straight-forward fact problems for biology classes.

However, one negative comment stuck out:

> This class was mostly about reading diagrams and not too much about Biology. Please rename the class "Reading Diagrams 100" if the knowledge of Biology is going to be compromised.

These last comments could indicate a major deficit with this teaching approach. Students may have difficulty making the connection between the biological-model and diagram that is being used. Drawing this connection may be more difficult when the diagram represents an observation rather than the model itself because the causal flow of the model is not visually displayed. However, even diagrams that are representations of the model can be misleading to students because students may not be able to distinguish between the representation of the model and the conceptual model itself, as discussed by Cartier et al. (2002). Also, it is a reminder that students learn in different modalities and that this use of diagrams may not be as useful and may in fact be challenging to students who are not visual learners. Further exploration of the use of diagrams in the GAMBR approach may indicate a need for additional support or modifications for non-visual learners to maximize the educational impacts for a broader range of learning types.

The analysis of student diagram use and how it relates to the building and running of mental models in relation to this course is far from complete. However, survey data and preliminary observations of the classroom suggest that further examination of the use of diagrams in the GAMBR classroom could reveal some interesting ideas for using diagrams in large lecture halls.

Summary of Preliminary Diagram Research

The GAMBR reasoning approach includes content goals, inquiry process goals, and model-based reasoning goals. Many of the problems that appear in class, on quizzes, and on exams relate to specific diagrams or diagram types. A survey taken by students relating to diagram use in the course indicated that many students viewed the diagrams as useful in learning the course content and visualizing the biological systems.

Summary and Discussion

GAMBR in Biology is a method of teaching biology in large lecture settings that engages students in scientific thinking well covering the necessary content and concepts. Taught in the format similar to that used in Question Driven Instruction, it promotes active learning in a student-centered environment. As in other model-based curricula, students and instructors work together to direct the class and generate ideas and build student understanding of scientific models in a constructivist environment. However, it is my belief that GAMBR differs from other model-based curricula in that it focuses on knowing how to use models as well as generate (modify or extend) them. This difference is important because in the world of biological science far more time is spent

implementing and modifying existing models than is spent creating new ones. While at the k-12 level of education this difference might not matter as much since students have not chosen a particular career path, at the college level the instructors are in the role of training future scientists.

Support for this instructional approach as well as an overview of course components and goals has been described in an NSF grant proposal. In addition, a 2008 pre-/post-test on hypotheses generation suggested that the instructional method may be supporting students in developing hypotheses and understanding causal logic. Preliminary data on the role of diagrams in the classroom was collected via a Likert survey, revealing that diagrams may be playing an important role in classroom learning. More detailed exploration of the instructional method will provide insight into the instructional modes, student behaviors and clicker questions that could have theoretical and instructional implications.

Perhaps, the most interesting aspect of GAMBR is that it provides a working alternative to traditional lecturing in large classes as well as current uses of clicker questions and the content based learning goals that go with it.

Case for a Case Study on GAMBR Instructional Approach

In this section I summarize five areas where there are gaps in the literature related to large lecture biology that a case study on the GAMBR instructional approach has the potential to address.

Complex Clicker Questions

While there are appeals for clicker questions and approaches that result in "cognitive" engagement (Beatty et al., 2006a, 2006b; Cooper et al., 2006; van Dijk et al., 2001), the bulk of literature on using clickers to reform biology courses remains focused on increasing student motivation and performance on traditional, content-based assessments (see Chapter 2). Peer instruction is becoming a common use of clickers in biology, with little else found in the literature about new or alternative methodologies presented or discussed. There are few ideas about using clickers in biology to change the way students think about science and assessing alternative learning goals, such as scientific reasoning. This may be due to the gap between the theoretical potential of clicker question (and course) design for optimal and deeply cognitive student learning (such as those presented but Beatty et al., 2006b) and the available guidelines for how to design and implement such questions for use with clickers in large lecture biology courses. The GAMBR instructional approach may provide a rich resource for the design of clicker questions to be used in large lecture biology courses that result in type and level of cognitive engagement called for by van Dijk et al. (2001) and Beatty et al. (2006a).

Inquiry/Process Skills

Biology education has not historically been approached as a problem-solving science; memorization of vocabulary and concepts has been the primary focus, thus limiting most existing clicker question banks to fact-checking, content driven learning tools. However, scientific models are the result of, and driving force behind, scientific

inquiry in biology (for relevant research see e.g., Cartier, 2000; Cartier et al., 2002; Gobert, 2000; Gobert et al., 2002; Lawson et al., 2000; Michael et al., 2002; Modell, 2000; Raghavan et al., 1998). One could argue that there is a gap in the current learning goals of most large lecture undergraduate biology courses and the expectations for future scientists. The use of clickers in the GAMBR instructional approach suggests that clickers may present an opportunity not only to increase engagement in traditional biology goals but to push biology education at the undergraduate level toward more model-based approaches that engage students in the types of thinking and reasoning that better mirror what biologists do, even in large lecture halls.

Model-based Learning

Further, Clement (2000) called for more research in the area of model-based learning to clarify and define the importance it plays in conceptual change and present research questions about which approaches are best to bring about such change. Since this time, progress has been made on model-based education, including some curricular and research related specifically to biology (examples include Rea-Ramirez, Nunez-Oviedo, Clement, & Else, 2004). Model-based education research and strategies are nicely laid out in Price (2013), including strategies for engaging students in model-based reasoning in the classroom. Clement and Rea-Ramirez (2008) present a method of model-based education they term model co-construction that is argued can address content and process goals. There is a heavy emphasis on class discussion and the role it plays in the process of model construction and evolution. Clement and Steinberg (2002), Nunez-Oviedo (2005), Williams and Clement (2007), and Clement and Rea-Ramirez (2008)

present a strategy, used within co-construction of scaffolding student movement toward the target model using what they have deemed the Generation-Evaluation-Modification cycle (GEM cycle). Both co-evolution and the GEM cycle may map to the GAMBR approach. The clicker questions that are used to move the students toward a target model focus on having students consider different possible scenarios for the model (i.e., what if this happens to a component in the model, or what if this were the outcome of the model), forcing them to practice and perturb the model, and thereby revise or extend it. However, there are key differences in the model-based education examples currently provided in the literature and the GAMBR approach. Where pervious literature has been based mainly in k-12, the GAMBR approach is the first attempt at implementing model-based biology education at the undergraduate level in a large lecture setting that was found.

Student Talk

Student talk is known to be an important aspect of the learning process (Dubrow & Wilkinson, 1984; Laurillard, 2002) and has become an ever increasingly common strategy in education. Class discussions in small classrooms are not a new instructional tool, and classroom discourse has been a popular research subject at the k-12 level (see Price, 2013 for an extensive review of the literature related to classroom discussions). However, research that looks directly at what students and teachers are saying and doing during large lecture discussions is virtually absent from the literature, biology or otherwise. Personal Response Systems have successfully generated opportunities for students to talk in large lecture halls (Boyle & Nichol, 2003; Cutts, Carbone, & van Haaster, 2004; Draper & Brown, 2004), and most applications of it in the literature

included some level of class discussion. However, no data were found on what specifically students are talking about during large lecture class discussions (peer or class-wide) beyond vague statements that they talk about the problem, defend their answer to their neighbor, or explain their answer to the class. This is perhaps related to the fact that the goals for undergraduate large lecture biology courses have remained largely the same as traditional large lecture biology goals, and, therefore, lack little more to talk about than what the correct answer is or what the previous definition was. Observations of the GAMBR instructional approach have shown it to be a classroom environment of rich discussion that has the potential to provide insight into what type of talk students are capable of in large lecture halls when given something interesting and challenging to talk about and what kinds of strategies are used by the instructor to support and manage such discussions.

Use of Visualizations

The use of visualizations in science education is another important educational topic as we move forward in this technology driven world. Diagrams and other visual aids have been shown to support learning in various ways (see Chapter 3 for more on this). Beyond traditional learning goals, external representations, such as diagrams, are believed to support the scientific reasoning processes that involve internal visualizations (Gilbert, 2007). Such internal representations or mental models are key components to model based educational approaches (Clement, 2000, 2008). The diagram rich clicker questions of the GAMBR instructional approach offer an opportunity to explore how diagrams may support not only the basic educational goal of generating fruitful class

discussions but also the more complex goal of getting students to generate mental models to engage in model-based reasoning in a large lecture setting.

The GAMBR instructional approach provides an opportunity to examine the use of clickers in large lecture biology with alternative learning goals and strategies that are in line with newer science education guidelines for engagement of inquiry and deeper learning of content. The fact that the novel approach being researched for this case study is an example of model-based learning makes it of further interest in understanding how such inquiry inquiry-rich approaches can be implemented in large lectures. Comparing it to the current knowledge of model-based learning might further the field by providing new strategies for instructors and/or extending those strategies into the large lecture hall. The GAMBR instructional approach also provides an opportunity to examine student discourse related to model-based reasoning during peer and/or class discussion in large lecture, something that has not previously been written about. The use of diagrams in conjunction with the clicker questions provides the opportunity to look at the impact and role of diagrams on both basic and complex instructional and learning goals in large lecture biology education, such as generating class discussion and supporting mental modeling.

List of Gaps in the Literature Related to Large-Lecture Biology and Broader Questions Motivating the Study

In summary, Table 4-2 below is a list of areas where there are gaps in the literature related to large lecture biology that a case study on the GAMBR instructional approach has the potential to address. Shown with each area is a broad, long range,

general question motivating this research project. Narrower, more specific questions actually addressed in this project will be formulated in the next chapter.

Table 4-2: List of areas where there are gaps in the literature related to large-lecture biology that a case study on the GAMBR instructional approach has the potential to address.

- Examples of courses with a heavy focus on inquiry/process/skills based learning objectives

  How would such a course be structured?

  Can student engagement in any of these processes be detected during courses?

- Model based educational approaches

  Can a course that is deeply model based be designed and implemented in college biology?

- Strategies for designing complex and provocative clicker questions

  In particular, what are some strategies for creating clicker questions designed to promote model based reasoning?

- Examinations of students' talk during [peer or] class discussions

  In particular, can any of the model based reasoning skills mentioned above be detected in classroom discussions?

- Strategies for using visual aids to support learning on different levels

  In addition, can the use of visual aids have an effect on model based reasoning during class discussions?

One of the researcher's long-range motives is to open avenues for large-lecture biology instructors to think about how to move away from a focus only on factual memorization toward more of a focus on scientific practices.

CHAPTER 5

RESEARCH QUESTIONS AND METHODS

Introduction

This chapter states the research questions for the study and the research methods used to address those questions. In large lecture biology courses, many instructors appear to use clickers merely as a quizzing and attendance tool. Less well documented and examined in large lecture biology are the cases where instructors use clickers in a way that facilitates cognitive engagement in scientific models and skills. In an attempt to understand the latter, an exploratory case study of the Guided Application of Model-Based Reasoning (GAMBR) in Biology Approach at UMass Amherst was conducted to examine three of its main components: 1. clicker questions, 2. student talk, and 3. instructional phases, and the relationships between them.

Previous chapters have provided the rationale for researching this use of clicker questions in biology including reviews of the literature and a preliminary look at the GAMBR instructional approach. The goal of this project is to develop a detailed description of the main components of this model-base reasoning instructional approach and the relationships between the above three components. An initial exploratory case study of the GAMBR instructional approach is the first step in understanding the main features of this novel instructional approach and will hopefully provide insight into wider possibilities for large lecture biology instruction and a basis for further research.

Research Subject

Previously, single case studies on exemplary subjects and experts have proven to make major contributions to the literature (Anzai & Simon, 1979; Hammer, 1995a, 1995b; Lampert, 1985; Stephens & Clement, 2010). This project was a case study of the GAMBR in Biology instructional approach as taught by Professor Randall Phillis. Professor Phillis has used this method of instruction for over 10 years to teach introductory biology at the University of Massachusetts Amherst, a Research I university. Professor Phillis received a UMass Amherst Distinguished Teaching Award in 2005, and is well respected as a science education presenter, having been invited to speak at several workshops and conferences, including the 2008 NSF CCLI Conference and 2008 and 2009 HHMI Summer Institutes.

When the semester data were collected, there were 333 first-years, 105 sophomores, 30 juniors, and 7 seniors in the class, for a total of 475 enrolled students. The majors consisted of 192 biology, 96 animal science, 180 other sciences, mathematics, and engineering majors for whom the course was a requirement (including majors, such as biochemistry, chemistry, psychology, civil engineering, nursing, and microbiology), and a few non-science majors. One hundred-two students were pre-med.

The course is aimed toward science majors, with many students planning to major in life sciences and/or pre-med/vet/dental. The classroom seats 480 students, and the class enrollment has traditionally been at or above capacity each semester it is offered.

Data Collection Processes

To speak to the broader questions at the end of the previous chapter and to implement the study described in the abstract for this dissertation, the following data sets were collected.

Data Set 1

Observational field notes on the GAMBR approach were collected from 2006, consisting of notes on student and teacher behaviors during class. This data set includes but is not limited to the student comments during class-wide discussions.

Collection Process

Throughout every class during the 2006 semesters, the researcher took observational notes while standing at the front of the auditorium. The main focus of the notes was the student verbalizations made to the entire class, which consisted mostly of short statements or questions during class-wide discussions. The researcher did not try to capture everything that was said or done by the professor, as this would have been extraordinarily difficulty, but rather made brief notes, such as mini-lecture, revisited previous information, introduced diagram. The researcher also took notes on what the instructor displayed using the document camera, the computer projector, or the chalkboard. Teacher actions, such as using a rubber band to demonstrate DNA coiling and uncoiling, were also recorded. Notes on student behaviors in general were also made, such as many students pointing and gesturing to the diagram displayed at the front of the room and student utterances during class-wide discussions.

Data Set 2

Data set 2 consisted of the 2006 course materials (PowerPoint's, handouts, projected materials, course website, clicker questions, text book, student performance on clicker quiz and exam questions).

Collection Process

The course materials and clicker questions were saved on a computer and a remote server. The researcher possesses a copy of the course textbook. The extensive classroom observation notes were dated so as to be easily synced with the course materials.

Additional Information Source

Informal discussions were held with the instructor before and after classes as well as throughout the research process to understand his view of the intended purposes of class activities and learning materials. However, the researcher's observations of the instructor's and the students' actual behavior are her own, and in some cases her interpretations of these have been different from the instructor's interpretations and held sway over them in this document.

Data Excluded from Analysis

Two days were excluded *a priori* that did not represent the typical GAMBR instructional environment that was being researched. These days included: (1) a day that did not represent the large lecture setting (with only approximately 35 students in

attendance) and (2) a day that did not represent the GAMBR instructional approach (when a quasi-experiment on lecture versus clicker questions was conducted for a different research project, and the clicker questions used were content oriented rather than model-based reasoning).

Overall Design of the Study and General Method

An overview of the study design is given in Figure 5-1. As an exploratory case study in an understudied area, analysis focused mostly on the course materials and field notes. The purpose, in general, of such an exploratory case study was to provide new descriptions and existence demonstrations of newly observed course structure and behavior patterns that promote the eventual generation of theoretical hypotheses about teaching and learning strategies. Qualitative case study description techniques were used for some areas, including a detailed and rich description of seven nested cycles in the course instruction sequence. Open coding, using constant comparison techniques (Corbin & Strauss, 2008), was used for others to differentiate and refine new constructs describing patterns of student behaviors and patterns in the instructor's behavior. The constant comparison method was used to develop descriptions and in some cases categories of teacher and student behavior. This involved an interpretive analysis cycle of making observations; returning to the data to look for more observations in the same category; and criticizing and modifying the focus of the category.

For categories of student talk, including types of model-based reasoning talk, development of fixed codes eventually took place as categories were created for initially uncategorized observations, redundant categories were combined, rubrics were

developed, and the clearest and most tractable categories relevant to the goals were selected for fixed coding. Then a second coder was used in iterative cycles of independent coding, with further refinements to the rubric until a final coding was done, and reliability statistics calculated. Relationships between phases of the instruction and student talk type frequencies were then examined in frequency tables, and this was also done for relationships between different types of diagram-enhanced clicker questions and student talk type frequencies.

Finally, qualitative observations and patterns from the case study were then used as a foundation to offer more speculative hypotheses that could explain patterns in these tables—patterns, such as why model-based reasoning talk occurred more often after clicker questions using diagrams of certain types. Hypothesized theoretical descriptors, models, and diagrams of teaching and learning processes were constructed in an analysis cycle by formulating models that could describe and explain some of the observations; followed by returning to the data to look for more applications of the same model; and criticizing and modifying the model. (See Figure 11-2)

Overview of Research Questions and Methods

Course Description (Chapter 6)

Prior to chapters on each research question, Chapter 6 provides an initial overview description of the course to help set up the context and background for the study.

Research Question 1 (Chapter 7)

What major patterns/cycles of instruction took place during the course?

(A) How is the course broken down into sections such as topics and units, and where do models occur? How many instances of each type of section occurred and how are they distributed over the semester?

(B) What is the qualitative structure of the instruction within the sections? Are there patterns or cycles in the instruction that utilize models?

Note below that part A uses a different method than part B. Question 1A could be approached by examining the structure of the materials for the course; whereas, Question 1B required analysis of field notes and open coding methods.

Method for Question Q1(A)

The course was broken down or segmented according to phases of instruction that were pre-determined by the content structure of the course. Three repeating phases (nested cycles) of instruction were identified, and the instructor confirmed this segmentation of the course structure for accuracy. The placement of each clicker question within the phases was noted, and the instructor confirmed the position of each clicker question within the instructional phases. The clicker questions that appeared in each phase were counted and reported.

Method for Question Q1(B)

Case study description methods with open coding were used to describe the instructor activities, including the purpose and manner of using clicker questions, within the different phases of instruction.

Findings sought:

1. Complete set of clicker questions segmented by instructional phase for one semester.

2. Detailed, qualitative description of the instructional patterns and cycles within the phases and the manner in which clicker questions were used in the phases.

Research Question 2 (Chapter 8)

How are clicker questions and different types of diagrams used in the course?

(A) For different types of diagrams that appear in association with the clicker questions used over the course of a typical semester, how often is each type used?

(B) How are these diagram/clicker questions used within the instructional design?

Question 2A could be approached by examining the structure of the materials for the course; whereas, Question 2B required analysis of field notes and open coding methods.

Method for Subquestion Q2(A)

There were two types of diagrams used in the course in conjunction with clicker questions: (1) model representation diagrams depicting a theoretical model, such as a flow chart or schematic representing a biological structure or process; and (2) data diagrams depicting observations assumed to have been collected from a clinical test or instrument (see Table 8-1). All the diagrams attached to clicker questions were examined to make sure that these were the only two types that were used. The instructor confirmed that those were the only two types of diagrams associated with the clicker questions. The clicker questions were sorted according to which diagram type they were associated with. Some clicker questions did not have diagrams, and a few were associated with both diagram types. This led to classifying clicker questions into one of the four categories

shown in Table 5-1. The instructor confirmed the sorting of the clicker questions and the clicker questions in each category were then counted.

Table 5-1: Clicker question diagram conditions and descriptions.

Clicker Question Diagram Condition	Description
Model-representation Clicker Questions	Clicker questions that were asked in association with a model-representation diagram
Data Diagram Clicker Questions	Clicker questions that were associated with a data diagram
Both Diagram Type Clicker Questions	Clicker questions that were associated with both a data diagram and a model-representation diagram
Non-diagram Clicker Questions	Clicker questions that did not have any diagram associated with them

Methods for Subquestion Q2(B)

Open coding of the field notes for the different diagrams conditions above was used to develop a brief description of how the diagrams were used and their relationship to the models and instruction.

Final Data Sets Sought:

1. Complete list of diagrams used in one semester in association with clicker questions.

2. Complete list of clicker questions sorted by association with diagrams (or in some cases no diagram) for one semester.

3. Counts for each clicker question/diagram type used during the semester

4. Qualitative description of the different diagram conditions in relation to the models and instruction.

Research Question 3 (Chapter 9)

What kinds of student talk were elicited during class-wide discussions following clicker questions?

(A) What categories can be formulated to describe student talk occurring during the class-wide discussions following clicker questions in the Instruction? Can any be considered to be model-related or indicative of model based reasoning?

(B) How many instances of each type occurred during the course?

Methods for Q3 (A) and (B)

The student talk data were pre-segmented by days and the clicker questions it followed, along with talk turns by students. No further segmentation was desired for the initial open coding. Starting from open coding of the field notes, a subset of categories related to student talk during class-wide discussions was generated. Converging on stable categories from the open coding process was difficult because of the complexity of student science talk by nature. This differed from the segmentation of the course structure and sorting of the clicker questions that were largely pre-determined by the course material and content and therefore could be confirmed by the instructor.

When initial categories for student talk had stabilized, an attempt was made to develop definitions for fixed coding. Then all the student utterances were compiled independent of information about what clicker question the utterance followed. This information was removed prior to beginning the coding process by compiling the student utterances into a separate document from the other course materials. This was done to prevent coder bias related to different segments of the course or clicker question diagram types (see below). Following this an iterative independent coding process was undergone with a second independent coder (see IRR procedure below). In addition to providing a

reliability check, independent coding was considered important because the student talk categories would later be used to attempt to measure the extent of model-based reasoning, and employing a second coder who was naive to hypotheses of the research helped to prevent bias in coding. This was also the reason the coding of the student utterances was done blind to the other course materials that could potentially influence the coding. That said, the second coder was familiar with the instruction, having taken the course previously but not familiar with the instructional phases and clicker question diagram conditions. The second coder's familiarity with the course, however, was important in her understanding and identification of student utterances in relation to models because of her prior knowledge of what a biological model referred to in the course.

The final dataset was used to examine the relationship of the student talk frequencies to other variables, such as clicker question type. Statistical comparisons were not used because the assumption of independence was not met (i.e., the data set contained more than one utterance per student).

Findings sought:

1. Categories and subcategories of student talk related to models, and not related to models

2. Complete set of coded student utterances during class-wide discussion following clicker questions for one semester.

Inter-rater Reliability Procedure

The approach to IRR used in this study was in line with that described by Hruschuka et al. (2004). Their approach uses two or more coders to develop the initial coding rules and work together in an iterative process similar to that described above to

achieve IRR prior to coding the entire data set. When possible (given the size of the data set) sub-samples of the data are randomly selected for individual coding by the researchers, and IRR is calculated after each round. If the *a priori* IRR is not reached, then the coders discuss the code and make modifications to the rubric, and IRR is again attempted on a new randomly selected sub-set (when possible) of the data using independent coding practices. This cycle continues until an IRR above the *a priori* cut off for agreement is achieved. Once IRR is successful, the two coders independently code the entire data set. In the case of Hruschuka et al. (2004), a midpoint check was made half way through the coding of IRR and necessary revisions could be made. However, they did not deem this a necessary requirement for the approach. Once coding of the data set was completed, the coders discussed their discrepancies and made modifications to create the final coded data set.

In their case and for the purpose of this study, Cohen's kappa (Cohen, 1960) was reported, as the data fit the assumptions for this statistic. This IRR statistic prevents inflation of the reliability scores by accounting for chance agreement between the coders and is, thereby, considered an important complement to percent agreement between coders. Hruschuka et al. (2004) present a variety of different approaches from the literature to determining kappa levels that are considered acceptable:

> Several different taxonomies have been offered for interpreting kappa values that offer different criteria, although the criteria for identifying "excellent" or "almost perfect" agreement tend to be similar. Landis and Koch (1977) proposed the following convention: 0.81– 1.00 = almost perfect; 0.61–0.80 = substantial; 0.41–0.60 = moderate; 0.21– 0.40 = fair; 0.00–0.20 = slight; and < 0.00 = poor. Adapting Landis and Koch's work, Cicchetti (1994) proposed the following: 0.75–1.00 = excel- lent; 0.60–0.74 = good; 0.40–0.59 = fair; and < 0.40 = poor. Fleiss (1981) proposed similar criteria. (p. 313)

The large data set of student utterances in this study, totaling over 300, allowed for random sub-samples of the data to be used while undertaking the iterative process described above of obtaining opportunities for the refinement of construct definitions prior to coding the full data set. However, due to logistics and time constraints, the researcher developed the initial coding rubric independently (rather than a tandem effort between both coders), and the final coding of the data set was completed in one piece without a midpoint check-in. Otherwise, the method of reaching IRR and coding the data set described by Hruschuka et al. (2004) was followed. The original version of Cohen's kappa from his 1960 paper "A Coefficient of Agreement for Nominal Scales" was calculated. In this exploratory study, an *a priori* kappa goal of >.60 was chosen. This kappa was considered by the researcher to be at the upper-mid level and was chosen as a conservative but optimistic goal for the rather high inference coding of the student utterances.

Research Question 4 (Chapter 10)

Are there patterns among student talk, clicker diagram conditions and instructional sections?

(A) Are there patterns of student utterances in the different student talk categories (from research question 3) across the different instructional sections (from research question 1)? In particular, does model-related talk vary across the different course phases?

(B) Are there patterns of student utterances in the different student talk categories (from research question 3) that appear within the different clicker question diagram conditions (from research question 2)? In particular, does model-related talk vary across the different question/diagram conditions?

Methods for Q4 (A) and (B)

The data sets on student utterances and clicker questions sorted by instructional phase and by diagram conditions were organized in a tabular form, using a variety of tables to look for possible patterns in the data (e.g., Table 1: number of student utterances during class-wide discussions in each student talk category that occur in association with each clicker question diagram type and Table 2: number of student utterances during class-wide discussions in each student talk category that occur in association with particular instructional phases). In particular, the study was concerned with whether different parts of the instructional approach be associated with student talk types indicative of model-based reasoning.

Ratios of student utterances per clicker question were used to compare amounts of student talk in the different clicker question diagram conditions and across the instructional phases non-statistically, as the data did not meet the assumption of independence (i.e., the data set contained more than one utterance per student).

Findings sought:

1. Comparisons for the number of student utterances that occur following clicker questions that occur during different instructional phases

2. Comparisons for the number of student utterances that occur following clicker questions that occur during different clicker question diagram conditions.

Overview of Methods

This study contains several different data sources used to generate both qualitative and quantitative findings. The findings will be used collectively to begin forming a hypothesized model of instruction for the course. Figure 5-1 provides a visual representation of the data sources and findings sought for this study.

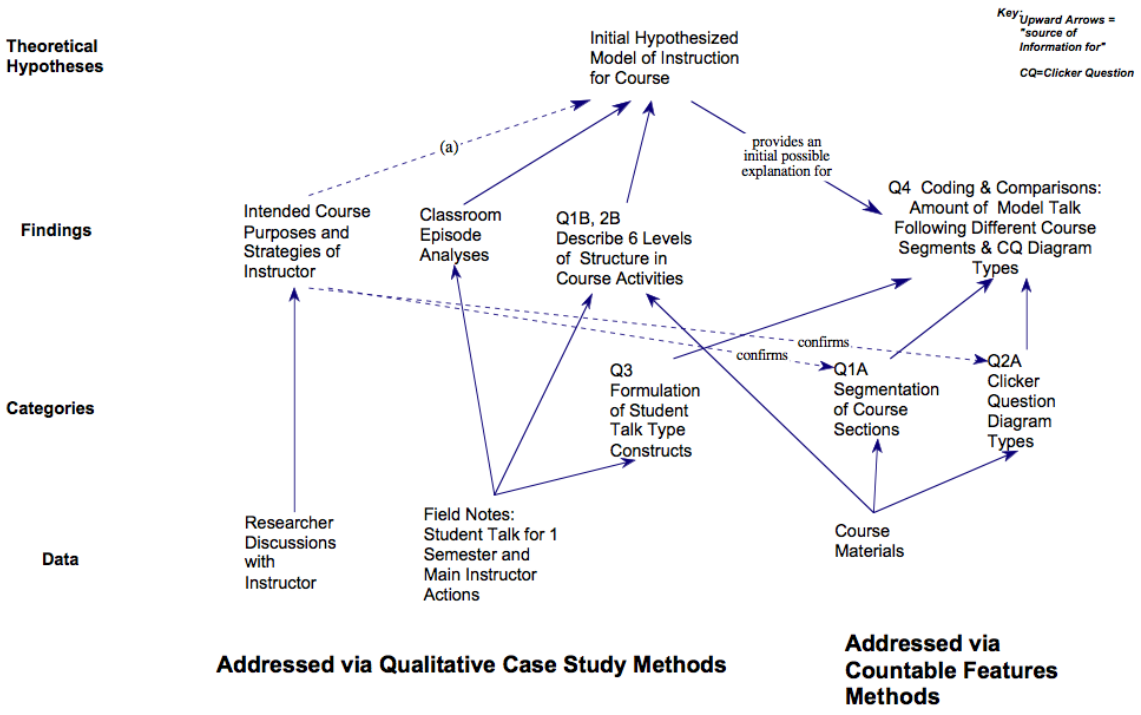


Figure 5-1: Data sources and sought findings for case study.

Dashed line (a) signifies information that influenced the understanding and interpretation of particular course features identified by the researcher. Nevertheless, the researcher endeavored to make independent observations and interpretations, and in some cases her interpretations differed from and held sway over the instructor's in this document. In the case of the physical/temporal structure of the course materials, the instructor was interviewed and confirmed those structures (dotted downward arrows).

CHAPTER 6

INITIAL DESCRIPTION OF THE GAMBR CLASSROOM

This chapter begins to address the following statement:

> A detailed description of the Guided Application of Model-Based Reasoning in Biology instructional approach will be generated... and presented in the final report to help place the findings in context and support understanding of any theories or implementation recommendations presented in the conclusion.

It also provides an initial overview description of the course to help set up the context and background for the study.

Introduction

As discussed in Chapter 4 the Guided Application of Model-Based Reasoning in Biology (GAMBR) instructional approach is a method of implementing clickers in large lecture biology courses that engages students in reasoning with biological models. Chapter 4 provided background on the GAMBR approach and described the learning objectives for the course, providing a motive for the present case study. This chapter focuses on describing the activities of the course to provide a foundation for understanding other research results. The GAMBR approach used in the course is complex and layered. The description will move from the highest level of organization in the course to the classroom details in hopes of providing a picture of GAMBR in action.

Method

The description of the course is based on personal observations and field notes collected during classes by the researcher and the course materials, including handouts, the textbook and the course website.

Results

Course Design

GAMBR is used to teach the first introductory biology course for majors at a large research university. There are usually no fewer than 480 students enrolled in the course. There are several parts of the course design that differ from traditional lecture including: overall course content organization, in class activities, pre- and post-class preparation, formative and summative question design.

Course Content Organization: Topics, Units, and Lesson Models

See Figure 6-1 for a visual representation of the organization of the course content.

Topics

The content of the GAMBR approach is organized at the highest level in overarching *topics* that are relevant to current biology research, such as stem cell biology, gene therapy, and cancer. These are the topics that make up the topical cycle described in Chapter 4. The topic is introduced to the students prior to engaging them with the models they will be reasoning with in the class. For example, prior to the students being

introduced to the stem cell self-renewal pathway model described in Chapter 5, the instructor talks about current stem cell research and provides examples of real signally pathways that have been modeled. This aims to ground the class model in a reality they identify with and increases their understanding of how and why working with the model ultimately impacts science and society. The instructor's intent is that this increases student buy-in because they see the relevance to “real” science.

As shown in Figure 6-1, the individual topics are continually connected at transitions between topics through the lessons. For example, the concept of signal pathways in stem cells is connected to producing changes in transcription and translation to accomplish gene therapy. The course appears to make the topics fully connected at the end of the course.

Units

Each topic contains two or more units. Each unit covers a specific content area. The units are presented to the students on the course website as an overarching concept, such as signal transduction, with a list of objectives that fall under this concept. An example list can be see in Figure 4-1 under the discussion of the course content goals.In that example, the unit is Control of Gene Expression. The instructor does not present these as separate units to the students but rather as the list of questions they should currently being focusing on. The course flows through several content areas, including Signal Transduction, Control of Gene Expression, Protein Structure and Function, Genetics, Metabolism, and Photosynthesis. These units can be thought of as the body of knowledge that the instructor is aiming for the student to build through application. The

units help build a complex knowledge set that is connected and applicable to real world material (e.g., stem cell science). The vocabulary and concepts are integrated into runnable mental models of phenomena (see models below) that the students are asked to reason with via clicker questions, with the instructional goal of students learning the content through applying the models that contain the content. As stated above, the units are situated within larger topics—topical concepts, such as stem cells or cancer. Several units relate to a particular topic, but they also bridge between topics, making the course a flow of connected content and topics. For example, the course starts with the topic of stem cells, situating the signal transduction and gene expression units within it. Genetic disorders (including mad cow disease and breast cancer) are the next topic and cover the units of gene expression, protein structure and function, and genetics and leads into metabolism.

Lesson Models

The content within each unit is taught through smaller associated lessons, each of which is about a scientific model that can be reasoned with. In looking back at the list of questions in Figure 4-1, the models are not specifically listed but rather are presented to the students as questions under the overarching unit. For example, the question within Figure 4-1, “How does transcription work and how is it regulated?” relates to the lesson on the model of transcription. However, the students are not presented specifically with a list of biological models that the course covers, on the website or elsewhere.

As shown in Figure 7-2, each unit contains 2 or more lessons. My use of the term model is consistent with Cartier (2000) who describes a model as "a set of ideas that

describe a natural process that can be mentally run to explain or predict natural phenomena" (Cartier et al., 2002). To elaborate, the term “model” means a relatively small set of interacting mechanisms that a scientist can reason with to generate predictions or interpret data. These models can be thought of as runnable via a mental simulation. The models are made of a series of interrelated steps that lead to a predicted outcome—changes in the input and/or structure of the model effect the outcome. The models also contain key vocabulary and concepts that the content within the unit(s) they are associated with are comprised of. For example, within the Signal Transduction unit, there are nested models of cell signaling that explaining the process of self-renewal and differentiation. Within the Gene Expression unit, there are nested models of gene regulation and transcription and translation that explain how genes are expressed. Units are connected through connecting the current lesson models back to models learned in previous lessons (i.e., by using clicker questions that ask students to reason about both models). For example, how improper transcription during gene expression will later impact the folding of a protein.

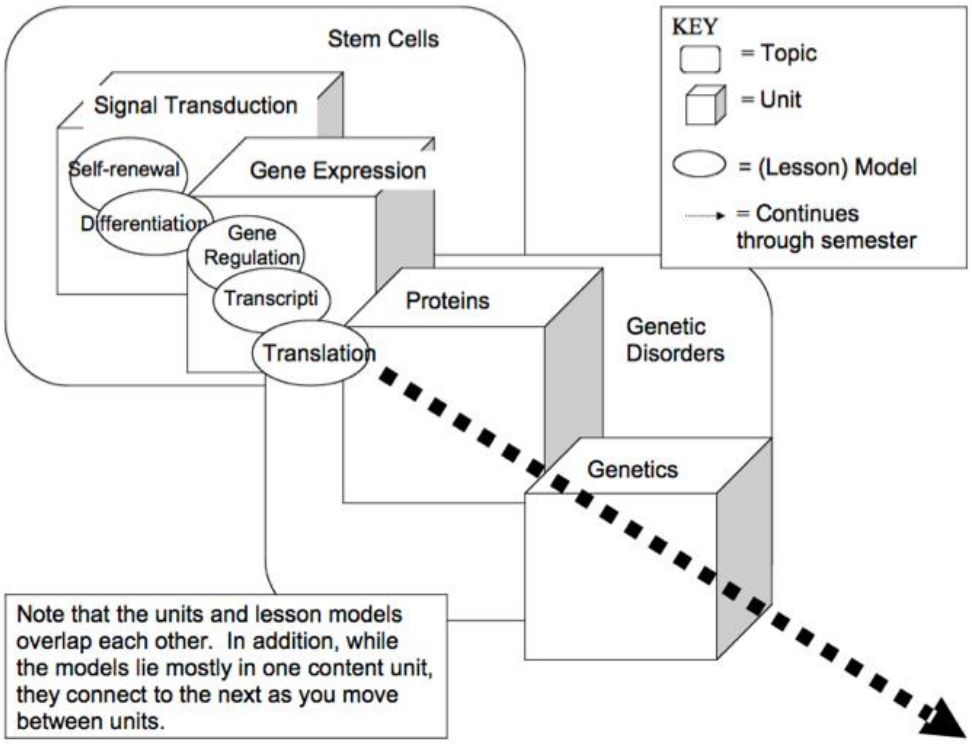


Figure 6-1: Organization of course content.

The content of the course is situated in real world topics. Each topic covers several units. The content of the units are casual models. The content is learned through applying the models. Clicker questions are used to get students reasoning with the models. The unit and initial model are introduced to the students prior to application and extension of the model with clicker questions. What is not shown here is that at each level of organization there is connection and continuity—topics are linked to topics, units to units, and models to models. These links are formed by the connecting of the lesson models.

In Class Activities:
Clicker Questions, Fun and Personalization, and Friday Quizzes

Clicker Questions

Clicker questions are used to guide the instruction in a format compatible but not identical with that described by Dufresne et al. (1996), termed Question Driven Instruction (QDI). There are specific learning goals, activities, and content structures related to the clicker questions used in the GAMBR instructional approach that make it different from QDI. Some of the key features of interest in the GAMBR clicker questions are described below under formative assessments. The main point of similarity to QDI is in the basic format of the question cycle, described below.

The QDI-type cycle begins with the instructor posing a clicker question to the students. The students then talk to each other in small groups about the clicker question and register a response with their clicker. After a set amount of time (typically 3-5 minutes), the instructor culls the clicker question, and the responses of the class are displayed in a histogram at the front of the class. The instructor solicits questions or comments about the clicker question from the students, generating a class-wide discussion. The class-wide discussion often includes or concludes with a mini-lecture on the key points of the clicker question. At the end of class discussion or mini-lecture, a new clicker question is posted, starting the cycle again.

Fun/Personalization

The instructor uses several approaches to humanize the large lecture experience. Prior to the beginning of each class, while students are finding seats the instructor posts a clicker question that is fun (e.g., “What is your favorite Halloween candy?” on

Halloween. These clicker questions will not be included in any analysis for this project). Responding to the question gives students the opportunity to get their clickers up and running before they are needed for class. Another way the instructor brings fun to the class is by sometimes reading the police report on Friday mornings. The instructor has pre-scanned the police reports prior to class and circled funny or interesting calls. This takes only a few minutes but creates a jovial atmosphere. Finally, the professor makes a point to have students state their name when they talk in class-wide lecture.

Friday Quizzes

The introductory biology class runs Monday, Wednesday, and Friday for 1 hour per day. At the end of every Friday class, there is a quick quiz on the material covered that week. The quiz is handed out when there are 5 minutes left in class, but students are allowed to stay later to finish. The quiz plays in important role in keeping both the students and instructor up to date on the student understanding. It provides motivation for students to keep up with what is happening in class and remain engaged and may prevent them from "cramming" before an exam because they are continuously revisiting the material. This is key because the models in class build on each other, so if a student fails to understand something from one class, she/he will likely have difficulty reasoning with future models correctly.

Pre-/Post-class Activities and Materials

In accordance with QDI methods in which GAMBR is grounded (see Chapter 4), the students are engaged in specific pre- and post-class activities to support their in-class learning. However, they differ slightly from the QDI approach as described below.

Course Website

Each semester the instructor develops a course website that provides the students with information about what they should be doing to prepare and review lessons as well as what to study for quizzes and exams. The learning objectives for each unit as well as the readings are posted prior to the start of a new unit and are embedded in the overarching topic. In some cases, a pre-week quiz is also posted on the website. After class, the instructor posts all of the clicker questions that are presented in class and occasionally ones that were not. The course website also serves as the place where students can find out about supplemental instruction sessions, upcoming exam, grades, and answer sheets for summative assessments.

Textbook and Other Readings

Students are assigned reading in most lectures. However, in a traditional lecture, it is not imperative that the students complete the reading prior to class, and the class closely follows the information that is presented in the textbook. In the GAMBR approach, the focus of units on current research topics and their relevant scientific models rather than units of biological content results in an unusual use of the textbook. The result of this organization is that the chapter divisions in the textbook are not relevant to what

the student might be learning in any particular GAMBR unit. The reading assignments, instead, list different pages and sections in the textbook as well as online websites the students should visit.

For example, the reading assignment for the Signal Transduction Unit in the semester studied reads:

> Readings from Freeman:
> Receptor mediated endocytosis is mentioned on p. 136
> Signal Transduction pathways are described on pp.170-175.

Through this approach, the textbook becomes a reference book rather than a book that the students read though chapter by chapter. This concept is emphasized when students ask what chapters they should be reading during class; the instructor commonly responds that they should look up the key works from the clicker questions in the back of the textbook to find the relevant sections. The recommended readings are also posted on the course website. This approach not only helps to blur the divisions that the textbook and most lecture structures create, it also aims to make students realize that they do not need to memorize everything; they can look something up if they forget it. Their textbook becomes a tool rather than a reading assignment.

Pre-week Quizzes

Occasionally students are asked to take a quiz prior to Monday's class based on their readings. The quiz is not graded by the instructor; rather, the main purpose of the quiz is to motivate students to engage with the readings prior to class so they will come to class having some knowledge of the terms and concepts that will be used in class. The clicker questions used in class help scaffold the vocabulary and concepts from the

readings onto the model, deepening students understanding of both the content knowledge and the model. However, during the observational period, the pre-quizzing approach was rarely used. Perhaps this is because the students seemed to be engaging with the readings without this motivational tactic. It is believed that the students likely complete the pre-class readings with the motivation that they will need the background knowledge to play along with the in-class clicker questions.

Used Clicker Questions

Clicker questions used in class are posted on the course website after class. The instructor aims to post the questions as soon as possible after class to allow students to revisit the ones they had issues with. Often the posted questions are accompanied by commentary by the professor that explains the reasoning behind each possible answer and how the knowledge that comes from that answer connects to bigger concepts related to the model. In some cases, the instructor will also post clicker questions that were not presented in class, ones that he might not have gotten to that day or were from previous years to provide more opportunities for the students to reason with the model. The professor also recommended to the students that they use the clicker questions posted on the website as study tools for Friday quizzes and unit exams.

Answer Keys for Quizzes and Exams

The quizzes and exams are posted along with the correct responses shortly after they are administered. This allows students to determine their grade and figure out which

ones they got wrong. The students are encouraged to use these as tools for practicing for future tests.

Formative and Summative Question Design

Aligning Formative and Summative Assessment

Another key feature of the GAMBR approach is the close alignment of the formative and summative assessments. The formative assessments in the class consist of daily clicker questions. On average, 3 clicker questions are posed per day. The summative assessment questions are used on weekly quizzes given every Friday at the end of class, 3 unit exams, and one cumulative final.

It is not uncommon for students feel there is a disconnect between what is taught in class and what is featured on quizzes and exams. The GAMBR approach addresses this issue through close alignment of the clicker questions and the quiz/exam questions. In a class setting of more than 400 students, multiple-choice, machine graded exams are the most simple and, therefore, common testing method; the multiple-choice clicker questions naturally aligns with this format. There are several differences, however, between the clicker questions and the quiz/exam questions that will be discussed below.

In addition to making students feel and be better prepared for exams, the close alignment of the formative and summative assessment provides motivation for students to play along with the in-class clicker questions and, hence, engage in the pre-class reading assignments. In addition, the students are likely motivated to understand the new model elements that are embedded in each clicker question and, thus, use the clicker questions as study tools.

Formative Versus Summative Question Design

The questions posed to students are designed to engage them in model-based reasoning. Model-based reasoning is the process of making predictions about or interpretations of biological systems using mental models that describe the system's components and the logical rules by which they interact.

The clicker questions are designed to be used during class time to get the students thinking and reasoning about the model and expanding their understanding of model—the terminology, mechanisms, concepts, and overall logic. These formative questions are often ambiguous and overly complex. There is often not a clear right and wrong answer among the choices provided. The goal is to get the student to run the model and think about how new concepts play into the logic and especially to give the students ideas to haggle over. In addition, the clicker questions are often used in progressive clusters to teach a particular lesson– termed clicker question clusters. These will be further described in Chapter 7.

The summative questions are designed to be used on exams and Friday quizzes. The summative questions are clearly written so they can be reasoned to a clear correct or incorrect end, aiming to test the students' understanding of the model and reasoning ability.

Case Description of a Day in the Classroom

To help the reader visualize GAMBR in action, this section of the chapter describes the events in one class. The ending of the previous class and beginning of the

following class is also briefly described to demonstrate the continuity and flow of the subject matter from one day to the next.

Sample GAMBR Class Sequence

The very first topical unit that is studied in the introductory biology course that GAMBR is implemented in is Stem Cell Research. The class sequence described below is set at the very beginning of the semester. It is important to look at a sequence of classes to visualize GAMBR because the classes build upon each other, with students continuously adding to their understanding of the models as the semester goes. One way to think about it in comparison to a regular lecture is to make an analogy to a TV series versus sitcoms. In general, you can watch any episode of a sitcom and pretty much follow what is going on without watching any earlier showings because the content can stand alone; this is similar to traditional lectures where one lecture covers a particular section of the text. In contrast, there are TV series where it is very difficult to jump into a single episode without having seen all the previous ones, and the further you get from the initial episode, the more difficult it becomes. The GAMBR approach is similar to TV series because fundamental information about the model covered in one class is needed to reason with the ever-increasingly complex model(s) in subsequent classes. Even as the units change, the models from the previous units are still applied, maintaining continuity across the entire semester.

Note: Numbering of students starts fresh with each Clicker question example. Therefore, Student 1 in one example is not likely the same student as Student 1 in a later example.

Day 1

The first topic covered in the introductory biology course that GAMBR is implemented in is Stem Cells. The following question is posed after a mini-lecture introducing overarching ideas in developmental biology, focusing students on life beginning with one cell that becomes an entire being made up of many different types of cells. How does this transformation happen? Toward the end of class the following clicker question is posted to plant the seed for the signal transduction model that students will be introduced to in the next lesson. It is important to note that the information being asked for in this clicker question was not covered in the proceeding lecture, nor are the students told the purpose of the question. Rather, this question is meant to get students to generate their own ideas about how stem cells receive signals. The research views this as allowing for creative scientific thought (starting from their prior knowledge from outside of the course):

How are signals received by stem cells?

1. DNA enters the cells and activates genes.
2. Proteins enter the cells and activate other proteins.
3. Proteins bind to the surface of cells and change cell behavior.

Day 2

The class sequence starts with the professor introducing the importance of stem cell research by showing and talking about different headlines found earlier that day on Google news. They include economic, political and legal issues, and cover areas of research ranging from hair loss to spinal cord injury. More specific information about stem cells is then presented, including that stem cells exist in 2 states (self-renewal in which they are waiting to divide and differentiated in which they have become committed

to become a particular type of cell but not yet matured into a fully functioning cell). Also relayed to the students is the idea that the medium stem cells are exposed to impact their state and course of differentiation. This takes no more than 20 minutes. He then posts the following PRS question for student to haggle about:

> Some attempts to treat diabetes in mice have transplanted embryonic stem cells into the pancreas. Unfortunately, the stem cells differentiated into a variety of tissues, including skin, muscle, bones and teeth, instead of pancreas tissue that could produce insulin.
>
> What could have caused these problems? (pick all that apply)
>
> 1. The mouse pancreas sent the wrong signals to the stem cells.
> 2. Mouse blood carried the wrong signals to the stem cells.
> 3. The stem cells sent a mixture of signals to each other.
> 4. Embryonic stem cells are programmed to become a whole organism and not just one tissue type.
> 5. The stem cells were being rejected by an immune response.

This question is a model-choosing question (see model-based reasoning learning goals in Chapter 4). The students have not yet been presented with a specific model with which to reason. The question aims to get the students to understand why a cell signaling model would be important in stem cell research by asking them to think about the idea that stem cells need to know when to divide or not divide and what to become or not become. The question also aims to get them thinking about how cell signaling might work. Once the students have discussed the question, about 3-5 minutes, the professor prompts them to enter a response via their clicker. The instructor then displays the histogram of the student responses. Often the instructor comments on the histogram, remarking on which response the students liked best or that there was no clear "winner."

He then solicits questions from the students or asks why they chose a particular answer. Below is an example of a class-wide discussion following the above clicker question:

> **Instructor:** Clarification questions?...What was wrong/incorrect?
> **Student 1:** Could eliminate 5
> **Instructor:** Why?
> **Student 1:** How could you get this variety if no stem cells are left?
> **Instructor:** Other things you could eliminate?
> **Student 2:** 4
> **Instructor:** Why?
> **Student 2:** It is obvious that cells don't become entire organisms.
> **Instructor:** (no verbal response, points to someone else)
> **Student 3:** 2, incorrect, blood could be the signal carrier
> **Instructor**: Yeah, okay but go more general
> **Student 3:** Pancreas can't be right because it would send pancreas signals
> **Instructor:** Okay…
> **Student 4:** Yes it is possible; in text said spontaneous generation can occur from different tissue cell types.
> **Instructor**: Is this consistent with the idea that the pancreas is supplying signals? What about receptors?
> **Student 3:** If the stem cells displayed new receptors then you could get signals from all parts of the body.

The responses suggest that students are engaged with the model and trying to reason with it. Students tend to ask questions to help clarify their understanding or provide an answer and an explanation (in some cases when prompted) for their reasoning. Students are using vocabulary words, referring to information that they have read in the textbook, and through asking questions and explaining their reasoning, they are providing formative feedback, thus, helping the instructor understand what their mental model is or where they are have gaps in their knowledge. The instructor facilitates the discussion by asking students to explain their answer and responding to questions about vocabulary words and concepts. The length of time for class discussion varies greatly depending on the student responses and the instructor's goals and often ends with a mini-lecture on key points raised by the clicker question. In this example, the class ends with the discussion

of this clicker question, but, if time had been available, more clicker questions would have been posed.

Day 3

When students enter class, they are instructed to pick up a handout of a diagramatic model representation of a stem cell self-renewal pathway (see Figure 6-2). The professor begins class by talking briefly (5-10 minutes) about cell signaling and showing some Powerpoint slides of different signaling pathways that have been modeled, ending with an image of the stem cell self-renewal signaling pathway diagram that will be used in class, introducing it as "the bio100 version of a cell signaling pathway." The instructor then introduces the components and basic logic of the stem cell self-renewal model by quickly (1-2 minutes) running through the diagram. This is promptly followed by the clicker question below, which is the first question of a clicker question cluster related to the stem cell signaling diagram.

> Problem 1 of Clicker Question Cluster on stem cell self-renewal signaling:
>
> If this cell is analyzed and TK2 is found to be phosphorylated, is the signal present?
>
> 1. Yes
> 2. No
> 3. Maybe

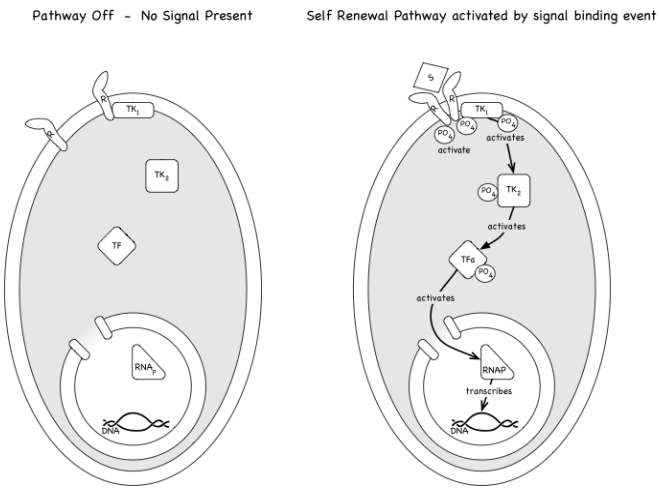


Figure 6-2: Diagram of the stem cell self-renewal pathway.

This diagram is handed out to students to be used in conjunction with the clicker question cluster shown here. This question is a model-using question (see model-based reasoning learning goals in Chapter 4) in which the students are being asked to run through the basic logic of the model. However, there is a twist to it that increases its complexity and opens the door for discussion and deeper understanding of how the model functions. In the diagram, TK2 is shown to be phosphorylated when the signal is present; however, the diagram is just a static representation of a dynamic system. In presenting the students with the Maybe option, they have something to think about: could the signal start the system and then go away, or does it have to stay there the entire time? While many students pick Yes, there are always a few who pick Maybe, and it is these students who help open the discussion about how long things last within the system, revealing the complexity of the simple model. The instructor begins this discussion by asking someone to explain why he or she picked Yes:

Student 1: The signal activates the TK to phosphorylate it.

The instructor agrees then asks someone to explain why he or she might pick Maybe:

Student 2: Maybe, the signal might not still be there –it must be originally but might not be now.

This is followed by several student questions:

Student 3: How long do these things last?
Student 4: By present, do you mean attached to the receptor?

These questions appear to be examples of students trying to clarify their understanding of the model. These are different from clarification questions in traditional lecture that asking for definitions or clearer explanations to be able to reproduce them later. One can hypothesize that these students are seeking the knowledge about the model so that they can better understand to be able to reason with it. I believe this motivation for knowing is key because they are looking to use the information, not just store for later use. Even in Student 2's response it appears that s/he is still thinking about how it might work and, therefore, likely to be open to gaining more information about the model in order to reason more confidently. It is important to note that students often seem excited by the puzzle solving nature of the model-based clicker questions. I have even heard many report it as fun.

The professor responds to each of the students' questions with brief explanations. The discussion ends with the professor re-asking the key ideas this clicker question provoked: How long does this signal last? What happens if the signal is not there? What regulates the length of time the signal is present? followed by a mini lecture in which he

responses to these questions. The next clicker question is then posed, which deals with modifying the model by introducing a new component.

> Problem 2 of Clicker Question Cluster on stem cell self-renewal signaling:
>
> The self renewal signaling pathway in a particular stem cell type has an additional kinase, TK3 that targets TK1. TK3 is produced from the expression of a gene activated by TFa. How would TK3 change the behavior of the pathway?
>
> 1. It would become a temporary circuit, even when signal is still present.
> 2. It would become a permanent circuit, even when signal is absent.
> 3. It would not change.

This question is a model elaborating and revising question (see model-based reasoning learning goals in Chapter 4). This question is asking the students to reason about how adding a new component to the model will impact the overall functionality of the system, expanding students understanding of the model. In addition, the flexibility of the model may be demonstrated to the students, meaning that students may begin to understand that the model they were first introduced to in the lesson is not the entire and only possible version of the model. The model can be manipulated to become a permanent or temporary signally circuit. This is an important biology inquiry concept—existing models are continuously revised and expanded as our knowledge of biology grows and used as spring boards to begin thinking about how unknown systems might be functioning and generating new models.

> **Student 1:** By targets, what do you mean by that?
> **Instructor:** Activates or inhibits, the target of a kinase is another kinase…[goes on to provide an example]
> **Student 2:** I said permanent because if you add something that adds a phosphate, it would make the signal be on with or without the signal
>
> The instructor runs through what student 2 said pointing at the diagram (projected at the front of the room). He agrees with the logic and defines this type of pathway as a positive feedback loop. This is followed by additional questions about the model.

Student 3: Where are the phosphates and tyrosine kinases coming from?
Instructor: Nucleus, made by genes, all these things—signal, TK1, 2, etc., all of them are made by the genes."
Student 4: How could you make it temporary?
Instructor: That sounds like a good quiz question.

The class ends on this note. In the following days, the course encourages students to continue to grow their knowledge of the stem cell self-renewal model with other questions from this clicker question cluster. The number of clicker questions used in class increases as the students become more involved with the model, as students learn the model through applying it. After about a week, the model is expanded to include differentiation as well, and a new diagram is handed out (see Figure 6-3) that shows both self-renewal and differentiation. This new diagram is, again, used in conjunction with a cluster of clicker questions over the course of several classes. The course continues in this vein, with each new model being either a direct extension to the current model or a biologically connected model. For example, from signal transduction the instructor moves to gene expression, where the link/connection is that signal transduction is what sets off gene expression (determines which genes will be expressed by activating a particular transcription factor).

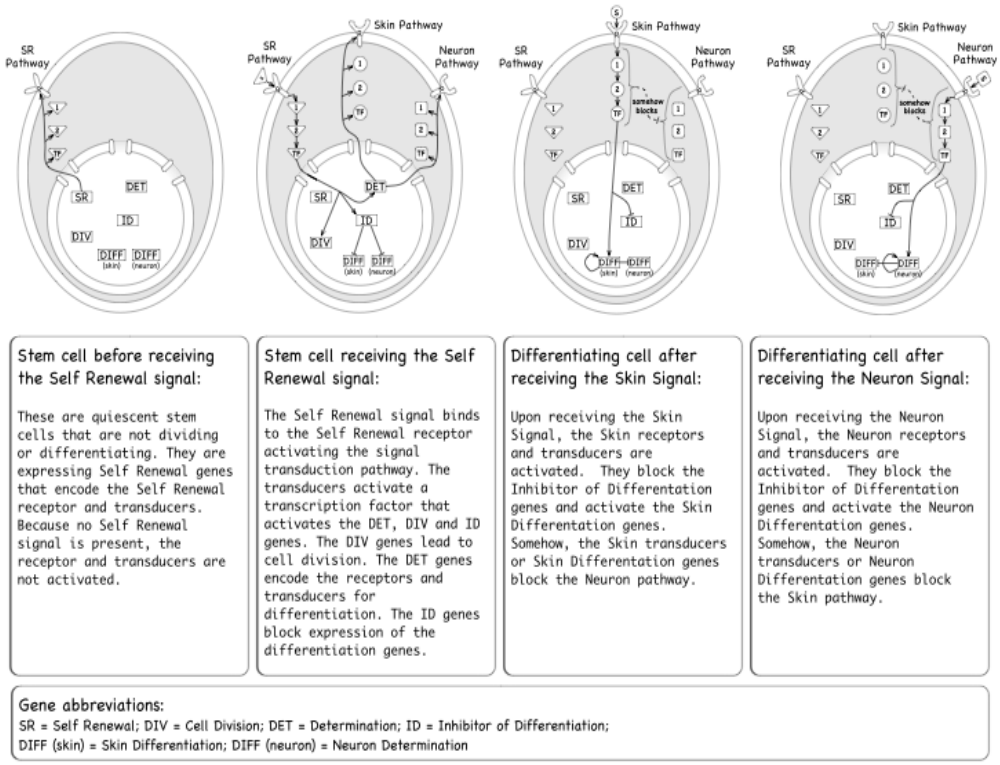


Figure 6-3: Diagram of the differentiation pathway.

This handout shows the progression of the cell signaling pathways from a stem cell in a state of self-renewal to a state of differentiation. The students use this diagram set in conjunction with a corresponding clicker question cluster.

Overview of Class Flow and Flexibility

The above example was chosen to demonstrate the flow of the class because it falls at the beginning of the semester and, therefore, is less complex in content than classes further into the semester (in the hopes that it requires the reader to have less biology background to follow). However, the disadvantage of this example is that is does not provide a picture of the great variety of class structures that appear during GAMBR, and

it errs on the side of "light" clicker days, or days when fewer clicker questions are posed because it falls at the start of the semester and the start of a new unit. Therefore, this section provides additional description of the variety of the class structure one might encounter over the course of a semester.

Generally, class begins with lecture. Classes may end with any of the possible activities: lecture, problem, group discussion, or class-wide discussion. In my experience, an instructor does not have to be particularly concerned with what type of activity closes the class period because clicker question clusters are designed to run over several class periods. Class flow depends on the topic being covered and how far into the topical cycle the class falls. The instructor reports a trend toward decreasing lecture and increasing use of problem clicker question clusters to guide instruction as a topical cycle progresses. The instructor commonly uses lecture to lay the framework for the model at the beginning of a topical cycle. Once students are familiar with the initial model, the class time increasingly revolves around the clicker question clusters.

It is critical to point out that the actual class structure is not planned down to the minute in advance. The instructor goes into class with instructional goals and a prepared sequence of GAMBR problems that might be used; however, the final class structure is heavily influenced by in-class interactions with students. By asking students to grapple with real biological processes, the instructor interacts with them in a very direct manner and can react to student misconceptions in real time and adjust the flow of class activity to meet their immediate learning needs. For example, an instructor could come to class with four problems about a model of gene expression. After presenting the first problem, the instructor may find that during the class-wide discussion, students raise concepts that

the instructor was planning to bring up with the second problem. At this point, the instructor can forego the "already covered" second problem in favor of pushing the topic forward, using the third problem in the cluster. The opposite might also happen. The instructor may plan for a problem to bring the class to a certain level of understanding, but PRS and student feedback makes it clear that the students are struggling. In the GAMBR approach, the instructor can step in and redirect the flow of class while the students are still in the classroom. The instructor could:

- Do a mini-lecture to clarify key points.
- Extend small group discussion to encourage debate and build consensus.
- Extend class-wide discussion to draw out clarifying questions and misconceptions.
- Ask an easier clicker question to ease the transition to the mode challenging problem.

Depending on which strategy the instructor chooses, the flow of the class may change from the original lesson plan. For some instructors, good questions occur in direct response to a student comment. This spontaneous question could then be chalked on the board, added to the lesson plan "on the fly" and polled using clickers. Perhaps one of the most interesting uses of the spontaneous clicker question is to turn a student question to the instructor into an opportunity for the class as a whole to work on a peer's question. This strategy could help shift students' perception that the instructor is the only source of knowledge to an appreciation that biological knowledge is something that can be generated through collaboration with their scientific peers.

Summary

This chapter aimed to describe the Guided Application of Model-Based Reasoning instructional approach. The major components of the course were identified and described and the flow of daily classroom activities was described in detail through an example that brings the reader through several consecutive classes.

The major components of the course include the overall structure of course content, classroom activities, pre- and post-class activities, and summative and formative question design. There are 3 levels of content organization. The highest level of organization is the Topic, motivating the content in real-life issues such as cancer research. The second level of organization is Units, including gene expression and signal transduction. At the third level of organization are Lesson models, such as stem cell self-renewal signaling pathways. There are 2 major activities that occur in class: Question Driven Instruction (QDI) and Friday quizzes. Class time is structured in accordance with QDI as described by Dufresne et al. (1996). Every Friday there is a quiz at the end of class. In addition, there are fun activities meant to personalize the classroom atmosphere. The pre-/post-class activities/materials play an important role in preparing students for class activities and summative assessments. These include the course website, textbook and other readings, online pre-week quizzes, clicker questions, and answer keys for quizzes and exams. The course design also includes the alignment of formative and summative assessments so the clicker questions used to guide instruction are reflective of what the students can expect on exams.

The class flow represents an example of flexible and responsive teaching using clickers. Samples of clicker questions and the class-wide discussions that follow were

described, including examples of what students say and instructor responses. The instructor moves from content to model application using mini-lectures, PowerPoint presentations, and clicker questions. Students ask questions, make statements, and explain their reasoning during class discussion following clicker questions. The following chapters examine these kinds of instructional patterns, clicker questions, and student talk types in more detail.

CHAPTER 7

PATTERNS/CYCLES OF INSTRUCTIONAL PHASES

This chapter addresses Research Question 1: What major patterns/cycles of instruction took place during the course? (A) How is the course broken down into sections, such as topics and units, and where do models occur? How many instances of each type of section occurred and how are they distributed over the semester? (B) What is the qualitative structure of the instruction within the sections? Are there patterns or cycles in the instruction that utilize models?

Introduction

The clicker literature has called for the use of questions that result in cognitive engagement (Beatty et al., 2006a, 2006b; Cooper et al., 2006; van Dijk et al., 2001). Peer instruction (which was the most commonly used approach to clicker use found in the biology literature) increases engagement in course material and provides students with the opportunity to gain tutoring from a peer, resulting in better performance on subsequent clicker question responses of the same question (Armstrong, Chang, & Brickman, 2007; Crouch, Watkins, Fagen, & Mazur, 2007; Crouch & Mazur, 2001; Herreid, 2010; Knight & Wood, 2005; Mazur, 1997; Preszler, 2009; C. Tanner, 2003). However, many of the examples of the uses of clickers in biology (including those using PI) remain focused on increasing student motivation and engagement during lecture (Armbruster et al., 2009; Brewer, 2004; Cain & Robinson, 2008; Caldwell, 2007; Collins, 2007; Crossgrove & Curran, 2008; Draper & Brown, 2004; Knight & Wood, 2005; Preszler et al., 2007; Suchman, 2006). Such clicker questions aim at assessing students' knowledge of what was just taught via lecture and are used to break up the lecture and

allow time for students to reflect on what they just learned. While this application of clicker questions has been reported to increase learning as assessed on subsequent exams (Crossgrove & Curran, 2008; Preszler et al., 2007; Reay, 2008), uses of clickers to engage students' scientific reasoning skills were not found in the literature.

Therefore, there appears to be a lack of available knowledge on how to implement the use of clickers as tools for increasing scientific reasoning skills in large lecture biology classrooms rather than as tools for enforcing attendance, preparedness, engagement, and performance on traditional content assessments. Guided Application of Model-Based Reasoning in Biology (GAMBR) is a skills-based instructional approach to teaching biology in large lecture halls that aims to use clicker questions to help students learn both content and model-based reasoning skills. As stated in Chapters 4 and 6, the model-based reasoning skills that the clicker questions aim to engage students in are related to a specific set of learning goals set forth by the professor, and the summative assessments of the course aim to test students content knowledge and model-based reasoning skills.

In this chapter, the patterns and cycles of GAMBR instruction are discussed on the basis of the course materials and field notes to describe the different phases of instruction. Later in the chapter, I begin to generate a model of the instruction cycle that will later be presented more fully in the conclusion. It is hoped that in doing so, the idea of clicker questions as tools to teach and provide experiences in scientific reasoning will become more accessible to other instructors.

Methods

Every class (total of 32) was observed for the fall semester of 2006 of an introductory biology course taught at the University of Massachusetts Amherst by 2005 Distinguished Professor Randall Phillis. Course materials used and observational field notes were recorded focusing on various elements of the course.

Research Question 1 was split into two parts:

(A) How is the course broken down into sections, such as topics and units, and where do models occur? How many instances of each type of section occurred, and how are they distributed over the semester?

(B) What is the qualitative structure of the instruction within the sections? Are there patterns or cycles in the instruction that utilize models?

See Figure 5-1 for a visual representation of how the data sources are used to address Research Question 1.

Data Sources

Field Notes of the Classroom Activities and Course Materials

The field notes include snippets of what the instructor said and did, including information and actions surrounding drawings made on the chalkboard, handouts, and PowerPoint presentations or other projected information. No audio or video recordings were made of the classroom, so the data are limited in that they does not include everything that was said by the professor but is a summary of observations of significant classroom activities in the order they occurred. The researcher did attempt to record the gist of every student utterance/turn during class discussions.

Question 1A: Identification of Major Course Components

Course materials were examined to determine the structure of the course content organized into phases and placement of the clicker questions within the course structure. The segmentation of the course and the placement of the clicker questions within those segments were confirmed by the instructor.

The clicker questions that occurred in each phase were counted and described.

Question 1B: Case Description of Instructional Activities

Case study analyses of field notes were used to generate descriptions of the general activities of the instructor, including use of clicker questions. More microscopic patterns and/or cycles of instruction that occurred within the lesson (smallest) phase analyzed were of particular interest.

Results

The focus of this research question was to gain knowledge about how the instruction flowed in relation to model-based reasoning, in other words, the researcher was actively looking for patterns or cycles of instruction related to the lessons used in the course to teach the models and engage students in model-based reasoning.

Structure of the Course

Three Phases of Instruction

The nested structure of the course content on which the segmentation of instructional phases is based is presented first. The instructor confirmed the segmentation

and structure of content, as well as the placement of the clicker questions. The total number and percent total of clicker questions found in each phase is reported. Descriptions of the instructional phases and the pattern and cycle of instruction within the lesson phases are presented.

The phases of instruction presented in this section aim at describing how the course-defined levels of content are used to support the content and model-based reasoning learning goals of the course. Examinations of the course content information provided to the students on the course website indicated the hierarchical structure of the course based on the different content levels described in Chapter 6. The instructor confirmed the content organization and segmentation of the course into phases of instruction for each level of content. Table 7-1 shows a complete map of the course content, and Table 7-2 shows the number of instances of each phase. Table 7-3 shows the characteristics of the different phases in the hierarchical organization and segmentation of the course agreed upon by the instructor, and Figure 7-1 aims to help the reader visualize the hierarchical content organization and nested instructional cycle that is pre-determined by the structure of the course content.

Table 7-1: Structure of the course content.

TOPIC	CQ	UNIT	CQ	Lesson (Model)	CQ
Topic 1: Stem Cell Research	1				
		Unit 1: Signal Transduction	4		
				Model 1:Self-renewal	4
				Model 2:Differentiation	2
		Unit 2: Gene Expression	1		
				Model 3: Gene Structure	2
				Model 4: Gene Regulation 1	7
				Model 5: Bacteria Gene Regulation	2
				Model 6: Transcription	2
				Model 7: Translation	3
				Model 8 gene regulation 2 (Clathrin gene model)	*3*
Topic 2: Metabolic Disorders, e.g. Mad Cow	0				
		Unit 3: Protein structure, enzyme function and energetic	1		
				Model 9: Protein Folding	1
				Model 10: Chaperone-Proteasome	2
				Model 11: Enzymes: Vmax/KM	5
				Model 12: Free Energy	6
				Model 13: Electro Transport Chain	6
				Model 14: Aerobic Respiration	5
		Unit 4: Photosynthesis	2		
				Model 15: Photosystem II and I	4
Topic 3: Cancer Genetics	1	Unit 5: Genetics	0		
				Model 16: Chromosome Segregation	4
				Model 17: inheritance patterns	5
Topic 4: Environmental Cancer	1				
		Unit 6: Cancer	1		
				Model 18: Cancer Stem Cells	2

Table 7-2: Total instances of instructional phases.

	Total Instances
Topic	4
Unit	6
Lesson (models)	18

Table 7-3: Characteristics of different phases in hierarchical organization and segmentation of course.

Phase	Purpose	Phase Characteristics of Organization and Segmentation of Course	Other Characteristics
Topic Level Phase	Motivate	Focus: Biologically relevant, motivating, general, real-world topic, e.g. stem cell research or "How do we heal? Content Level: Super Macro	Main Instructional goal: motivate student engagement Main instruction format: PowerPoint Talk
Unit Level Phase	Scaffolding	Focus: Introduces more specific biological phenomena and processes related to the content unit, e.g., signal transaction Content level: Macro	Main Instructional goal: raise big question about the general causes of the biological phenomenon and provide background content for Lesson models addressed below Main instruction format: Extended (Instructional) Lecture
Lesson Level Phase	Apply	Focus: Even more specific model, e.g. stem cell self renewal signaling pathway Content level: Micro	Main Instructional goal: Get students to reason with models to actively apply and extend content knowledge and model-based reasoning skills Main instruction format: Clicker questions and Micro (application) lecture

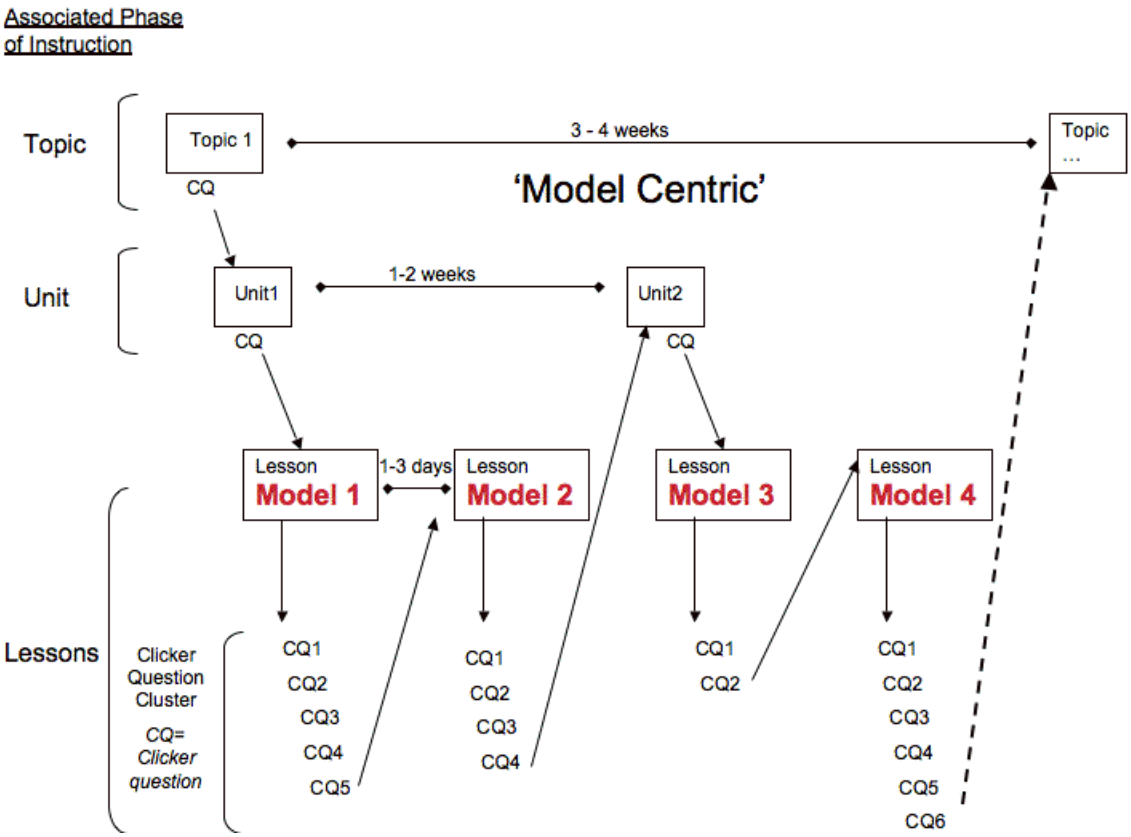


Figure 7-1: Structure and cycles of content and instruction.

The diagram shows a hypothetical progression of content and instruction through the course. Topic Phase is used to introduce a real-world topic (T) of interest to motivate student engagement. The Unit Phase introduces the course unit (U) and scaffolds the models. The Lesson Phase contains several lessons that each introduce specific models and ask the student to reason with them. The location of the models within the course structure are noted in red. (Dotted oval is expanded in Figure 7-4).

Clicker Questions Across Instructional Phases

The placement of the clicker questions in each phase was confirmed by the instructor and then counted and described. Table 7-4 shows the results of the count.

Table 7-4: Total clicker questions per instructional phase.

	Total # CQ	% Total
Topic Phase	3	4%
Unit Phase	9	12%
Lesson Phase	65	84%
Total Clicker Questions	77	100%

The majority of the clicker questions fall during the Lesson phase of instruction. A total of 77 clicker questions were used over the examined semester. Clicker questions were not always used in the Topic and Unit Phases and totaled only 3 and 9 consecutively. Clicker questions were used in abundance in the Lesson phases, totaling 65.

Case Study Description of Instructional Phases and Related Clicker Questions

Differences in Clicker Questions Across Instructional Phases

Clicker questions used in the Topic Phase focused on the topic that was being used to motivate the students and polled opinions or personal relationships with real-world issues (e.g., students feelings about the use of embryonic stem cells in research, whether students knew someone with cancer, whether students smoked cigarettes, etc.).

The Unit Phase clicker questions focused on a biological phenomenon related to the content unit and asked students to consider general causes of the biological phenomenon. The Lesson phase clicker questions focused on the model and asked students to reason about specific cause and effects related to model elements. In addition, the clicker questions in the Lesson phase often had diagrams associated with them. These

will be discussed in Chapter 8. See Figures 7-2 for a visual representation of the differences between clicker questions across the instructional phases.

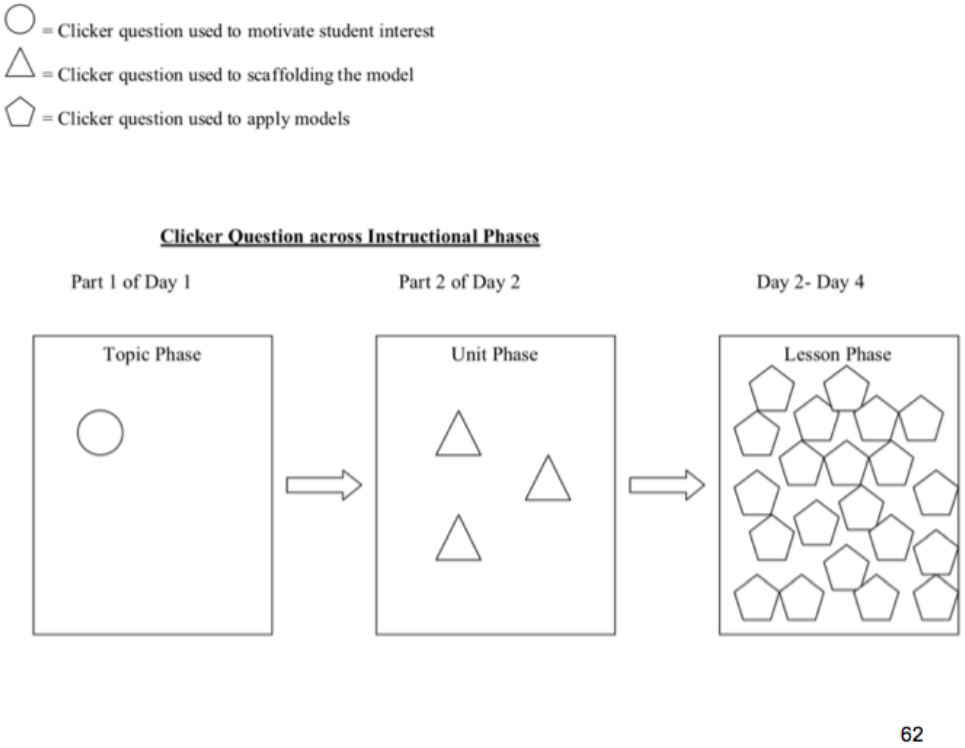


Figure 7-2: Clicker questions across phases.

Each box represents a different instructional phase and shows the comparative average number of clicker questions used in that phase. The times at the top of the boxes and arrows between them represent a possible time progression for the instructional cycle.

Description of Instructional Phases and Modes

As stated above, each instructional phase correlated to one of the levels of content organization discussed in Chapter 6. The first phase of instruction is Topic; in this phase,

the instructor motivates student engagement by presenting information on a world-wide topic related to biology that is of current social interest, for example, stem cell research. The second phase of instruction is Unit; in this phase the instructor introduces on content related to a specific unit, e.g. signal transduction, scaffolding the models that will be reasoned with in the next phase of instruction. The third phase of instruction is Lesson; in this phase the instructor executes several lessons on specific models and asks the students to apply the model (using clicker questions to stimulate student and instructor activities). There are three modes that occur within a lesson: introduce the model and revised and extend comprehend and revise the model, connect the model. All of the phases and modes are described below in Table 7-5.

Table 7-5: Brief description of instructional phases.

Phase	Description
Topic	**Motivate engagement with a real-world topic**
Unit	**Introduce course Unit and scaffold models**
Lesson	**Revise and extend model through application**
	Introduce model
	Extend, revise, and comprehend model through application
	Connect models through application

Topic, Unit, and Lesson are the three instructional phases that surround a lesson in the GAMBR Instructional approach. Lessons include modes of Introduce, Extend/Revise/Comprehend, and Connect the model.

The subject moves from macro to micro across phases (e.g., Stem research is current, pertinent, and controversial subject in biology. Stem cells can be used to cure disease. Controlling stem cell division and differentiation is required for their use as medical treatments. Understanding the intricacies of the self-renewal and differentiation processes is necessary for controlling these processes). Topics last three to four weeks, units last one to two weeks, and lessons last one to three days.

Topic Level Phase

Instructional Goal. Provoke student interest in the course material through relevance to real-world biology topics of social interest.

Overview. The initial phase of the learning cycle is to introduce an overarching real-world topic that will motivate student interest (e.g., stem cell research, cancer, etc.). This situates the content in the broader context of the world and science. Further, it prepares the students for reasoning with the models by providing specific real-world application for the knowledge: if you want to cure medical conditions using stem cells (topic), you need to control what stem cells differentiate into. This is done by controlling the signally (unit). To control the signally, you need to understand how it works (model).

The instructor starts at the human level by talking about the overarching topic while showing images of people who are sick, headlines of related world or political

issues, and the like. The goal of this is to get the students motivated: this is a topic of major world importance. The instructor connects the real-world topic to research conducted by biologists by showing current scientific findings that are in the news. The goal of this is to get the students to see the role that biologists play in this topic. This tends to be a PowerPoint-centered activity, with mainly images rather than text: pictures, headlines, or scientific article title. The students are not expected to memorize or even really learn the material being presented; rather, the goal is to get the students motivated and bring real-world application to what they will learn.

Clicker Questions.

- Zero or one clicker question is used in this phase.
- If used, clicker questions focus on students' opinions or relationships with real-world issues.

Classroom Example. Teacher presents a PowerPoint about Stem Cell Research (peaking student interest). The PowerPoint demonstrates to students that stem cells are a current research topic of interest to biologists as well as to the general public. This supports the idea that they are learning real information, information that is relevant to them and others.

Initial slides present headlines of research on potential and current uses of Stem Cells in the news:

Hair lose therapy

Heart patients

Growing new hearts

Spinal cord injury

Sperm and eggs

Tendons

Cartilage

Instructor states, “I just found these headlines on Google News this morning,” briefly reads each headline, making commentary on them. The next set of slides shows news headlines, pointing out current social issues related to stem cells, including:

Economic

Political

Legal

Example Clicker Question:

Should embryonic stem cells be used for research?
1) Yes
2) No

Unit Level Phase

Instructional Goal. Raise big questions about the general causes and effects of biological phenomenon and provide background content to scaffold the models that will be reasoned with in unit lessons.

Overview. Once the overarching topic has been introduced, but before the students begin reasoning with models, the instructor presents content related to the unit, leading the students from a macro to a microscopic understanding of what is happening. This provides scaffolding that aims to help the students when they begin reasoning with

the models associated with the unit (e.g., that there are different types of stem cells, that stem cells self-renew to maintain their population, that once stem cells start down the path of differentiation, they become at least partially committed to a particular cell type, eventually reaching the idea of signal transduction pathways being the mechanisms that control self-renewal and differentiation). This phase also aims to help the students understand the broader application of the model: if you want to control what stem cells (topic) differentiate into so you can use them to cure health issues, you have to control ***signaling*** (unit). To control the signally, you need to understand how it works (associated models).

During this phase, the instructor conveys information to the students via lecturing. The lecture period includes writing on the board, PowerPoint with text and images, and animations from the web. For example, signal transduction is introduced by talking about the roles that cell signaling plays in stem cell differentiation. By the end of this lecture-based phase, students are meant to know that stem cells differentiate and self-renew and that these behaviors and their outcomes are controlled by signals received from outside the cell. Key vocabulary words have been presented on an ever-increasing level of microscopy, for example, starting with terms, such as adult and embryonic stem cells to differentiation, determination, and self-renewal, to signal transduction. The terms and relationships introduced in the lecture scaffold the initial models of signal transduction that the student will learn and reason with in the Lesson phase.

Clicker Questions. The following are clicker question possibilities.

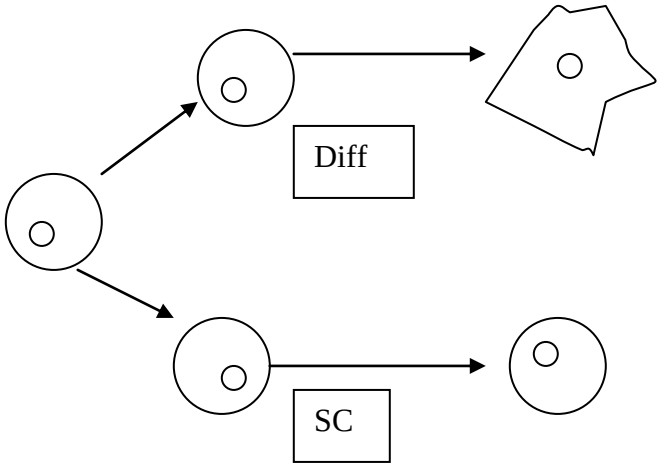
- None, or few clicker questions are used in this phase.
- If used, the clicker questions focus on general cause of biological phenomenon related to the unit and aim at setting up the model (e.g., signs in the environment control stem cell differentiation. Models of signal transduction are needed to understand and control differentiation).

Classroom Example. See below for a classroom activity.

The instructor talks about how stem cells are found in just about any tissue. They exist in 2 states:

- Just waiting for something to happen: Not differentiated, self-renewal
- Others are differentiated

Instructor draws the diagram below on the board:



SC – stands for Stem Cell

Instructor talks about how when a stem cell is signaled to divide, the stem cell divides into daughter cells; one daughter cell differentiates, the other one remains a stem cell—maintaining the population of stem cells. He states that division is asymmetrical.

He then talks about how the medium used for growing stem cells results in different differentiation.

He writes on board:

Soft vs. Stiff

↓ ↓

Neurons Other things

The instructor talks about how:

- Different Media lead cells down different differentiation pathways
- Stem cells in the brain move to the proper place in the brain after differentiation starts.

The instructor also discusses: Master genes, Tricking Immune system, Miro RNA

A student asks a question: "If stem cells are not differentiated yet, how does the body know it is fragmented?

Instructor: Not really sure, possibilities I can make up: 1) Markers on cell surface… 2) markers appear once differentiation occurs…

The instructor shows via PowerPoint a diagram of a typical embryonic cell and images of real cells while talking about different cell types:

Cells can join together (shows muscle cells)
Cells can express diff things (shows neuron cells)
Cells can form complex structures (shows different tissues, organs, etc.)

The instructor posts clicker question 1 (shown below), allows for peer discussion followed by class discussion. Then posts clicker question 2 (shown below), again allowing for peer discussion and followed by class discussion. The class discussions are

closed using one of the strategies discussed in Chapter 6, for example, a mini-lecture summing up key points from the clicker question and discussion, or introducing additional content information. During the mini-lectures the instructor continues to put new terms and drawings up on the board.

Eventually the instructor reaches the more microscopic level of signal transduction:

The instructor tells the students:

> Researchers want to know: What's going on in the cell when signals bind to the receptor? and How can you regulate these signals to make stem cells differentiate in a desired fashion?

The instructor projects a diagram of a complex signally model, and states:

> This is a real signaling pathway, really complicated, lot of stuff going on in here...There are ways to summarize these pathways to make them easier to work with and comprehend.

The instructor projects a simpler signaling pathway, and states:

> Here is a less complicated pathway, we can see that the cell receives a signal from the outside [points to receptor] that sets off a series of things that happen inside the cell [pointing while following down the pathway] resulting in gene expression [points to nucleus].

Example Clicker Questions.

Clicker Question 1 of 2:

Some attempts to treat diabetes in mice have transplanted embryonic stem cells into the pancreas. Unfortunately, the stem cells differentiated into a variety of tissues including skin, muscle, bones and teeth, instead of pancreas tissue that could produce insulin.

What could have caused these problems? (pick all that apply)

1. The mouse pancreas sent the wrong signals to the stem cells.

2. Mouse blood carried the wrong signals to the stem cells.
3. The stem cells sent a mixture of signals to each other.
4. Embryonic stem cells are programmed to become a whole organism and not just one tissue type.
5. The stem cells were being rejected by an immune response.

Clicker Question 2 of 2:

In an experiment embryonic stem cells were exposed to growth media that had been conditioned with mature pancreatic cells prior to being transplanted into the pancreas. These cells then differentiated properly, and formed islets that produced insulin.
What must have happened to these cells to prevent them from forming a teratoma? (pick all that apply)

1. The conditioned medium contained signals that triggered development.
2. The conditioned medium caused the stem cells to display new receptors.
3. The conditioned medium caused the stem cells to lose some receptors.
4. The conditioned medium caused the stem cells to lose some genes.

Lesson Level Phase

Instructional Goal. Students apply and extend their knowledge of the model and their model-based reasoning skills to achieve the course content and model-based reasoning skills goals.

Overview. The Lesson phase is composed of lessons on various models associated with the content unit. The goal of this phase is for students to develop a robust mental model that is complex, detailed, and connected to other models. The approach for teaching the models is to have students apply the models by posing model-based reasoning questions and discussing the issues and ideas that arise during application. Model-based reasoning in biology is defined by the instructor as the process of making predictions about or interpretations of biological systems using mental models that

describe the system's components and the logical rules by which they interact. His goals include:

a. Actively using the concepts and vocabulary in a model to understand how the components work collectively to predict the outcome of the process.

b. Skill of extending or revising the model when the presented model does not explain newly revealed aspects of the system. (Sometimes this subcategory of model-based reasoning is called model-based learning)

c. Skills employed by expert scientists: generation of predictions, interpretation of data, and revision or elaboration of the original model. Learning to reason with the key explanatory models in a science promotes, indeed largely constitutes, the understanding of the science.

d. Use of diagrammatic or physical models to support reasoning.

It is these processes that the Lesson phase aims to engage students with. (Note that physical models were not used in the lecture hall, but may have been used in the labs; however, the lab section of the course was not investigated.)

The models that are taught in GAMBR are pre-existing models of well-known biological processes that are generated through and used in research. For example, there are models of the processes of transcription and translation that are used in research. These same biological processes are commonly studied in biology courses, but in traditional courses, they are not approached as models but rather as a collection of related terms and concepts. This is important for two main reasons that will re-occur in the conclusion so they are only mentioned here: (1) students likely have some prior knowledge that can support them in reasoning and talking about the models, and (2) working with these models may better support students in becoming

Clicker Question Clusters

Clicker questions are employed to help the students learn and apply the models to increase their content knowledge and reasoning skills. There are often several clicker questions used in a single lesson; these are called clicker question clusters. The clicker questions are used to stimulate other classroom activities: peer discussion, class-wide discussion, and micro-lectures. One way to envision this is to imagine several clicker questions in a vertical cluster underneath each of the target Models M in Figure 7-1.

A lesson revolves around applying the model. The clicker question clusters are central to the lesson structure and help students learn the model in a step-wise fashion as they reason with it. The clicker questions present manipulations of the model and ask the student to apply and run the model to predict the effect or impact, going from data to outcome or outcome to data. The course model-based reasoning skills goals are addressed by these model manipulations, pushing students to use, revise, and extend the model. The clicker questions are also used to stimulate other classroom activities that help engage students with the model.

Other Lesson Activities Stimulated by Clicker Questions

Micro-lectures, peer discussions, and class-wide discussions are all focused on the information and/or ideas about the model that the clicker questions aim to bring to the students attention.

Micro-lectures. A micro-lecture is defined here as a brief talk given by the instructor on a very specific and tightly defined topic. This may include drawing on the

board or projecting visual or textural information. Though no time measurements were made, the researcher estimates micro-lectures last between 1 and 10 minutes. Micro-lectures are used to:

- Introduce the model.
- Review known elements of the model.
- Introduce new elements of (extend) the model.
- Connect the model to previously covered models.

Peer Discussion. Peer discussion is the period of time when students are encouraged to talk to each other. It starts as soon as a clicker question is posted and officially ends when the clicker question is called. The general length of time provided is 5 minutes, but this can be adjusted depending on how much the students are talking. (This is a ”known” factor because the instructor sets a timer on the clicker question in the personal response system that automatically calls the question, and this timer is most often set for 5 minutes, but the instructor can stop it early or extend it as desired.) This time is meant for the student to voice their ideas and questions to their peers as they try to answer the clicker question. No direct observations of what students say at this time were looked at in this study, but the goal of the instructor is that (1) students will recognize gaps in their knowledge of the model and either get help filling them by their peers or generate questions they can ask the professor during class-wide discussion, and (2) students will reach a new understanding of the model that they can share with the class.

Class-wide Discussion. Class-wide discussion follows the peer discussion period and starts after the histogram displaying the results of the clicker questions responses has been posted at the front of the class. The length of time provided varies greatly depending on how many questions students have and the length of the instructor's responses. The instructor then opens the floor for the students to ask questions and make comments. He responds to each question or comment, either answering the student question or affirming or confronting the comments. (Note that the field notes did not contain detailed information about the instructor's responses, as the focus at that time was on collecting data about what the students were saying, so specific teacher moves at this stage are not known, and provide an interesting opportunity for future research.) One important observation, however, is that the instructor rarely directly relays the correct clicker response to the clicker questions. It is also important to note that the class-wide discussion period is not a time when students engage in a back and forth discussion with peers or the instructor, but rather it is a time when students share ideas with the class and get information and feedback from the instructor, .

Lesson Pattern

There was a pattern within the individual lessons.

Introduce Model. The Lesson phase often starts with a micro-lecture that introduces the model and initiates the clicker question cluster that addresses the first associated model the students will reason with. This micro-lecture introduces specific components of the model that are needed for the student to begin reasoning but not the

entire target model the students are intended to learn by the end of the clicker question cluster.

Extend, Comprehend, and Revise Model. Once the instructor has briefly introduced the model, the first clicker question in the cluster is posed to the students, which begins the extend, comprehend, and revise the model mode of the lesson. (This is called ”extend model mode” for short.) Each clicker question in the cluster aims to help students explore the model elements and recognize gaps in their knowledge of the model and/or introduce new elements of the model. It is expected that the clicker questions contain model elements that students do not fully understand and/or have not yet been directly exposed to during class time. (Note that students are supposed to have completed readings prior to class and, therefore, in theory should have some related prior knowledge.) In this way, the clicker questions aim to both exercise and perturb the students’ current model. For example, adding a new component to the model that disrupts its predicted outcome aims to engage students in running the model as well as extending the model to account for the new element.

As stated above, the students are provided the opportunity to discuss the clicker question with their peers and provided the chance to ask the instructor questions about the model and/or make statements based on their understanding to the class. The instructor responds to the students’ questions and comments both briefly and through micro-lectures on main points, prior to moving to the next clicker question in the cluster. These talk times present additional opportunities for new model elements to be introduced by the students and/or the professor.

The student talk examples presented in Chapter 4, Day 3 provide some support for this mode of the lesson being thought of as extend, comprehend, and revise the model. For example, the first student statement in response to the initial clicker question posed on Day 3 suggests to the researcher that the student comprehends the (current) model presented to the class: “The signal activates the TK to phosphorylate it.” The second student comment suggests a model revision: "Maybe, the signal might not still be there – it must be originally but might not be now."

One way the researcher has come to look at the purpose of a clicker question cluster is that it is to expand the students’ initial model (generated in the introduce model mode) to a more complete, or target, model through application. Figure 7-3 shows a representation of how the clicker question cluster may facilitate the movement of the students’ understanding from an initial model to a target model. A cluster starts with a simplified version of the model, and each question adds to the complexity of the model (e.g., by introducing new model elements and perturbing the model). Therefore, the classroom knowledge of the model progresses as the instruction moves through the cluster to reach the target model. The researcher presents this hypothesized model of student learning in GAMBR here to be able to build upon it in later chapters and the conclusion.

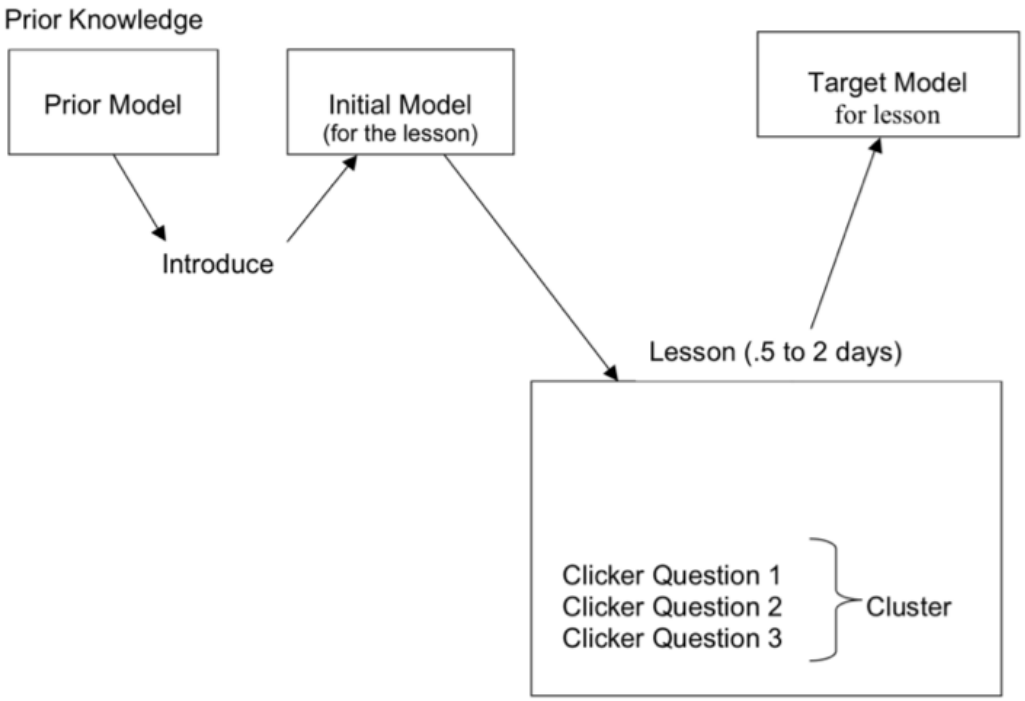


Figure 7-3: Hypothesized function of a clicker question cluster within a lesson.

Students are assumed to have a model based on prior knowledge obtained previously in the course and elsewhere. The professor introduces some elements of the model at the start of the lesson, which may help the student to generate an initial model that is assumed to include the student's prior model. The clicker questions build on each other, introducing new model elements, leading to a more complete model or Target model.

Creation of Clicker Question Clusters. It is important to point out that the clicker question cluster is not a prescribed, predefined, ordered set of clicker questions. The instructor develops a set of questions prior to class with a specific goal of what he

wants the students to learn about the model on that day. The instructor rarely uses the entire set of clicker questions he has developed for one day, and sometimes a new ”on-the-spot” question is generated to address a point or difficulty revealed through the students’ responses to a clicker question (either through popular answers to a clicker question displayed in the personal response system histogram or student questions and comments made during class-wide discussion). The clicker questions developed before class might not be used in the originally intended order, again with the instructor making adjustments based on student responses. When the target model is not reached in one class session, the lesson continues into the subsequent day and the instructor may use some of the clicker questions that were not used previously the next day of class. In multi-day lessons, additional clicker questions are created prior to classes as needed to introduce new elements and reach the target model. In this way, the clicker question cluster that is used in class to move the students is built over the course of the lesson. Questions that are not used in the lesson are often posted on the course website along with those that were used to provide students with additional opportunities to practice reasoning with the model. Therefore, the teacher maintains an agile approach to teaching, such as that described by Beatty,et al. (2006b).

Connected Models

Models are connected within the lessons. At the end of a lesson, the model may be connected back to previous models in the course, in the same unit, or a previous unit. The final clicker question(s) in the cluster may be used to do this or just a micro-lecture. This always appeared to occur in the final lesson of a given unit but sometimes also

happened at the end of other lessons. In addition, the models in a given unit and across units are usually built on each other by which one model became nested in the next model(s). For example, the first model of the signal transduction unit is the stem cell self-renewal signaling pathway, and this pathway model then becomes nested in the model for stem cell differentiation, and the model of signal transduction then becomes part of the model for gene regulation. Figure 7-4 below provides a visual representation of the nested and connected nature of the course models.

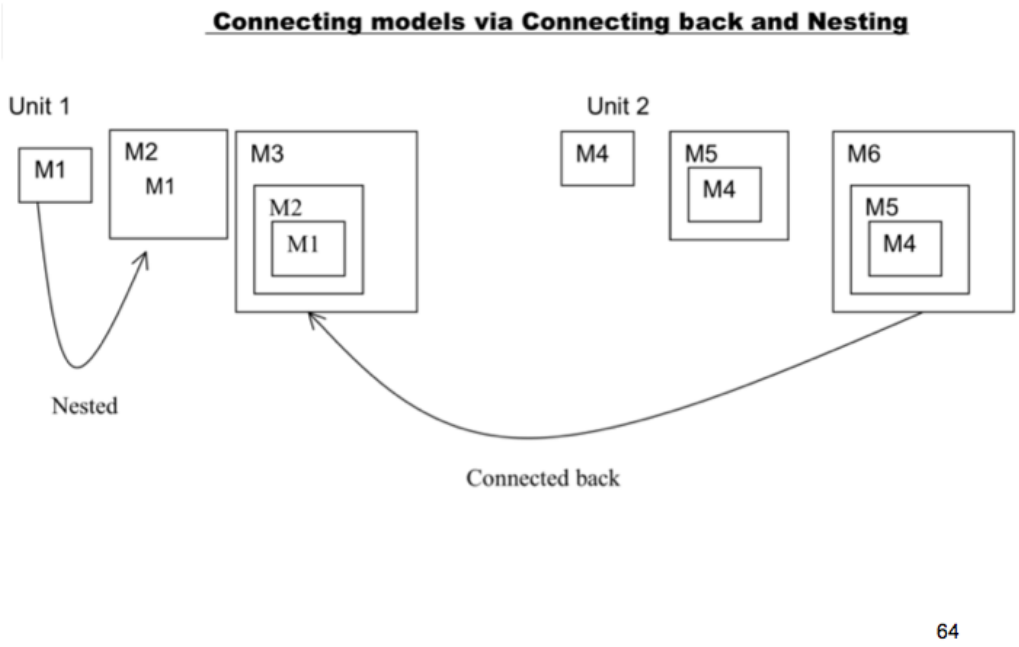


Figure 7-4: Connect model mode.

The model of one lesson is often nested in the model of the next lesson. At the end of the lesson, the model is sometimes connected back to previous models in the same content unit or a previous unit.

Lesson Phase Pattern and Cycle

Generally the lessons that occur within the Lesson phase can be described as following a pattern of Introduce the model; Extend, Comprehend, and Revise the model through application; and Connect the model through application.

As shown in Figure 7-5, once a lesson on a given model is complete, the instructor moves to the next model related to the content unit. The next model associated with the content unit is then introduced with a micro-lecture, starting a new lesson in the Lesson phase cycle. Once all the desired associated models in the content unit have been covered, the instructor moves back to the Unit phase of instruction, and a period of lecture (sometimes broken up with a few clicker questions) on a new content unit is given. See Figures 7-1 and 7-5.

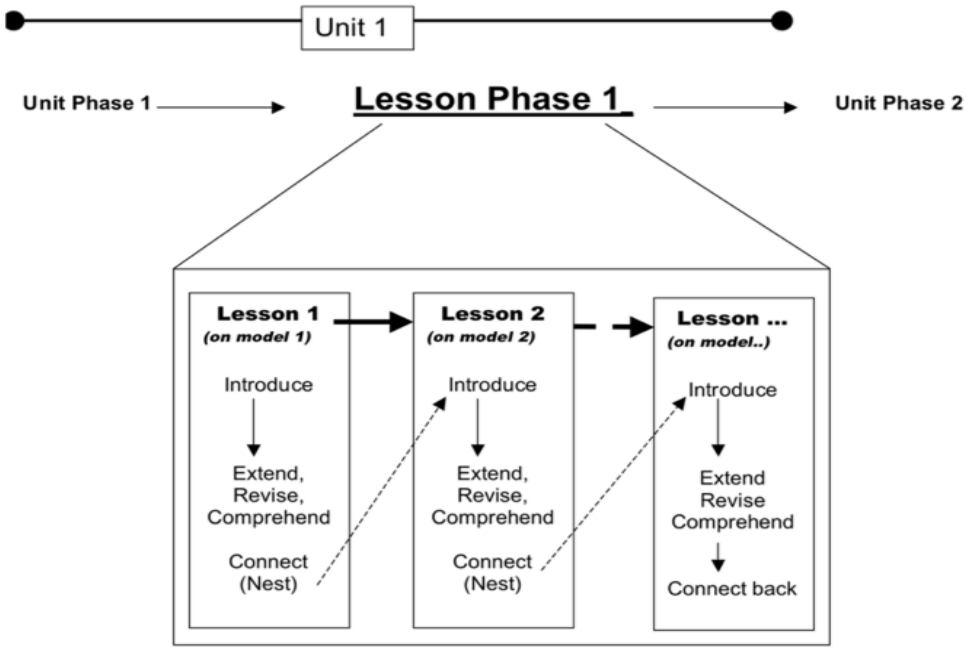


Figure 7-5: Lesson phase pattern.

The Lesson phase is composed of several lessons on different models. The lessons start with introducing the model. The model is then applied to help the students extend, revise, and comprehend the model. The model is then sometimes connected to previous models. Once all the desired models have been covered, the instructional cycle returns to the Unit phase. This figure is a hypothetical magnification of a unit enclosed in dotted line in Figure 7-1. The dashed arrow above represents the nesting shown in Figure 7-4 of the model from Lesson 1 becoming nested in the model of Lesson 2 and so on.

Clicker Questions.

- Clicker questions used for each lesson
- Instructor uses clicker questions to engage students with reasoning about the model to help students comprehend, revise, and extend their model and sometimes to connect the model to previous models.

Classroom Example. See Day 3 in Chapter 6.

Clicker Question Cluster Example. Clicker questions below are from the cluster associated with the electron transport chain model.

Clicker Question 1 of 4

Analysis of the tyrosine kinases in a cell show that TK2 is phosphorylated.
Is the signal present?

a. yes
b. no
c. maybe

Extensions, revisions, and comprehension this focuses on:

1) understand the basic logic of the model, interaction of components
2) idea that the signal transduction pathways can have limited time periods,and question of how a signals go off

3) Components/concepts: receptor, equilibrium, phosphorylation/dephosphoylation, signal binding/unbinding

Clicker Question 2 of 4.

The self-renewal signaling pathway in a particular stem cell type has an additional kinase, TK3 that targets TK1. TK3 is produced from the expression of a gene activated by TFa. How would TK3 change the behavior of the pathway?

1. It would become a temporary circuit, even when signal is still present.
2. It would become a permanent circuit, even when signal is absent.
3. It would not change.

Clicker Question 3 of 4.

You perform an analysis of a cell and find that the signal is present and that TK1 is phosphorylated, but TK2 and TFa are not phosphorylated:

The occurrence of which of the following best explain these results?

1. Receptor mediated endocytosis
2. Equilibrium of PO4 binding
3. Phosphatase activity

Clicker Question 4 of 4.

Which of the following would create a positive feedback cycle that would make signaling permanent?

1. TK1 activates a phosphatase that targets TFa.
2. TK1 inhibits a phosphatase that targets TK2.
3. TFa activates a gene that encodes an inhibitor of receptor mediated endocytosis.
4. TFa activates a gene that encodes a kinase that targets TFa.

It is important to understand the high level of nested and connectivity in the course, as the initial description of the course at the beginning of this chapter might make the course look linear and easily parceled into separate chunks of knowledge that are not interconnected, related to lessons on models, within units, within topics. However, as the description of nesting and connecting of models in the previous section begins to reveal,

the nested organization and focus on reasoning with models may create a structure of very fluid and connected course content. This is one of the goals of the instructor: to help generate students' understanding of the connectivity of biology content and generate a body of knowledge that is integrative. This is attempted by having all levels of content (topic, unit, and lesson) build on each other and intentionally connecting back to each other, as shown in the revised model of the instructional organization in Figure 7-6. Further exploration of this aspect of the course and its impacts on students' knowledge of and feelings toward biology present a rich topic for later research.

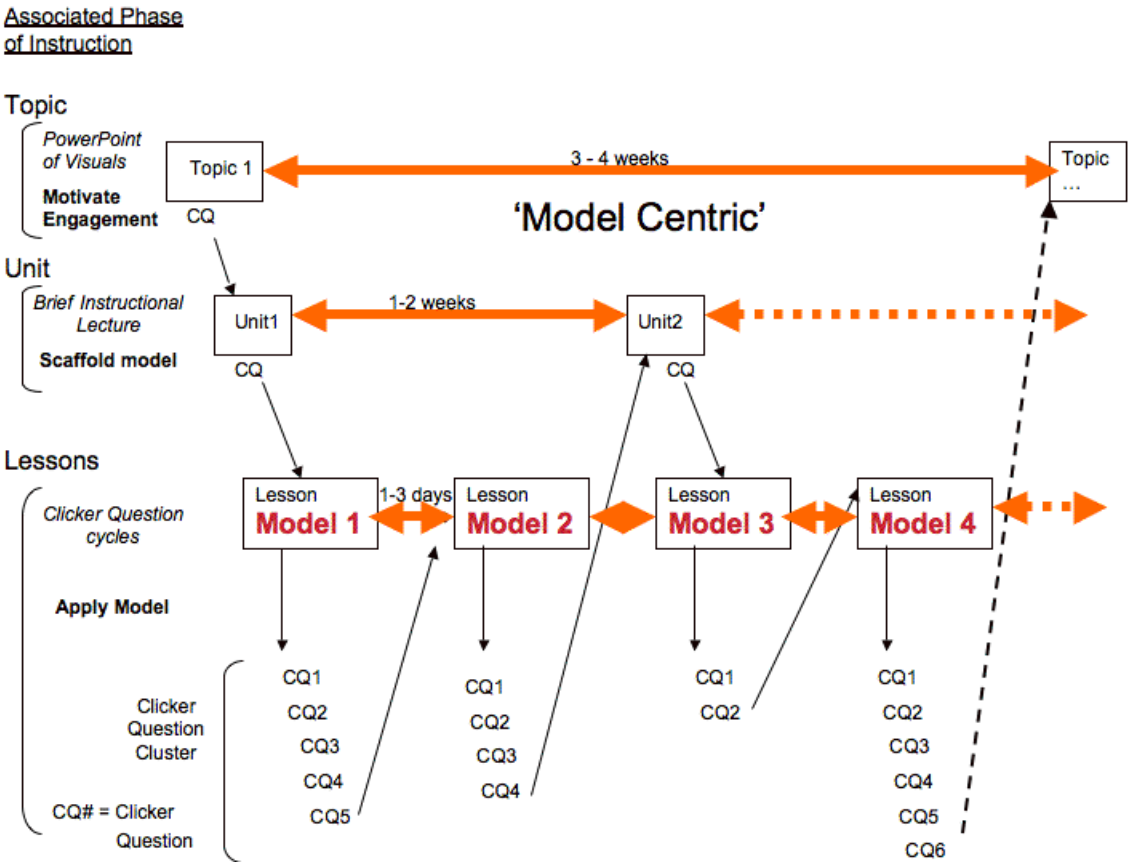


Figure 7-6: Connected nature of course content.

The double-headed orange arrows represent the instructor's goal of connectivity throughout the course. Models are nested within other models as the instructor moves

through the course, and topics, units, and lesson models are continuous connected back to previous topics, units, and lesson models.

Summary

The course had a hierarchal structure of content and nested cycle of instruction that was confirmed by the instructor. These pre-existing instructional phases were used by the author to segment the course. The instances of the different content levels and the clicker questions found in each segment were confirmed by the instructor and counted. The field notes and course materials were used to examine and describe the instructional phases and search for patterns and cycles related to model instruction.

The phases of instruction were defined as: Topic, Unit and Lesson, corresponding to the level of the content they addressed. The instruction and content was presented in a nested cycle. The cycle progressed from Topic to Unit to Lesson and back to topic, with a nested a cycle between Unit and Lesson under the topic.

For the semester examined, 4 topics, 6 units, and 18 lessons were presented and applied. The clicker questions used at each instructional phase total 3 topic, 9 unit, and 65 lesson (model). This finding supported the idea that a majority of the clicker questions used in the Lesson phase focus on having students reason with the model. In Clicker questions were not always used at the Topic phase, and if they were, it was only one. Likewise, the Unit phase also did not always use clicker questions, and only 9 were used over the course of the semester, whereas, every lesson within the lesson phase included at least one clicker question.

The Topic phase aimed to motivate student interest in the content with a relevant real-world topic, such as cancer. The main form of instruction was a PowerPoint presentation with images and visuals used to demonstrate real-world significance. The goal of the Unit phase was to present content related to the associated model and to scaffold the models that students would be asked to reason with. The main instruction format in the Unit phase was described as an instructional lecture. These two phases were used to set the students up for the lessons on different models that would be learned in the Lesson phase.

The lessons within the Lesson phase were found to have a pattern within them and a cycle between them. The lesson pattern was to first introduce the model with micro-lecture and then move to a period of extend, revise, and comprehend the model. The central instructional tools for the lessons were clicker question clusters and the student and instructor activities that were associated with them: peer and class-wide discussions and micro-lectures. The clicker questions in the cluster are used to introduce new elements of the model so that the model is envisioned by the researcher to evolve over the course of the lesson. One way this can be thought of is the lessons aimed to move students from an initial model to a target model through engaging them in model-based reasoning. Another mode of the Lesson phase was to connect models. The models were often connected to each other through nesting older models within newer models and connecting back to previously learned models. The nesting and connection of models comprise a high level of integration of the course material so that topics, units, and models all appeared to be interconnected, which was a learning goal of the instructor.

It is during the Lesson phase that the clicker questions were observed to be designed to engage the students in model-based reasoning occur. For this reason, it is these clicker questions that are considered unique and will be focused on for categorization into types of questions in the next chapter.

CHAPTER 8

CLICKER QUESTIONS AND DIAGRAMS IN THE LESSON PHASES

This chapter addresses the findings of Research Question 2: How are clicker questions and different types of diagrams used in the course?

(A) For different types of diagrams that appear in association with the clicker questions used over the course of a typical semester, how often is each type used?

(B) How are these diagram/clicker questions used within the instructional design?

Introduction

In Chapter 3, previous research was presented that suggests the use of diagrams to support learning and that students should be actively engaged with these visual aids to optimize their impact (Chan & Black, 2006; Eysink et al., 2002; Mayer, 2002; Mayer & Moreno, 2002). Many interactive animations and simulations have been developed for use in science education; unfortunately, the use of such technologies is limited in large lecture halls because the setting is not equipped to allow students to interact with these tools in the ways that research has shown them to be most effective. For this reason, it seems prudent to examine innovative teaching methods that include external representations that might foster learning in a highly visual manner in large lecture halls.

The Guided Application of Model-Based Reasoning in Biology (GAMBR) approach provides an opportunity to examine an interactive use of visual learning in large lecture halls. Many of the clicker questions used in the Lesson phases of instruction had diagrams and other visual representations associated with them. Diagrams were not found

to be associated with the clicker questions in the Topic or Unit phases of instruction, making the use of diagrams a characteristic of Lesson phase clicker questions only.

Including diagrams is only one characteristic of the clicker questions used in GAMBR that may provide new ideas for clicker question design. As discussed in Chapter 2, the process of generating effective clicker questions is challenging and time consuming (Allen & Tanner, 2005; Boyle, 2006) and more strategies for design are needed (Dangel & Wang, 2008; Kay & LaSage, 2009). Various recommendations for design exist in the literature (Allen & Tanner, 2005; Beatty, 2004; Beatty et al., 2006a; Caldwell, 2007; McCabe, 2006; Poulis et al., 1998; Woods & Chui, 2003), but they are not specific to engaging student in biology related process skills, such as model-based reasoning. Examining the clicker questions used in the Lesson phase to engage student in model-based reasoning may result in general recommendations for clicker question design as well as for specific design ideas for instructors interested in model-based learning.

This chapter explores the clicker questions used in the Lesson phases of instruction in relation to their associated diagram types as well as other characteristics that are important to the instructional goals.

Methods

For Question 2A

Data Collection

All of the course materials relating to clicker questions from the course website were downloaded. These materials consisted of text and pdf files containing the clicker

questions asked each day and diagrams that were handed out in class. Occasionally, take home messages related to the clicker questions were also included in the documents.

Sorting and Counting Clicker Questions in Relation to Diagrams

The subset of clicker questions in the Lesson phase of instruction (described in Chapter 7) were examined for their association with diagrams to insure that all diagrams fell into to the two categories described in Chapter 4 (shown in Table 8-1): diagrams that depict biological models or diagrams that depict data.

The instructor confirmed that those were the only 2 types of diagrams associated with the clicker questions and that the four types of clicker questions shown in Table 8-2 accurately described all the clicker questions. The clicker questions were sorted into the four conditions.

For Question 2B

A case study description of the role of clicker questions in the overall design of the course was developed using the downloaded course materials and field notes.

Results

Two categories of diagrams were associated with clicker questions in the course: Model-representation diagrams and data representations. Four clicker questions conditions existed in relation to the two diagram types: model-representation diagram clicker questions, data representation clicker questions, both visual representation types clicker questions and non-diagram clicker questions.

Research Question 2(A)

> For different types of diagrams that appear in association with the clicker questions used over the course of a typical semester, how often is each type used?

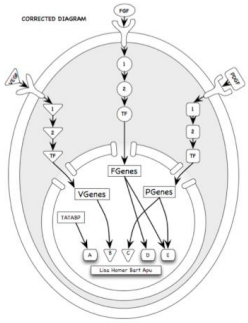
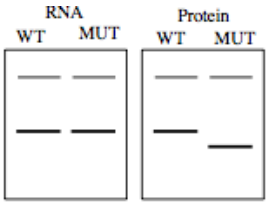
The initial step was to ensure that the two diagram types previously identified as being used in the instructional approach (see Table 8-1) were indeed the only diagram types associated with clicker questions; this was also confirmed by the instructor.

The first category was labeled Model-representation diagrams (MD), defined as follows: The model-representation diagrams were a graphical depiction, such as a flow chart or schematic, that is a theoretical explanatory representation of some (but not all) aspects of the target model for the lesson. The diagram's aim to provide a useful explanation and description of why and how a biological process works. These diagrams were handed out for use with related clicker questions that asked the students to reason with the model.

The second category of diagrams was data diagrams (DD) that were defined as a graphical depiction of hypothetical data collected from an experiment or study performed to test a part or the whole model, such as a graph of the effects of a particular drug on an enzyme or locations of genes along a chromosome. These diagrams were embedded in the clicker questions, and the clicker question required the interpretation of the data in order to reason about what might be happening with the model. Table 8-1 shows examples and descriptions of the two diagram-types.

Table 8-1: Two diagram types used in the course.

Diagram Types Associated with Clicker Questions

Example Diagram	Diagram Categories	Description
 Signal Transduction Model	**Model Representation Diagrams**	Depiction of a specific model, such as a flow chart or schematic, that is, a theoretical explanatory representation of a biological structure or mechanism. These diagrams aim to provide an explanation and description of why and how a biological process works. Associated clicker questions required an application of the model represented in the diagram.
 Electrophoresis Gel	**Data Diagrams**	Depiction of data on observable features or behavior, assumed to have been collected from a clinical test, instrument, or observation. Examples are measured locations of genes along a chromosome or a graph of the effects of a particular drug on an enzyme. Associated clicker questions required the interpretation of the data in the diagram in order to answer the question.

Sorting Clicker Questions According to Associated Diagrams

Additional conditions were needed to sort all the clicker questions in accordance with their associated diagram types to account for clicker questions that did not have a diagram associated with them (simply called: non-diagram clicker questions), and clicker questions that had two both a DD and an MD associated with them, termed Both Diagram (BD) type clicker questions. As shown in Table 8-2, the result was four conditions used

to sort the clicker questions in relation to diagrams. The instructor again confirmed that these conditions could account for all clicker questions used in the course.

Table 8-2: Clicker question conditions and descriptions.

Clicker Question Category	Description
Model-representation Clicker Questions (MD-CQ)	Clicker questions that were asked in association with a model-representation diagram
Data Diagram Clicker Questions (DD-CQ)	Clicker questions that were associated with a data diagram
Both Diagram Type Clicker Questions (BD-CQ)	Clicker questions that were associated with both a data diagram and a model-representation diagram
Non-diagram Clicker Questions (ND-CQ)	Clicker questions that did not have any diagram associated with them

There were at total of 65 clicker questions used over the course of the semester during the Lesson phase of instruction. The majority of the clicker questions had diagrams associated with them, and of these, most were MDs at 27. The DDs had a similar number of questions, at 21, while the BD category only had 2 clicker questions in it. The ND CQ category had 14 clicker questions. The totals and percent totals of each of the clicker question are shown in Table 8-3.

Table 8-3: Total and percent total of clicker questions per category.

Clicker Question Diagram Conditions	Total Clicker Questions	Percent Total
Model-representation Diagram Clicker Question (MDCQ)	27	42%
Data Diagram Clicker Questions (DDQC)	22	34%
No Diagram-Clicker Questions	14	22%
Both Diagram Type Clicker Questions (BD-CQ)	2	3%
Total Clicker Questions	65	

Clicker Question Diagram Conditions and Models

The diagrams conditions were associated with specific models and corresponded to the clicker question cluster used in the lesson associated with that model (see Figure 8-1). This section provides a brief description of the clicker question diagram conditions.

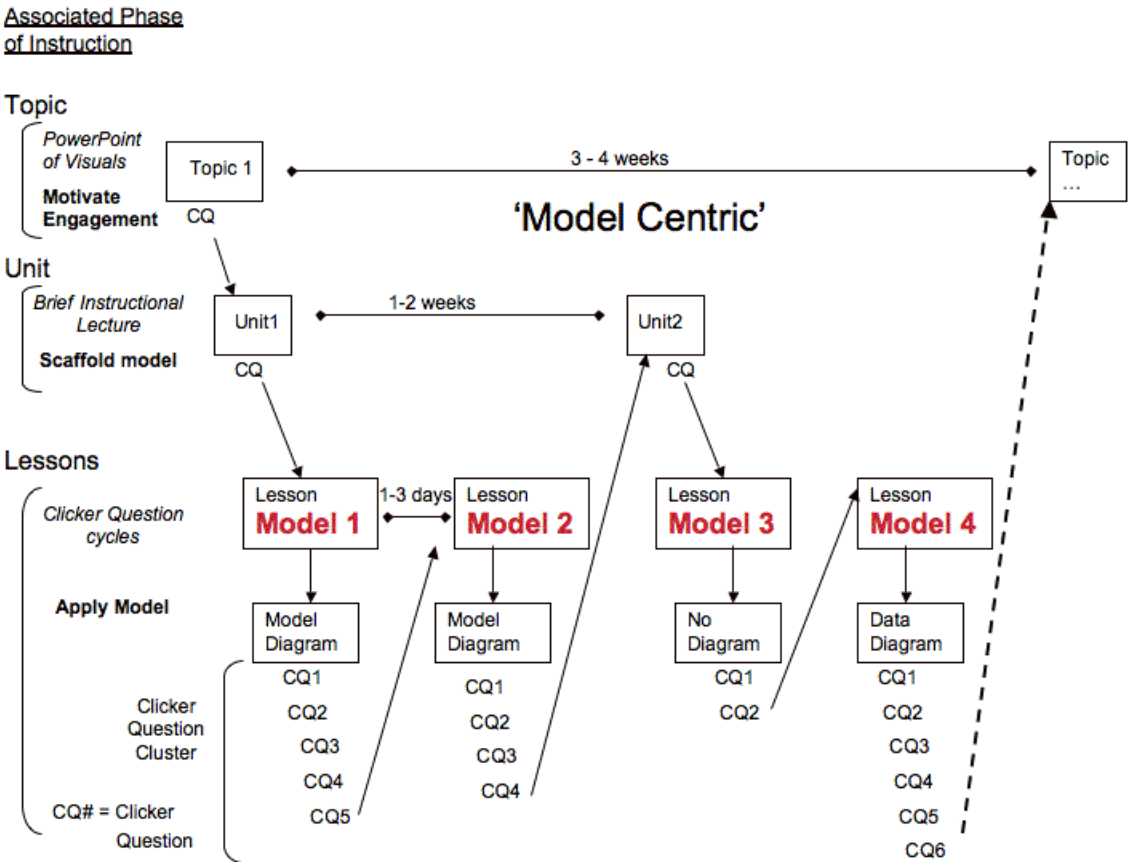


Figure 8-1: Diagrams and clicker question clusters within the instructional structure of the course.

The clicker questions were associated with particular models and could be grouped in clusters (clicker question clusters) relating to a particular model. The diagrams were also found to relate to particular models, as they were associated with particular clicker question clusters. The clicker questions that did not have diagrams also related to a particular model, but there was no related diagram.

Research Question 2(B)

How are these diagram/clicker questions used within the instructional design?

This section discusses the qualitative case study findings on the role of clicker questions and diagrams.

Model-Representation Clicker Questions (MD-CQ)

Model-representation clicker questions included diagrammatic partial representations of the model introduced at the start of the lesson (see Chapter 7: Lesson phase section). They were handed out to the students during class and intended for use with the related clicker questions. The instructor told the students to use the diagrams while answering the questions and the diagrams were usually projected up at the front of the class while the clicker question was running. The diagrams were referred to directly during the class-wide discussions following the clicker questions associated with them.

Figure 8-2 depicts a hypothesis for how the model-representation diagram relates to the learning of models. Note that even when there is only one clicker question used in the lesson, the same (very sparse) model of student learning could be applied because the clicker question and diagram are also accompanied by other lesson activities (peer instruction, class-wide instruction, and instructor responses (micro-lectures).

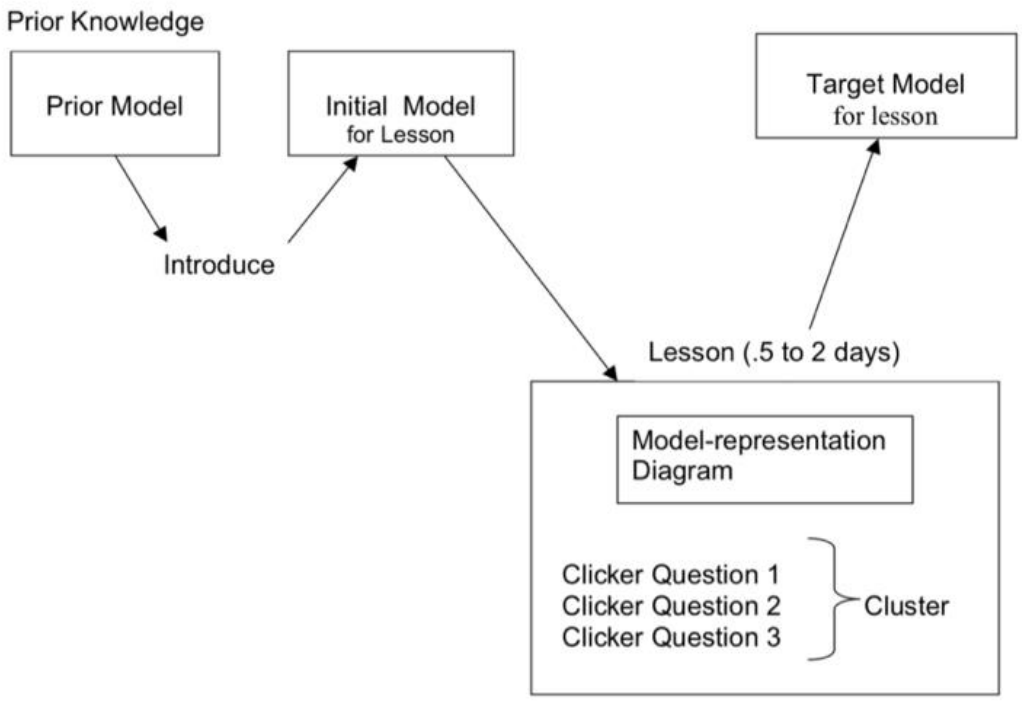


Figure 8-2: Model-representation diagram clicker question clusters.

Students are assumed to have a model based on prior knowledge obtained previously in the course and elsewhere. The professor introduces some elements of the model at the start of the lesson that aims to generate an initial expanded model that is assumed to include the student's prior model. During the lesson, clicker questions are used to ask students to apply their model to reason with and make inferences about new elements introduced through the question text and model-representation diagram. The clicker questions in the cluster build on each other, aiming to fill in gaps and to extend the model to move toward the target model.

A total of 27 clicker questions were in this category, making up 42% of the total clicker questions used in the Lesson phase for the semester analyzed. Below are two

example clicker questions. Table 8-4 shows all of the model-representation diagrams handed out in class and used in association with clicker questions over the course of one semester. Examining the model representation diagrams used in the course further emphasized the nested nature of the models and class structure. Models can actually be seen nested within other models. For example, the depiction of the stem cell self-renewal pathway that appears on its own in the model-representation diagram used in conjunction with the self-renewel model clicker question cluster (first diagram in Table 8-4) becomes the first diagram in the series of diagrams shown below in Figure 8-3 that are then used in the subsequent lesson focusing on the model of differentiation.

Example Clicker Questions

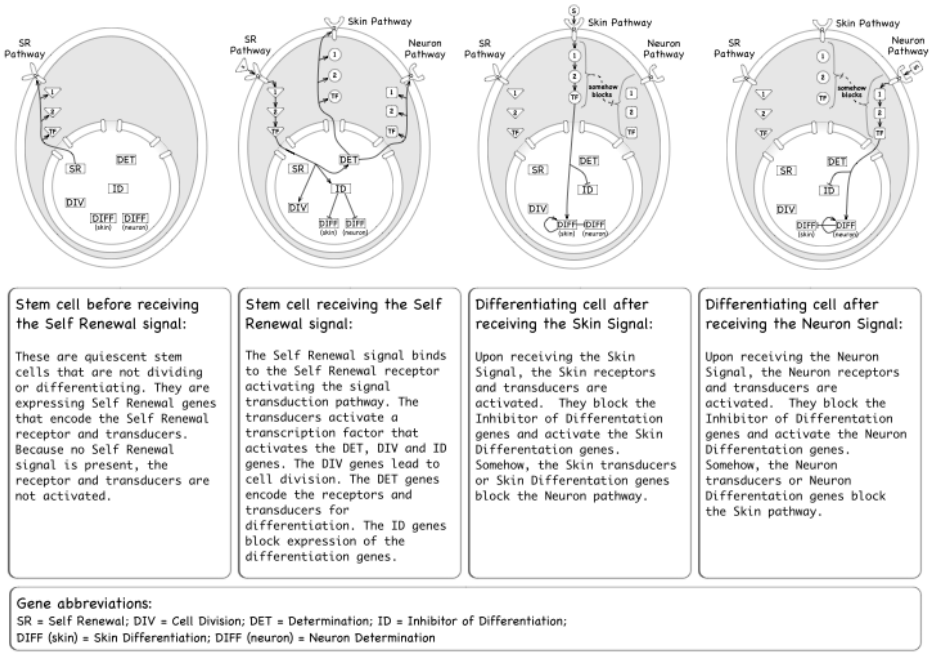


Figure 8-3: Diagram of differentiation pathway.

The diagram of stem cell differentiation below was handed out to students prior to the clicker questions. The diagram shows a series of images of the signal transaction pathways in a stem cell as it undergoes differentiation. The first image is the same depiction of the self-renewal model used with the clicker question cluster that precedes this lesson.

Clicker Questions Used with this Diagram.

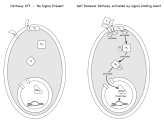
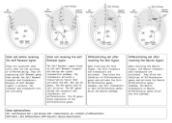
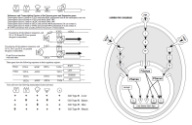
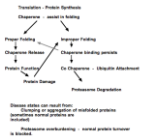
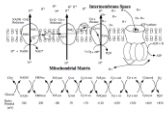
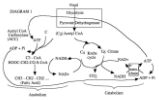
The self-renewal pathway and differentiation pathways are mutually exclusive. Which of the following cause only one or the other to be active?
(PICK ALL THAT APPLY)

1. The skin transducers
2. The ID genes
3. The DET genes
4. Receptor mediated endocytosis
5. The SR genes

A stem cell was first exposed to self-renewal signal then was exposed to neuron signal. The cell has changed shape and no longer is dividing. Which genes are on?
(PICK ALL THAT APPLY)

1. SR genes
2. DIV genes
3. ID genes
4. DET genes
5. DIFF (skin) genes 6

Table 8-4: All the model-representation diagrams were handed out .

Model Representation Diagram (Handout used with Clicker Questions)	Topic	Content Unit	Associated Model	Total Clicker Questions
Self-Renewal Pathway 	Stem Cells	Signal Transduction	Self-renewal	4
Differentiation Pathway 	Stem Cells	Signal Transduction	Self-renewal and Differentiation	2
Simpson Genes Diagram A Diagram B 	Stem Cells Gene Expression	Signal Transduction Gene Expression	Regulation of Gene Expression	A only = 6 A&B =3
Protein Chaperone-Proteasome Pathway 	Metabolic Disorders	Protein structure, enzyme function and energetics	Chaperone-Proteasome Pathway	1
Electron-Transport Chain Diagram 	Metabolic Disorders	Protein structure, enzyme function and energetics	Electron-Transport Chain	6
Aerobic Respiration Summary 	Metabolic Disorders	Protein structure, enzyme function and energetics	Aerobic Respiration	5

The diagrams shown above were handed out for use with clicker questions over the course of one semester. The topic, content unit, and model (and order it appeared in

class) that the diagram is linked to are also shown as well as the number of clicker questions.

Data Diagram Clicker Questions (DD-CQ)

The data diagram clicker questions (DD-CQ) were visual representations of authentic data about the model. The data diagrams were embedded into the clicker question. They were projected as part of the clicker question at the front of the room while the clicker question was running and during the class-wide discussion. The instructor referred to the data diagrams during the class discussions. Figure 8-6 represents a data diagram clicker question cluster.

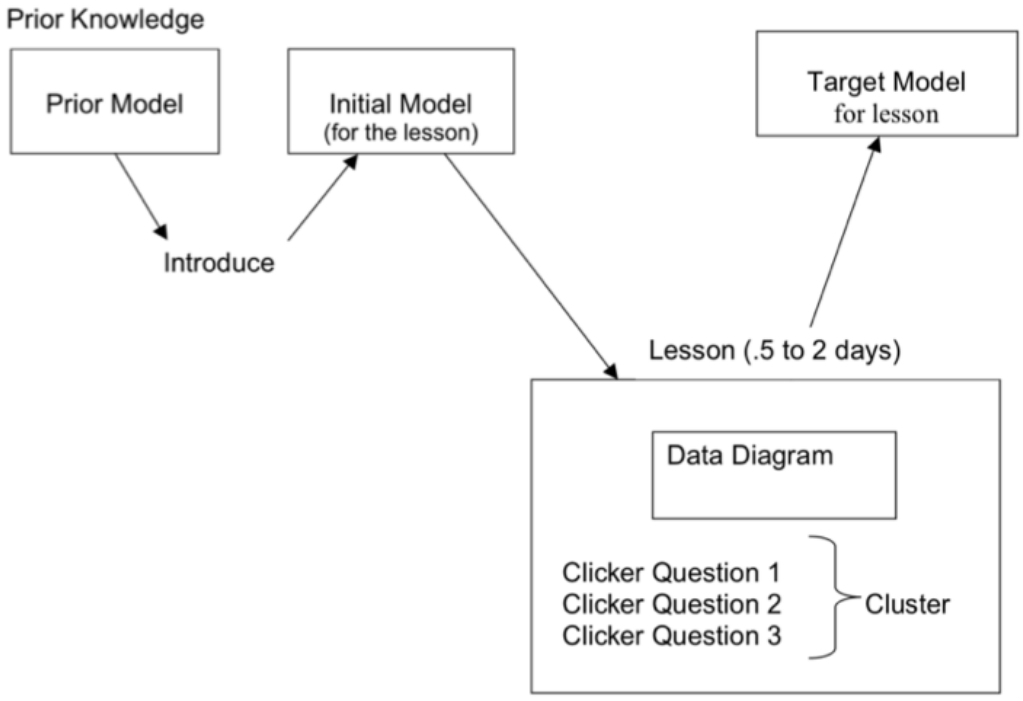
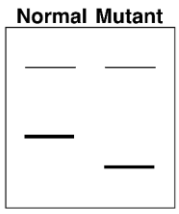


Figure 8-4: Data diagram clicker question clusters.

Students are assumed to have a model based on prior knowledge obtained previously in the course and elsewhere. The professor introduces some elements of the model at the start of the lesson that aims to generate an initial model that is assumed to include the student's prior model. During the lesson, clicker questions are used to ask students to apply their model to reason with and make inferences about new elements introduced through the question text and data diagram. The clicker questions in the cluster build on each other, aiming to fill in gaps and extend the model to move toward the target model.

A total of 22 clicker questions were in this category, making up 32% of the total clicker questions used in the Lesson phase for the semester analyzed. Below are two example clicker questions. Table 8-5 shows all of the data diagrams embedded in clicker questions over the course of one semester.

Example Clicker Questions



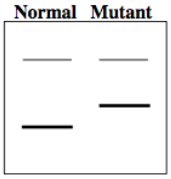
The gel above shows RNA from a normal gene and a mutant copy of the gene. Which of the following could account for these results?

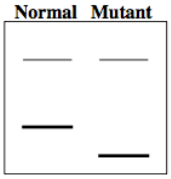
(PICK ALL THAT APPLY)

1. The mutation disrupted the TATA box.
2. The mutation blocked the binding of DNA bending transcription factors.

3. The mutation prevented the removal of introns.
4. The mutation caused an exon to be removed along with the normal introns.
5. The mutation disrupted the normal termination signal and prevented hairpin

A gene has a mutation that deletes the acceptor site of intron 2. Which result would you expect from gel electrophoresis of RNAs from this mutant gene compared to a normal gene. (PICK ALL THAT APPLY)

1.


2.


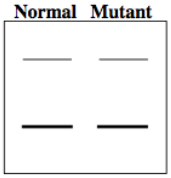
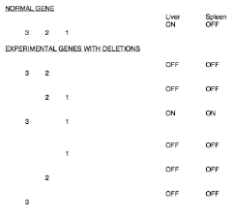
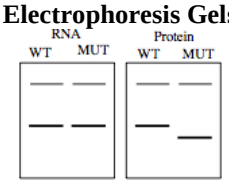
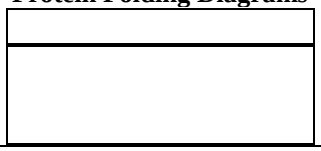
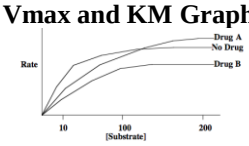
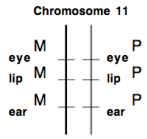
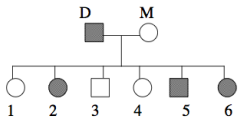
3.


Table 8-5: Examples of data diagrams embedded in clicker questions.

Data Diagram (Imbedded into Clicker Questions)	Topic	Content Unit	Associated Model	Total Clicker Questions
Data Table 		ion	Transcription	2
DNA and RNA sequence Strands RNA= GCAGCC DNA= 3'-GCGCGTCGGTACA-5'	Stem Cells	Gene Expression	Transcription	2
Electrophoresis Gels 	Stem Cells	Gene Expression	Translation	3
Protein Folding Diagrams 	Metabolic Disorders	Protein structure, enzyme function and energetics	Protein Folding	1
Vmax and KM Graphs 	Metabolic Disorders	Protein structure, enzyme function and energetics	Enzyme Function	5
Gene Mapping Diagrams 	Genetic Disorders and Cancer	Genetics	Chromosome Segregation	4
Pedigree Charts 	Cancer	Genetics	Inheritance patterns	5

The topic, content unit, and model (and order it appeared in class) that the diagram is linked to are also shown as well as the number of clicker questions.

Both-Diagram Types Clicker Question (BD-CQ)

The both diagram clicker questions (DD-CQ) had both a model-representation diagram handout associated with them and a data diagram embedded in them. Both diagrams were projected at the front of the room while the clicker question was running and during the class-wide discussion. The instructor referred to both diagrams during the class discussions. A total of two clicker questions were in this category, making up 3% of the total clicker questions used in the Lesson phase for the semester analyzed. Below is an example clicker question. Table 8-6 shows the diagrams that were used during the Both Diagram Clicker Questions over the course of one semester.

Connectivity

Table 8-5 showing the diagrams in the Both Diagram category of clicker question illustrates the connectivity of the course across units. In both cases, the clicker questions were used to connect the current lesson model back to models in previous units. The clicker question in the example below appeared at the end of the second unit in the course, on gene expression. This clicker question asks the students to reason with models that are in this unit and Unit 1. In Figure 8-5, the diagram on the left is a depiction of a model of gene regulation, and the one on the right is a depiction of a signaling pathway model. The gels that appear in the body of the clicker question are similar to those that

were previously used in conjunction with the lesson on the model of translation (see Table 8-5).

Example Clicker Question.

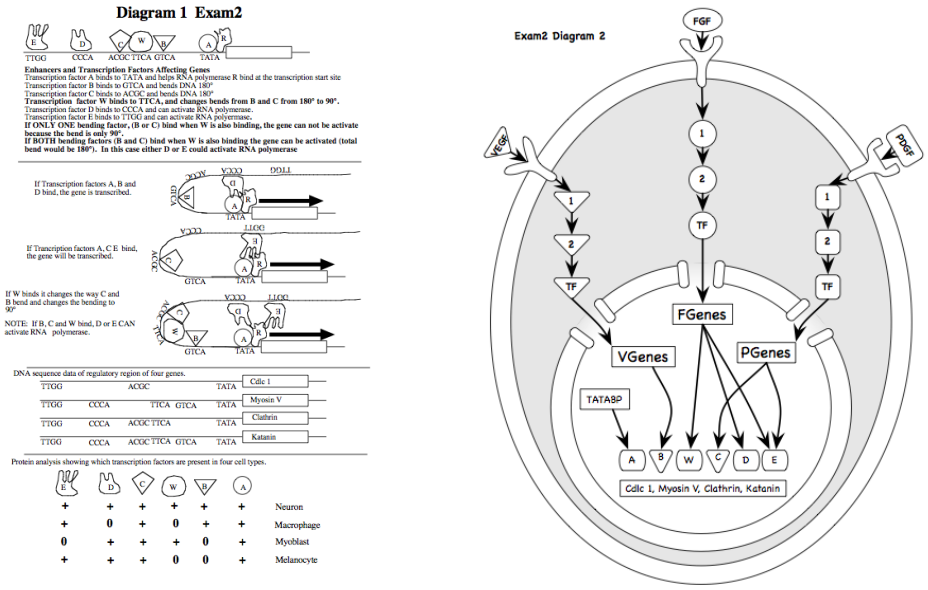


Figure 8-5: Diagram of gene regulation and signaling.

The diagrams below of gene regulation were handed out to students prior to the clicker questions. Diagram A details the interactions of a set of transcription factors and diagram B shows different signaling pathways that turn on different genes coding for different transcription factors that can then, in turn, lead to the expression of a particular gene.

Clicker question used with this handout (diagram):

> A cell receives signals from VEGF, FGF and PDGF.
> Expression of Katanin causes alternate processing of the CDlC1 gene.
>
> > This causes an exon to be excluded from the CDlc1 mRNA.
> > This exon is 25 bases long, and contains coding sequences.

The altered CDlc1 protein formed from the mRNA activates a phosphatase that targets TK1 in the FGF pathway, causing it to have temporary activity.

Which of these could be gels that correspond to Cdlc1 gene products?

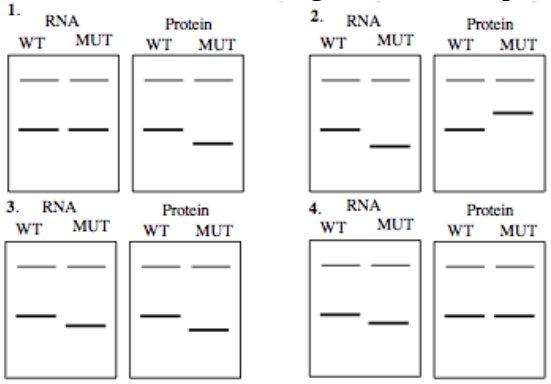
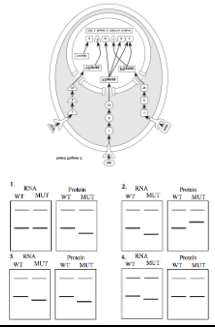
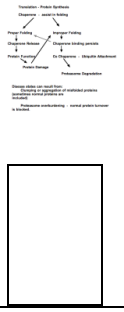


Table 8-6: Sets of both diagram types**.**

Both Diagram Types (Requires handout diagram and imbedded diagram)	**Topic**	**Content Unit**	**Associated Model**	**Total Clicker Questions**
	Stem Cells	Signal Transduction and Gene Expression	Signaling Pathway and Transcription/Translation	1
	Genetic Metabolic Disorders	Gene Expression and Protein structure, enzyme function and energetics	Chaperone-Proteasome Pathway and Transcription/Translation	1

Two sets of diagrams were used in the both diagram clicker question category over the course of one semester. The topics, content units, and models (and order it

appeared in class) that the diagrams are linked to are also shown, as well as the number of clicker questions.

Non-diagram Clicker Question (Non-diagram-CQ)

The non-diagram clicker questions (ND-CQ) had neither a model-representation diagram handout associated with them, nor a data diagram embedded in them. Figure 8-6 represents a no-diagram clicker question cluster (note that this diagram matches the one previously presented in Chapter 7, Figure 7-3).

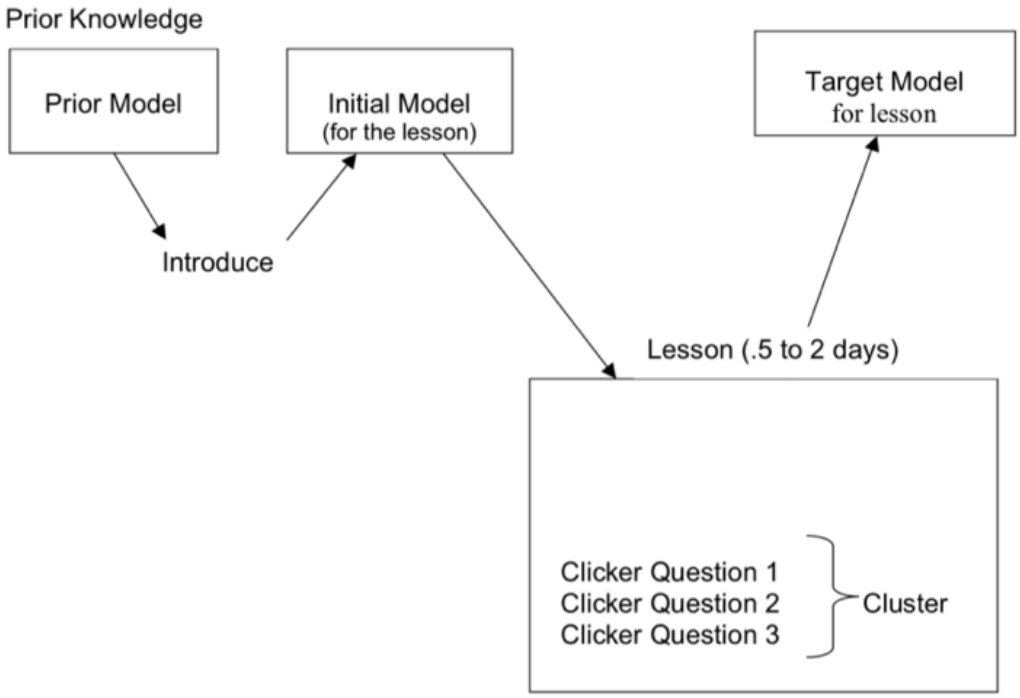


Figure 8-6: No-diagram clicker question clusters.

Students are assumed to have a model based on prior knowledge obtained previously in the course and elsewhere. The professor introduces some elements of the

model at the start of the lesson that aim to generate an initial model that is assumed to include the student's prior model. During the lesson, clicker questions are used to ask students to apply their model to reason with and make inferences about new elements introduced through the question text. The clicker questions in the cluster build on each other, aiming to fill in gaps and to extend the model to move toward the target model.

A total of 14 clicker questions were in this category, making up 22% of the total clicker questions used in the Lesson phase for the semester analyzed. Below are two example clicker questions. Table 8-7 shows the models that did not have clicker questions associated with them over the course of one semester.

Example Clicker Question

> cAMP is artificially added to an E.coli cell but no lactose is present at what level would lacZ be transcribed?
>
> 1. High
> 2. Basal
> 3. Off
>
> If high levels of expression of LacZ are occurring, which must be present? Pick all that apply
>
> 1. Lactose
> 2. Galactose
> 3. Glucose T4.cAMP

Table 8-7: Sets of no-diagram clicker questions.

No-Diagram (no diagram directly associated with Clicker Questions)	Topic	Content Unit	Associated Model	Total Clicker Questions
None	Bacterial Gene Regulation	Gene Expression	Lac Operon and Transcription	2
None	Metabolic Disorders	Protein structure, enzyme function and energetics	Free Energy Equation	6
None	Photosynthesis	Metabolism	Phsotosystems I and II	4
None	Cancer	Cancer Genetics	Cancer Stem Cell	2

The topics, content units, and models (and order it appeared in class) that the no-diagram clicker questions related to are shown as well as the number of clicker questions.

Fine-grained Description of GAMBR Clicker Question Features and Theoretical Hypotheses About Effective Question Design

Every clicker question in the Lesson phase was examined and found to ask the student to reason with a specific model. An open case study analysis approach was used to begin to form hypotheses for how clicker questions were used to support the learning goals of the course. This section is partially grounded on observations, including some descriptive features I discern in the clicker questions (observations of how the questions are embedded in and used in the course, and occasionally on specific things, I observed students doing with the questions). However, this section goes well beyond those

observations to propose speculative hypotheses for why the questions may be effective opportunities for learning. Since I do not have detailed protocol data on individual student's thinking aloud about the questions, here these take the form of theoretical hypotheses.

The goal of the instructor for clicker questions was to engage students in the practice of applying and perturbing the model rather than to measure correct responses. Most papers on the use of clickers, in biology and otherwise, discuss the student's "success" on clicker questions, indicating that clicker questions aim to assess students ability to choose the correct answer. For example, in the two most well known designs of clicker question use, peer instruction and QDI, the goal or intent is to get students to answer clicker questions correctly. This indicates that the clicker questions are written to have a definitive correct response. It appeared that most questions were single answer multiple-choice in which the students needed to choose *one* correct response. These attributes differ from the approach to designing clicker questions for GAMBR in Biology. GAMBR instruction clicker questions are designed to be very challenging and to involve different causal structures, such as going from perturbations of a model to predict effects, going from unusual effects to infer model-based causes, and being challenged to modify the model to explain anomalous data. The GAMBR approach uses clicker questions to focus students on reasoning with models. The clicker questions aim to get the student to run the model, to think about how new concepts play into the logic, and especially to give the students ideas to haggle over and pertinent questions to ask the instructor. In this way, the clicker questions aim to get students to practice applying and perturbing the model rather than to measure correct responses.

Unique GAMBR Clicker Question Features

The following are discernible features of the GAMBR clicker questions that together appear to make the approach unique. Within these items, I also pose theoretical hypotheses about why the features may be important for learning.

Clicker questions were based on reasoning about existing models that represent biological processes commonly taught in biology courses

The simplest aspect of how the instructor designs complex clicker questions in biology is that he designs them around the scientific models that are already present and abundant in the world of biology. Looking through the list of models presented in Figure 7.1, several of the model names would be recognizable to anyone familiar with high school biology (e.g., transcription, translation, etc.). Yet these are not normally presented as models in traditional biology classes. Rather, they are presented as terms, conditions, and facts that go together. For example, one might learn that transcription is the process by which the codes in genes are "read" and many of the components that play a role in that process, such as RNApolymerase, but it is less likely that they have been asked to reason about how all the components work together and what might happen if a component fails to do its job, or in other words reason about how the model of transcription actually works.

Clicker questions asked students about possible manipulations of the model

Scientific models are causal by nature, and it can be easy to generate any number of complex multiple-choice questions about the logic of the model more easily than from

a set of facts and figures. In a short paper published in the Quick Tips section of the American Biology Teacher, Phillis, Barlow, and Fitzgerald (2008) describe GAMBR question design and several example questions. The tips that are provided in thinking about designing multiple-choice questions that can engage students in mode-based reasoning include centering the questions around a *model* of a biological process. A variety of questions can be developed by the instructor based on the logic of the model that:

- Describe the state of one component and ask students about the state of other components.
- Ask the students to use the model to make predictions about the effect of doing a to b.
- Trigger or disrupt some aspect of the model and ask student what would be the impact of that disruption on other components or on an observable outcome.
- Opposite to this, one can pose a particular unobservable change in a model feature or observable outcome and ask what could have caused it.
- Present data and ask students if that data is consistent with predictions of the model.
- Present new data inconsistent with the model and ask students to revise the model based on these findings. (Phillis, Barlow, & Fitzgerald, 2009, p. 201)

In looking at the clicker questions used in the Lesson phase of instruction for one semester, it was clear that the instructor does indeed use pre-existing (although sometimes simplified) models of biological processes, and he appeared to employ all of the strategies presented above for designing clicker questions.

One way to think about it is that the model generates a focused question space from the possible manipulations of the model. Once the instructor has defined the parameters of the final target model, he can work through the above list, using any number of the model components to engage the students in reasoning with the model. Similar terminology used by the instructor when he encourages students to study for

quizzes and exams by making up their own questions about the model by changing the function or a component or the considering what might generate a different model outcome.

Clicker questions used multiple True/False format.

The clicker questions were often *multiple* true/false format. (This is the same as multiple-choice with more than one correct answer.) This was most often done by stating, “Pick all that apply,” in reference to the possible responses for the clicker questions. This format offers more flexibility and content to fit into one clicker question and requires that students reason through each possible answer rather than just trying to find the one right one and then stopping. Therefore, in one clicker question, the students are asked to run the model multiple times and ways to assess how each possible outcome would impact the model. Each question can, therefore, introduce multiple new ideas to the students and have them processing those ideas and integrating them with their knowledge of the model. Traditional multiple-choice questions limit the amount of thinking the student needs to do to reach the answer because they only need to find the one right response. And responses that are incorrect in traditional multiple-choice are often referred to as “distracters” that are meant to distract from the correct answer. The concept of ”distracters” does not apply well to the GAMBR approach because even wrong answers are based in the logic of the model and get the students to practice applying their model and to engage in model-based reasoning, which are course learning goals.

Clicker questions were sometime ambiguous.

The clicker questions often do not have only clear right and wrong answers among the choices provided but rather are written to be intentionally ambiguous to bring up gaps in the students' knowledge about the model that promote classroom discussion that will lead to new information about the model. The goal of the clicker questions is to get students to reason and also to give them something to haggle about with their peers. The main way this is done is to not have the clicker questions be about generating the exact right answer but rather to get them to think about what might happen to the model. Whereas traditional clicker questions are used to make sure that students are understanding information that has been previously presented, engagement in GAMBR is aimed at having students learn the models.

An excellent example of this is the clicker question below, which also appeared in Day 3 of the description of the course in Chapter 6:

> If this cell is analyzed and TK2 is found to be phosphorylated, is the signal present?
>
> 1. Yes
> 2. No
> 3. Maybe

As described in Chapter 6, many students select response 1 because it is the most logical response to the current model the students have been introduced to. However, response 3 is also possible and open to or having several possible meanings or interpretations. This gives students something to think and talk about, which is the goal of the question. The question aims at getting students to think about the element of time in

the model, for example, how long does the signal need to be attached for the pathway to come on and stay? The ambiguity may help the students realize that they do not have a complete understanding of the model. This at least appears to be what happens in the instance of the above question, where as shown/discussed in Chapter 4, some students did select Maybe for the purpose of wondering about the issue of time.

The clicker questions introduced new model elements.

Clicker questions are used to have students think about things they have not yet learned in the class; this is discussed in Chapter 7 under the lesson pattern section. The clicker questions are used to extend the model, which means that they have information in them or ask about elements of the model that have not yet been "taught" in the class.

The third clicker question used in the cluster presented in Chapter 7 to teach the model of stem cell self-renewal is a good example of this because it introduces the new components "phosphatase" and "receptor mediated endocytosis" to the model.

> You perform an analysis of a cell and find that the signal is present, and that TK1 is phosphorylated, but TK2 and TFa are not phosphorylated:
>
> The occurrence of which of the following best explain these results?
>
> 1. **Receptor mediated endocytosis**
> 2. Equilibrium of PO4 binding
> 3. **Phosphatase activity**

Clicker questions were not connected to points for correctness.

There are not points attached to right/wrong clicker question responses, and students need only to click once a day to get full clicker participation credit. Yet, students seemed to enjoy and actively engage in answering the clicker questions. Though no countable data were collected for this study on student talk during peer discussions, observations of students during this time suggested most were interested in solving the problems and motivated to figure them out, despite having no points attached. Stemming from the above characteristic of using the clicker questions to introduce new model elements, the students may be motivated to engage with the clicker questions because they know they will learn something new about the model, and that is needed for summative assessments (see alignment with summative assessments characteristic below).

Clicker questions allowed space for creative scientific thought.

Also the fact that there is no point value for getting it correct allows them more freedom to be creative in their thinking by removing the pressure of being wrong. Ambiguous clicker questions, such as the example above with the possible responses of (1) yes, (2) no (3) maybe, allows for the students to think outside the box of the presented model. This appeared to be a frequent style of clicker questions and is thought by the researcher to allow for room for creative scientific thinking on the part of the students.

The confidence and experience in engaging in creative scientific talk and reasoning could be linked back to the study on hypothesis generation done by Barlow and Fitzgerald (2011) that showed increased number of hypothesis generated on a matched pre-/post-test question about explaining observations with a novel model.

Note that this characteristic of clicker questions is one that is generated out of the combination of other characteristics and is still being explored by the researcher.

Clicker questions were aligned with the summative assessments.

As stated in Chapter 6, the clicker questions are designed to be closely aligned with the types of questions the students will see on quizzes and exams. This close alignment is likely to help motive engagement by the students because they know that engagement in the clicker questions prepares them for the test. This might also help alleviate the need for assigning points for right answers.

Clicker questions were designed in progressive clusters.

As discussed in Chapter 7, model lessons often use clicker question clusters to help guide instruction on the model. The clicker question clusters aim to help the student learn the model in a step by step manner through the lesson, which can be thought of as helping them go from an initial model to a target model for the lesson through what the researcher thinks of as a series of intermediate models that contain revisions and extensions of the initial model. This concept will be elaborated on in the conclusion.

Clicker questions often used diagrams.

As shown above, use of diagrams appears to be a major strategy of design of clicker questions. Eighty-one percent of the clicker questions used in the Lesson phase had either a data or model-representation diagram associated with them, or both. Diagrams did not appear in conjunction with the clicker questions in the other phases (see Figure 8-7). Hypotheses on the benefits of the different diagrams types to students will be explored in the conclusion.

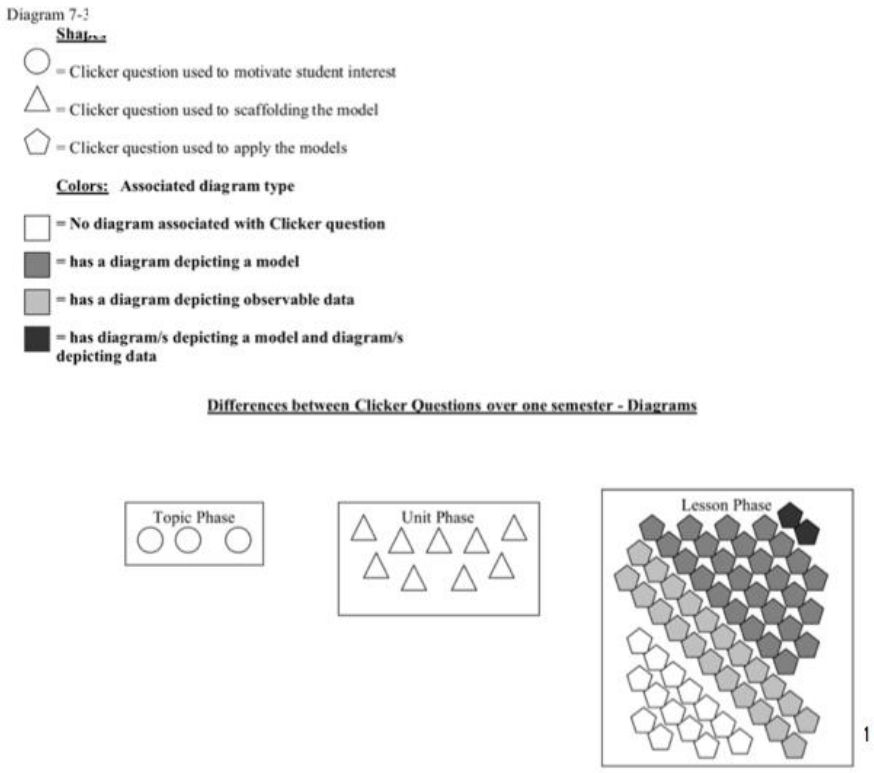


Figure 8-7: Clicker questions across instructional phases—diagrams.

The number of objects within each box represents the total number of clicker questions used in the phase over the course of the semester. Diagrams were only used

with clicker questions in the Lesson phase of instruction. Two types of diagrams were present, data diagrams and model-representation diagrams, creating four clicker question diagram conditions (represented by the shades of grey in the lesson phase).

Summary

Many visual aids are used in conjunction with clicker questions to support the content and model-based reasoning learning goals of the GAMBR approach, but these were all found to fall into one of two types: those that depicted models and diagrams that depicted data. Four conditions of clicker questions were generated based on their association with diagrams: Model-representation diagram clicker questions (MD-CQ), data diagram clicker questions (DD-CQ), non-diagram clicker questions (non-diagram-CQ), and both diagram type clicker questions (BD-CQ).

The clicker questions for one semester were sorted and counted using the conditions. Forty-eight percent of the clicker questions were associated with a model-representation diagram that was handed out to students and projected during clicker question activities. Thirty-two percent of the clicker questions had data diagrams. Only 7% of the clicker questions were associated with both a model-representation and data diagram. Thirteen percent of the clicker questions were not associated with any diagram.

The clicker questions in the Lesson phase were all found to ask the students to reason with a specific model and were clustered in groups related to the models (clicker question clusters). The different diagrams were each related to the specific models that their associated clicker question cluster asked the students to reason about. Even when there was no diagram, the clicker questions could still be grouped by model. The models

had different numbers of clicker questions associated with them ranging from 1 to 6. This range was fairly consistent between MD-CQ (1-6), DD-CQ (1-6) and no-diagram CQ (2-6).

The instructor's goal for the clicker questions was to engage students in practice applying and perturbing the model rather than measuring correct responses. Several other discernable clicker question characteristics were noted that together appear to make the approach unique:

- Clicker questions were based on reasoning about existing biological models.
- Clicker questions asked students about possible manipulations of the model.
- Clicker questions used multiple True/False format.
- Clicker questions were sometimes ambiguous.
- Clicker questions introduced new model elements.
- Clicker questions were not scored via points for correctness.
- Clicker questions allowed space for creative scientific thought.
- Clicker questions aligned with the summative assessments.
- Clicker questions were designed in progressive clusters.
- Clicker questions often used diagrams.

A number of more speculative hypotheses were proposed concerning why the above characteristics may be important. The specific use of diagrams in association with clicker questions is an interesting aspect of the GAMBR teaching approach. Research Question 2B, How are these diagram/clicker questions used within the instructional design? will be addressed further in the conclusion when more analysis is in place.

Chapter 10 will examine patterns of student talk within the different clicker question diagram types.

CHAPTER 9

CATEGORIZATION OF STUDENT TALK DURING CLASS-WIDE DISCUSSION FOLLOWING CLICKER QUESTIONS

This chapter addresses the findings of Research Question 3: What kinds of student talk were elicited during class-wide discussions following clicker questions?

> (A) What categories can be formulated to describe student talk occurring during the class-wide discussions following clicker questions in the instruction? Can any be considered to be model-related or indicative of model-based reasoning?
>
> (B) How many instances of each type occurred during the course?

Introduction

Teacher and student dialogue is at the core of the educational process (Dubrow & Wilkinson, 1984; Laurillard, 2002). Many named teaching strategies currently in use, including cooperative learning, case-based learning, clicker questioning, process-oriented guided inquiry learning, just in time teaching, and peer-led team learning, have student discourse as a main component (M. Tanner & Landon, 2009). However, dialogue is complicated in large lectures because the teacher cannot possibly converse with all or even a majority of the students in the class (Laurillard, 2002). Classroom response systems have aimed and been successful at addressing this issue by creating a mode of communication as well as a means to generate class discussion and peer discussion (Boyle & Nicol, 2003; Cutts et al., 2004; Draper & Brown, 2004). There are several question-based, large, lecture instructional methods that have been developed to increase the interactivity between the teacher and the students (See: Just-in-time teaching: Novak,

Patterson, Gavrin, Christian, & Forinash, 1999; peer instruction: Crouch & Mazur, 2001; Mazur, 1997; Question Driven Instruction: Dufresne et al., 1996).

There is much literature examining science classroom discourse at the k-12 level (see Price, 2013 for an in-depth review), determining how it occurs on the part of the teacher and the students, as well as its impacts on learning. Far less has been published about student talk at the college level, especially in large lecture classes. Though classroom and group/peer discussion is reported as a positive outcome of clicker use, only one article was found to look in-depth at what students were saying, and this was in peer instruction discussions (Knight et al., 2013). No in-depth studies of class-wide discussion in large lecture were found. Rather, the focus of the research has been on the instructional methods and overall outcomes (increased engagement, attendance, positive feedback from students, etc. See Chapter 2 for a review of clicker literature). This is perhaps because most large-lecture clicker instruction formats have maintained their traditional content-based learning goals. Such environments are not expected to lead to unique student talk, eliminating the need or interest in examining classroom discourse (as has been done in inquiry and model generation instructional methods being implemented at the lower grade levels). What we do learn from the literature is that in many cases class discussion is used as a way to enforce participation by picking students at random to explain their answers rather than being used as a time for students to workout issues they are having with the content and/or expand their understanding. In most cases, in Biology, class discussion appears to be skipped altogether and replaced completely with PI.

This chapter aims to examine the student talk that occurs during class discussion following clicker questions in the Guided Application of Model-Based Reasoning

(GAMBR) Instructional Approach. Through this, we hope to gain insight into some of the student behaviors that are occurring in the GAMBR classroom. It is important to note that this teaching method is non-traditional, even in the world of clicker application. It would not be expected that the data presented here is representative of student talk in other classrooms in which the learning objectives differ, and therefore extrapolation should be done cautiously, but if the amount and kind of student talk is unusual, it would be important to document. It seems important to develop constructs for recognizing sophisticated talk, such as model-based reasoning.

Method

Data Collection

Students' questions and statements were logged during class-wide discussion along with the clicker question they were associated with and notes on classroom activities. No audio or video recordings were made of the classroom, so the data are limited in that it does not include everything that was said by the professor, but it is a summary of observations of significant classroom activities in the order they occurred. The researcher did attempt to record the gist of every student utterance/turn during class discussions.

Each student turn was considered an utterance to be coded. The student utterances were entered into two Excel workbooks. One workbook was the same workbook containing the clicker question data. The second workbook contained only the student utterances, so they could be coded independent of the clicker question and instructor behaviors. This second workbook was used for the coding described in this chapter.

Categorization and Coding

Open coding using constant comparison methods was performed on the field notes focusing specifically on the student utterances to generate potential categories for student behaviors during the course. The main focus was on generating new categories for describing student talk occurring during class discussion following clicker questions in all phases of instruction. Since the course focuses on model-based reasoning, and the learning is centered on biological models, the categorization was approached through this lens.

Once stable codes were achieved, a second coder was brought in. The two coders engaged in an iterative process to refine the coding rubric and reach an acceptable rate of inter-rater reliability using the method described in Chapter 5 under Research Question 3. The complete coded data set was examined to record the frequency of the different types of student utterances in relationship to each other.

Results

Open coding generated eight categories of student talk[5], five of which were related specifically to model talk (i.e., talk about the current model), and three of which covered non-model talk (e.g., housekeeping). The vast majority of the student talk in the classroom related to the model (89%). The five model talk categories fell into two overarching categories: (1) questions about the model and (2) statements about the model. The open coding process leading to student talk categories and final coding

[5] Student utterance, student talk refers to a verbalization made by a student during class, corresponding to a full turn. "More student talk" then means, "More utterances or turns of student verbalizations," not "more minutes of talk time" (although the two may very well correlate).

process are discussed below as well as the information the coding provided about the student talk in the classroom.

Open Coding

In open coding of the field notes it was found that students are doing many things that are likely to occur in other large lecture instructional settings were clickers are used: asking questions about course details, seeking clarification about the wording of the clicker questions, seeking definitions or clarification about content, and providing answers to the clicker questions. Student comments also revealed misconceptions, however, this project did not focus on the impact of GAMBR instruction on misconceptions, so no effort was made to code them. This project aimed to see the student utterances through the model-based reasoning lens that the course is designed to generate. Thus, each utterance was examined with the question: what does this tell us about the student's engagement with the model? Codes were developed to address utterances that clearly did not relate to the model as well in order to cover all utterances.

The initial categories were non-model and model talk, model talk was then broken into *questions* about the model and *statements* about the model. From here the student utterances were examined in more depth to detect (code-able) differences between the types of questions and statements students were making. Many different characterizations were developed and collapsed and re-developed until a stable categorization was reached. One of the objectives for generating categories of student talk was to be able to compare student talk later across the clicker question categories. To make this comparison more reliable, a second goal was to generate categories that could be used by a second coder to

generate IRR and that the coding was not dependant on other course activities/materials. For these reasons, the researcher strove to develop categories of student talk that were not overly complex and could be used for coding in the absence of any other information about the course (e.g., clicker questions which they were related to).

Student Talk Categories

A total of eight student talk categories were defined. Five categories related to engagement in the model (model talk) and three categories represented engagement in talk not about the model (non-model talk). Below are detailed descriptions of the eight categories of student talk generated through open coding. (Note that the descriptions were refined during the IRR coding processes which will be discussed below.) See Table 9-1 for a brief description of each category.

Model Related Talk

Statement About the Model

Must fit all criteria below:

- Statement (not including a question asked in the form of a statement)
- Relays the student's understanding of part of the model or why they selected an answer, but does not provide a causal explanation (does not explain the relationship between different aspects of the model that lead the student to a given understanding).

Examples:

- "I said oxygen because it is released"
- "It goes into the ATP bond"
- "The obese gene product is what the obese mice don't make any more"

Causal Explanations.

Must fit all criteria below:

- Statement (not including a question asked in the form of a statement, with the exception being when the student ended an explanation with a question word – e.g. right?)
- Explains the event/s and/or mechanism/s that cause something to happen
- Contains a causal connection between at least 2 model elements

Supporting Features.

- Often contains at least one action word
- Often can easily re-word into 'if/then' language

Examples:

- "It is no longer more positive than Q, it can no longer pull electrons from it."
  --- REWORD – "{IF} It is no longer more positive than Q, {THEN} it can no longer pull electrons from it."
- "I think it would slow down because the pump is pumping against a force, the gradient"
  --- REWORD – "{IF} the pump is pumping against a force, the gradient,
  {THEN} it would slow down"
- "TK2 was activated by TK1, and activates TF and also activated phosphatase to block TK1, back tracking to stop the signal"

Questions—Model Content

Must fit all the criteria below:

- A question (sometimes might be in form of a statement e.g., 'I don't understand what is meant by activated')
- Student is seeking definition/clarification of specific term or process related to the model, or asking about aspects of the model in a broader context

Examples:

- "What is pyruvate again?"
- "What's the difference between self-renewal and DEV?"
- "Doesn't the kerb cycle make NADH? Is it like supply and demand?"
- "What do you do if you don't want stem cells to differentiate?"
- "Is cancer similar in a way that it is a malfunctioning cell?"

Questions—Model Logic

Must fit all criteria below:

- A question (sometimes might be in form of a statement e.g. I don't understand what is meant by what causes the signal to go off")
- Seeking clarification about causal mechanisms and/or sequences in the model, e.g. the effect one element of the model has on another, where an element comes from or when/how it is activated.
- One or more model element is included in the question

Supporting Features.

- Often contains at least one action word
- Often can easily be re-worded into 'if/then' language, or "if this, then what?'

Examples:

- "Couldn't an improperly folded protein not be able to be binded by the co-chaperone?"

  ---RE-WORD: "{IF} improperly folded protein, {THEN} not able to be binded by the co-chaperone?"
- "So once all the protons come down and the gradient doesn't exist, does the flagellum stop"

  ---RE-WORD: "{IF} all the protons come down, and the gradient doesn't exist, {THEN} does the flagellum stop?"
- "When the redox of cytochrome drops to +/-200, does it just move to the next one up?"

  ---RE-WORD: "{IF} the redox of cytochrome drops to +/-200, {THEN} does it just move to the next one up?"

Non-model Talk

Housekeeping

- Student comments or questions related to course aspects other than content, e.g. questions about where or when an exam was.

Examples:

- "Will there be questions like this on the exam?"
- "Do you need to use a pencil?"
- "Will you have class the day before thanksgiving?

Clarification About the Clicker Questions

- Student comments or questions seeking clarification about the format or wording of the clicker question or the answer to the question, e.g. did you mean 'it' instead of 'to'; is this multiple true false?; I don't understand the question.

  Examples:
  - "Are we entering the numbers as ½ for each T/F, or what?"
  - "Does the question actually mean OB-/OB-, like you wrote on the board just now?"
  - "No offense but you just totally lost me on that"

Answer Without Explanation

- Must be a comment that stated only the answer to a question
- Can be just a number or letter indicating the clicker response they selected
- Can be a brief statement that relayed only the answer they picked

  Examples:
  - "I picked A"
  - "C"

<u>Insufficient Data</u>

- Student statement or question was recorded as being missed or was too incomplete to code.

Table 9-1: Categories of student talk used for coding.

Student Talk-Category		Description	Example
Non Model Talk	**Housekeeping**	Not about course content	"Will there be questions like this on the exam?"
Non Model Talk	**Clarification about Clicker Question**	Clarification of wording or entering of clicker question	"Are we entering the numbers as 1 or 2 for each T/F, or what?"
Model Talk	**Question about Model Content**	Question about model components and concepts – definitions, etc.	"What is pyruvate again?"
Model Talk	**Question about Model Logic**	Question about causal relationships between model components and concepts	"So once all the protons come down and the gradient doesn't exist, does the flagellum stop?"
Non Model Talk	**Answer (without explanations)**	Provides answer to the clicker question without explaining	"I picked A"
Model Talk	**Causal Explanation**	Statement providing a causal explanation	"It is no longer more positive than Q, it can no longer pull electrons from it."
Model Talk	**Statement about Model**	Statement about the model (general)	"It goes into the ATP bond"
N/A	**Insufficient Data**	Not enough information	[Missed]

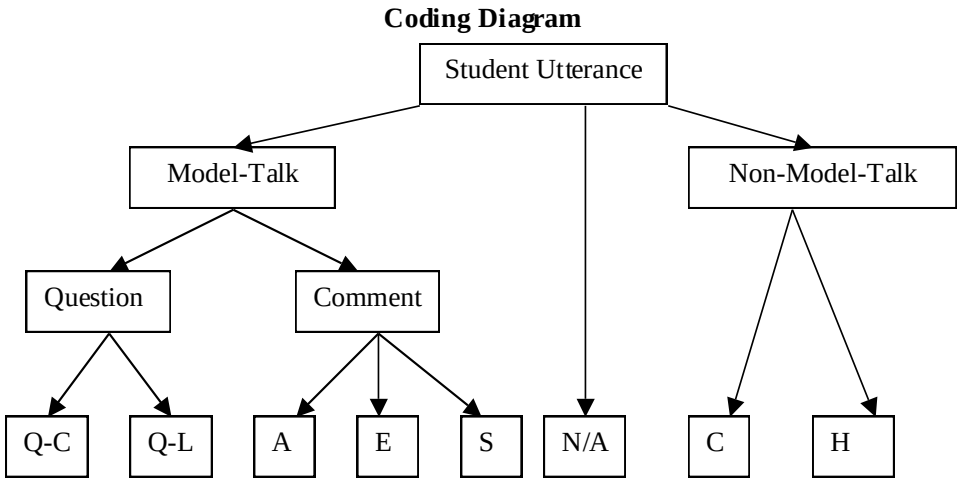
This table shows category, brief description, and example. The column all the way to the left represents whether the category fell under non-model talk or model talk.

Discussion of IRR Coding Process

Once stable categories were generated by the researcher, a second coder was brought in to generate inter-rater reliability. The second coder was an older undergraduate student who had taken the introductory course in which the model-based instruction approach was implemented a few years prior. The second coder's experience

with the learning environment was considered to be an important factor in reaching IRR, and was in line with the assumption of Cohen's kappa that the coders are knowledgeable and specifically selected to take part in the study rather than chosen at random. The student utterances were assigned numbers, and a random number generator was used to select the student utterances for the sub-samples. The initial training of the second coder was done on a subset of 30 randomly selected student utterances, whereby the researcher and the second coder worked side by side while coding to develop the second coders understanding of the rubric. This initial training resulted in some refinements of the coding rubric. Two rounds of independent coding on 50 items then took place. After each round IRR was calculated using the original version of Cohen's kappa (Cohen, 1960), and the two coders discussed any discrepancies, resulting in refinements to the category descriptions and the coding process.

One of the first discoveries was that a branched coding method increased the ease and reliability of coding. Therefore, the coding became a multi-step process: first the student utterances were coded as (1) model talk, (2) non-model talk, and (3) insufficient data; utterances in model talk were then coded as either questions or comments and then finally as one of the final model talk categories; utterances in non-model talk were coded accordingly. See Figure 9-1 for a branch diagram of the coding.



Code key

H	Housekeeping
C	Clarification about Clicker Question
Q-C	Question about Model Component/s
Q-L	Question about Model Logic
A	Answer (without explanations)
E	Causal Explanation
S	Statement about Model
N/A	Insufficient Data

Figure 9-1. Branch diagram of coding method.

The categories that were the most difficulty to describe and code were Student Questions about Model Content (Q-C) and Student Questions about Model Logic (Q-L). This is not surprising as students were learning the content of the model as they applied it. Almost all discrepancies in coding fell in attempting to distinguish between these two codes. While some student utterances fell clearly to one side or the other, there were some that were difficult to code. For example, the student question, “Does RME happen before the signal is binded?” was initially categorized by the second coder as a *question*

about model content and by the researcher as a *question about model logic*. Post-coding discussion revealed that both coders had difficulty deciding which category to place this student utterance in; further discussion resulted in the decision that this question dealt with the *sequence* in the causal chain as opposed to *causation*, but still suggested that the student was working out the logic of the model. Therefore, before the next round of independent coding, wording was added to the *question about model logic* category to ensure that student questions dealing with the sequence of the causal chain were included. The other categories, including the differences between statements about the model and explanations of reasoning did not pose a significant challenge.

On the third round of independent coding of 50 items Cohen's kappa was calculated to be 0.809, with 88% agreement. This fell above the *a priori* kappa of $> .60$, which was based on acceptable ranges in the literature (discussed in Chapter 5 under General Research Methods). The entire data set of student comments and questions from one semester were then coded by both the researcher and the second coder. The two coders then discussed each item that was coded differently and came to mutual agreement about how to ultimately code the item, resulting in the final data set.

Results of Student Talk Coding

One complete semester of data was coded. A total of 328 student utterances were recorded and later coded. Eight categories were used. The categories were further grouped together into non-model talk, and model talk. Model talk was again grouped into model talk suggestive of model-based reasoning (student questions about the model logic and causal explanations) and other (student questions about the model content and

student statements about the model). Subtotals were calculated for all groups. The grouping allows us to look at student talk that is model-related (model-based questioning or statements) versus student talk that is not, and compare the occurrences of student model-based statements versus questions during class time, as follows:

Non-model Talk
- Housekeeping
- Clarification about Clicker Question
- Answer (without explanation)

Model Talk
- **Model Based Reasoning (GAMBR)**
  - Question about Model Logic
  - Causal Explanation
- **Other**
  - Statement about Model
  - Question about Model Content

Insufficient Data

Table 9-2 below shows the results of the coding for the individual categories as well as the sub-categories for model talk and non-model talk.

Table 9-2: Instances of student talk by category.

Total, Percent Total and Subtotal			
Student Talk Category	**Instances**	**% Total**	**% Subtotal**
Non-model talk	**32**	**10%**	--
Housekeeping	7	2%	22%
Clarification about Clicker Question	17	5%	53%
Answer (without explanation)	8	2%	25%
Model talk	**293**	**89%**	--
Model-based reasoning	**97**	**30%**	**33%**
Question about Model Logic	72	22%	25%
Causal Explanation	25	8%	9%
Other	**196**	**59%**	**67%**
Statement about Model	62	19%	21%
Question about Model Content	134	41%	46%
Insufficient Data	3	<1%	--
Total	**328**		**--**

The subtotals for model talk and non-model talk are shown, as well as the percent of those subtotals for other items.

Model Versus Non-model Talk

As noted above, each category of student talk was also labeled as either non-model talk or model-related talk. The goal of this delineation was to identify how much of the student talk during classroom discussions was related to the model. This is important because each time a student either asks a question or makes a statement related to the model during class-wide discussion it provides information to the professor and the other students. The professor uses the student questions and statements to address parts of the model that need to be modified, expanded, or corrected, and as starting points to

move the class knowledge forward (toward the target model). The non-model talk is also important in that it provides students with the answers to questions they have related to the course or issues with the clicker question format or wording. However, this type of student talk does not contribute to the model-based content or reasoning knowledge of the classroom.

Note that in this document, when I say 89% of student talk was model related, I mean that 89% of the student utterance turns were model related, not that 89% of total talk time was model-related. In Table 9-2 and Figure 9-2, we can see that 89% of the total student talk was model-related. Of this 89% of model talk, about 1/3 was considered to be suggestive of engagement in model-base reasoning, while about 2/3 was considered to be related to the model but not necessarily suggestive of engagement in reasoning. Non-model student talk comprised 10% of the total talk. Less than 1% of the talk recorded was insufficient data and shown in yellow.

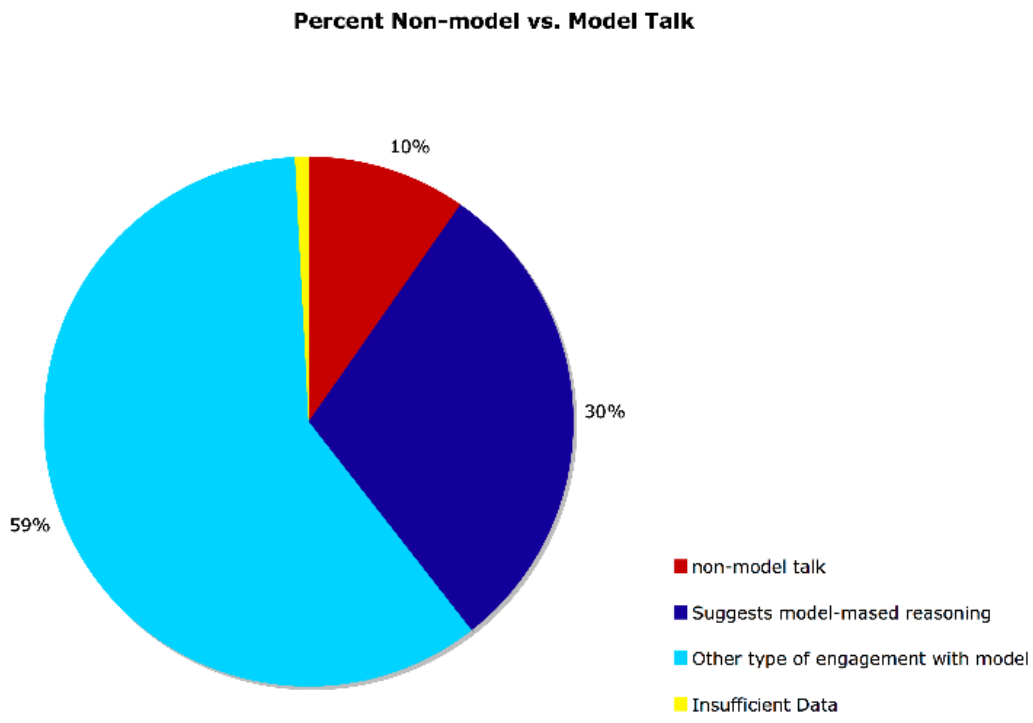


Figure 9-2: The percentage of non-model versus model talk.

The red slice represents the total percent of non-model talk. The blue slices represent the total model talk, with the dark blue being student talk that was suggestive of engagement of model-based reasoning, and the light blue slice indicates other model related talk.

Examining Patterns of Student Talk over the Course of the Semester

The student talk was examined over the course of the semester for differences and patterns among categories. Model-related talk occurred every day while non-model talk did not. The average number of student utterances per day was 11, with a high of 25 and a low of 0, and a mode of 6. While there were highs and lows throughout the semester, there was no clear pattern related to student talk types**.** See Figure 9-3.

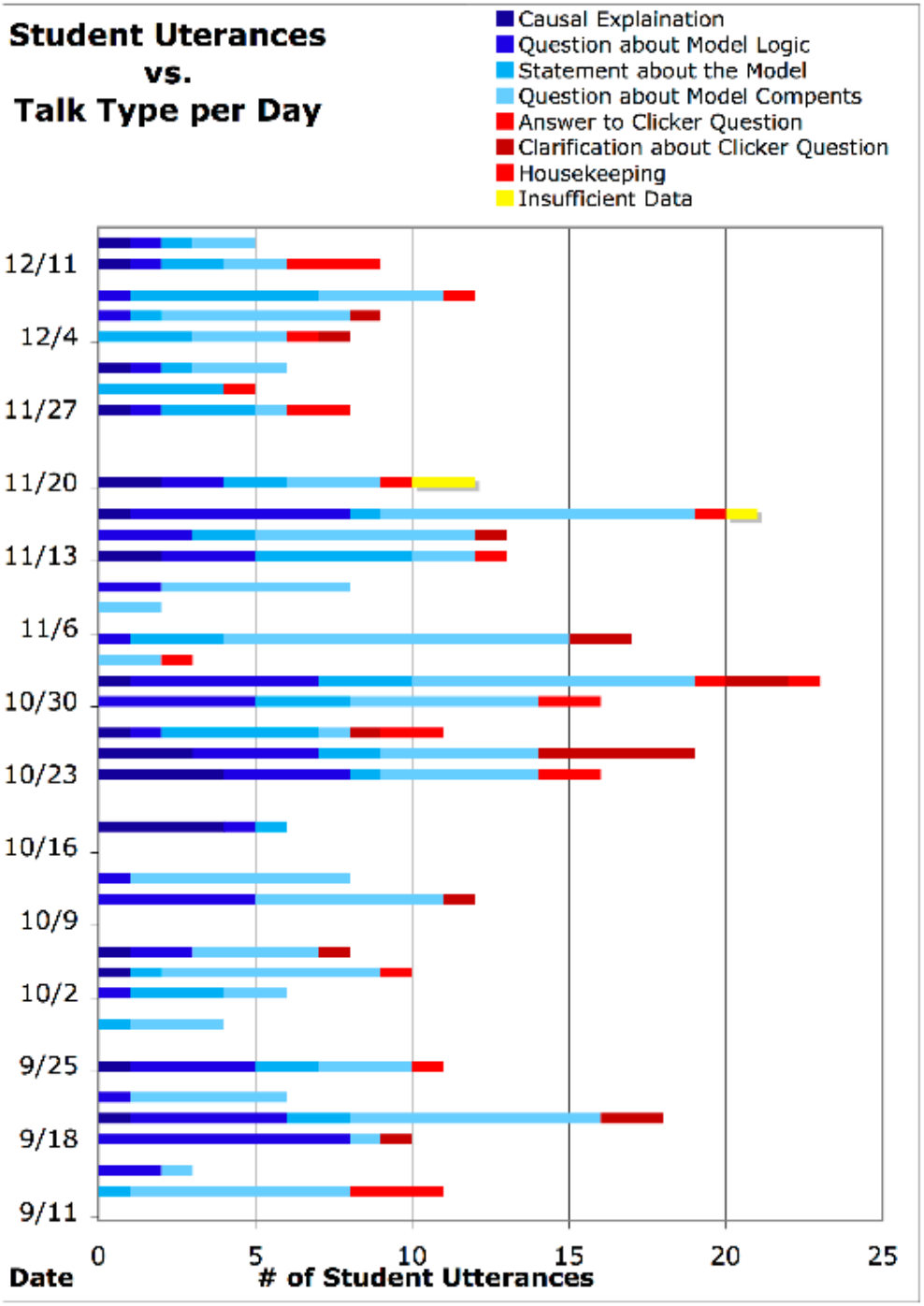


Figure 9-3: Profile of talk type occurrences on each day.

Figure 9-3 traces student utterance types over the course of the semester. The y-axis shows the progression of classes over the semester, while the x-axis shows the

number of student utterances. Each student talk category is represented by a different color. The blue shades representing model talk, with the two darker blues being model talk that suggested engagement in model-based reasoning. The red and orange represent non-model talk, and the yellow represents insufficient data. There is no time sequence shown within days.

Summary

Open coding of the field notes was used to generate categories for student talk during class discussion. Two individuals coded all the student utterances for one semester independently. After coding was complete, the distribution of student talk was explored.

Eight categories of student talk were developed, which could be divided into talk about the model (model talk) and talk not about the model (non-model talk). Of the model talk categories, two suggested engagement in model-based reasoning. Analysis of the total utterances in the different categories revealed that a predominant majority (89%) of the student utterances indicated that the students were engaged with the model on some level, and about 1/3 of these utterances were suggestive of engagement in model-based reasoning. The other 2/3 of the model talk suggested that students were thinking about the model or parts of it, but were not necessarily indicative of reasoning. These included statements about the model and questions about components or concepts related to the model (model content). All model talk is considered important because it suggests that the instructional method is indeed succeeding on some level in getting the students to engage with biological models.

Utterances that did not relate to the model are also important to the successful execution of the instructional approach. Students asked general questions about the course, such as the location of exams or time changes for labs (Housekeeping) and improving communication about course details. Students asked questions about the wording or logistics of the clicker questions (questions about the clicker questions), improving understanding about what the clicker questions are asking and providing some formative evaluation of the course, allowing the professor to improve them for the future. Occasionally, a student utterance was only a letter, number,or few words that correlated to a possible clicker question response they chose (e.g., I picked A). These utterances might have suggested engagement in the model, but because they did not provide much information, they were excluded from the model-related category.

In Chapter 10, I will examine the student talk categories in conjunction with the clicker questions (discussed in Chapter 8) and GAMBR instructional phases (discussed in Chapter 7). This is intended to provide insight into how the different clicker question conditions (model-representation diagram clicker questions, data diagram clicker questions, and non-diagram clicker questions) impact student talk in the classroom. Both diagram type clicker questions are included but not focused on because there were only two in this condition.

CHAPTER 10

EXPLORATION OF PATTERNS AMONG CLICKER QUESTION TYPES, INSTRUCTIONAL MODES, AND STUDENT TALK DURING CLASS-WIDE DISCUSSION

This chapter addresses the findings of Research Question 4: Are there patterns among student talk, clicker diagram conditions, and instructional sections?

(A) Are there patterns of student utterances in the different student talk categories (from Research Question 3) across the different instructional sections (from Research Question 1)? In particular ,does model-related talk vary across the different course phases?

(B) Are there patterns of student utterances in the different student talk categories (from Research Question 3) that appear within the different clicker question diagram conditions (from Research Question 2)? In particular ,does model-related talk vary across the different question/diagram conditions?

Introduction

As discussed in Chapter 2, effective clicker question design is one of the biggest challenges in the use of clickers. The clicker questions used in the instructional phases of Guided Application of Model Based Reasoning (GAMBR) were identified to have different teaching goals (i.e., motivation, scaffolding, or reasoning with the model). The clicker questions used in the Lesson phase were examined for unique characteristics that related to the instructional goals of the course (including engage in discussions), with a focus on the associated diagrams.

As discussed in Chapter 3, diagrams can be effective education and reasoning tools. Among other things, diagrams help students organize information, draw connections, visualize components, concepts, and processes, and can reduce cognitive load during reasoning. Diagrams are believed to be important in developing mental

models of scientific processes. Guidelines have been developed for effective use of diagrams in education, which include getting students to actively engage with them via problem-solving. Current research on the use of visualizations in the science classroom has focused on comparing the effect of lessons using different visual methods (drawings versus animations and simulations) and generating best practices for implementation of simulations. The studies have been concentrated in k-12 and focused on learning outcomes, for example, performance on pre- versus post-test. Here, we look at the impacts of diagram use on a specific classroom objective: generating class discussion about the models.

GAMBR implements a use of diagrams in the large-lecture classroom that has not been presented in previous literature, providing a unique opportunity to examine the effects of diagram use in conjunction with clicker questions on class discussion. As described in Chapter 8, diagrams often appear in class material. They are used to represent models of biological processes as well as data, providing central information in many clicker questions. One of the main learning components of the QDI approach (the starting point out of which GAMBR was developed) is class discussion. Class discussion provides the instructor with information about where the students are having issues, that is, why they got a clicker question incorrect, as well as an opportunity for students to share their knowledge, that is, what they do know about the model. One of the goals of using clicker questions, therefore, is to generate useful class discussion about the model being learned.

The clicker questions used in GAMBR have been sorted by the instructional phase they occurred in, in relation to the type of diagram associated with them, or the

disassociation with a diagram (see Chapters 7 and 8). The student utterances that occur during class-wide discussion have also been categorized (see Chapter 9). In this chapter, the data from Chapters 7, 8, and 9 will be used to search for patterns that emerge between the different clicker question conditions and the student talk during class discussion to gain insight into the impacts of the clicker questions on class-wide discussion.

Methods

Data Collection

See Chapters 7-9 for details on data collection for student talk, clicker questions and instructional phases.

Data Analysis

The student talk and clicker question data for one semester were entered into an Excel spreadsheet to create a table allowing for comparisons between student talk following clicker questions in different instructional phases and diagram conditions. Each row represented a different clicker question. The columns contained information about the clicker question: date it was implemented, text of the clicker question, clicker question diagram type, instructional phase it occurred in, total student talk during class discussion following, number of student utterances in each student talk category (see Table 10-1 below).

Table 10-1: Data organization to explore relationships.

Date	Instruction Phase	Clicker Question	Diagram-Type	Total	H	Q-C	Q-L	C	N/A	A	S	E
09/18	Lesson	You perform an analysis of a cell and find the following results: ex...	**Model diagram**	10	0	1	8	1	0	0	0	0

H=Housekeeping (student question or statement not about model)
Q-C=Student asks question about model content
Q-L=Student asks question about model logic
C= Student seeks clarification about clicker question format or wording
A=Student answers to clicker question (without explanation)
S=Student makes a statement related to the model
N/A=Insufficient data to categorize

Using the spreadsheet above, tables comparing frequencies of student utterances in student talk categories and different instructional phases and clicker question categories were generated and used to look for possible relationships in the data. Differences in frequencies between groups were noted and discussed.

Results

The number of student utterances following clicker questions within the student talk categories varied across the instructional phases and between the different clicker question diagram conditions.

For the tables shown below, there are subtotals of student talk shown. The subtotals consist of:

Non-model talk (subtotal of total talk)=

Housekeeping + Clarification about Clicker Question+ Answers

Model talk (subtotal of total talk)=

Questions model content + Questions model logic +Causal Explanations + Statements

Model-based Reasoning (sub-total of model talk)=

Questions about model logic +Causal Explanations

Other model talk (sub-total of model talk)=

Questions about model content + Statements

Student Talk Categories vs. Instructional Phases

There was a total of 328 student utterances observed over the course of the semester during class-wide discussions following clicker questions. Of the total student utterances, 91% occurred during the Lesson phase, 8% during the Unit phase, and less than 1% during the Topic phase. The total student utterances within the student talk categories for each instructional phase are shown in Table 10-2.

Table 10-2: Total student utterances across instructional phases.

	Topic Phase	Unit Phase	Lesson Phase	Total Utterances
Non-Model Talk				
	0	**3**	**29**	**32**
Housekeeping	0	2	5	7
Clarification about Clicker Question	0	0	17	17
Answer to Clicker Question	0	1	7	8
Model Talk	1	24	268	293
Model-based reasoning talk	**1**	**4**	**92**	**97**
Causal Explanation	1	1	23	25
Question about Model Logic	0	3	69	72
Other model talk	**0**	**20**	**176**	**196**
Question about Model Content	0	15	119	134
Statement about Model	0	5	57	62
Insufficient Data	0	0	3	3
Total Student Utterances	1	27	300	328
% of Total Student Utterances	<1%	8%	91%	100%
Total No. Clicker Questions	3	9	65	77

Subtotals of model talk are suggestive of model-based reasoning, other model talk, and non-model talk are shown in bold.

To draw fairer comparisons of student talk between the different instructional phases,Table 10-3 shows the ratio of student utterances per clicker question for each group.

Table 10-3: Ratio of student utterances per clicker question across instructional phases.

Student Utterances per Clicker Question: Student Talk Categories vs. Instructional Phases	**Topic Phase**	**Unit Phase**	**Lesson Phase**	**Total Student Utterances**
Non-Model Talk	0.00	0.33	0.45	0.42
Housekeeping	0.00	0.22	0.08	0.09
Clarification about Clicker Question	0.00	0.00	0.26	0.22
Answer to Clicker Question	0.00	0.11	0.11	0.10
Model Talk	**0.33**	**2.67**	**4.12**	**3.81**
Model-based reasoning talk	**0.33**	**0.44**	**1.42**	**1.26**
Causal Explanation	0.33	0.11	0.35	0.32
Question about Model Logic	0.00	0.33	1.06	0.94
Other model talk	**0.00**	**2.22**	**2.71**	**2.55**
Question about Model Content	0.00	1.67	1.83	1.74
Statement about Model	0.00	0.56	0.88	0.81
Insufficient Data	0.00	0.00	0.05	0.04
Total Student Utterances	0.33	3.00	4.62	4.26
Total No. Clicker Questions	3	9	65	77

Subtotals of model talk suggestive of model-based reasoning, other model talk, and non-model talk are shown in bold. Red indicates differences across instructional phases that are most interesting to the researcher.

Areas of Most Interesting Differences

The ratio of student utterances per clicker question increased from the Topic phase to the Unit phase to the Lesson phase, with the Lesson phase having a ratio 1.5 times larger than the Unit phase. The most interesting differences to the researcher in the ratios across instructional phases appear in the Lesson phase under the sub-category of

student model talk and student talk suggestive of model-based reasoning within that sub-category. The ratio for talk suggestive of model-based reasoning in the Lesson Phase is more than three times that of the either the Topic or Unit Phases, with the main difference concentrated in questions about the model logic.

Student Talk vs. Clicker Question Diagram Conditions[6]

A total of 300 student utterances were observed in the Lesson phase of instruction during class-wide discussion following clicker questions. Table 10-4 shows the total student utterances for each student talk category across the clicker questions diagram condition. As stated in Chapter 7, there are a disproportionate number of clicker questions in the clicker question diagram conditions, with almost half of them (48%) in the model-representation diagram condition.

[6] Although the Both Diagram Type-Clicker Question condition is included in the tables below, it was not compared to the other three clicker question conditions in the discussion. This is because of its small size of 2 items.

Table 10-4: Student utterances across clicker question categories.

Student Utterances: Student Talk Categories vs. Clicker Question Diagram Condition *(Lesson Phase Only)*	**Model-Representation Diagram**	**Data Diagram**	**No Diagram**	**Both Diagram Types**	**Total Student Utterances**
Non-Model Talk	**13**	**9**	**2**	**5**	**29**
Housekeeping	3	1	0	1	5
Clarification about Clicker Question	7	5	1	4	17
Answer to Clicker Question	3	3	1	0	7
Model Talk	126	88	37	17	268
Model-based reasoning	**56**	**19**	**10**	**7**	**92**
Causal Explanation	13	7	2	1	23
Question about Model Logic	43	12	8	6	69
Other model talk	**70**	**69**	**27**	**10**	**176**
Question about Model Content	52	42	16	9	119
Statement about Model	18	27	11	1	57
Insufficient Data	3	0	0	0	3
Total Student Utterances	142	97	39	22	300
% Student Utterances	48%	32%	13%	7%	100%
Total Clicker Questions	27	22	14	2	65

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Subtotals of model talk suggestive of model-based reasoning, other model talk, and non-model talk are shown in bold.

To draw fairer comparisons of student talk between the different clicker question diagram conditions, Table 10-5 shows the ratio of student utterances per clicker question for each group.

Table 10-5: Ratio of student utterances per clicker question among clicker question categories.

(Lesson Phase Only)	**Model-Representation Diagram**	**Data Diagram**	**No Diagram**	**Both Diagram Types**	**Total Student Utterances**
Non-Model Talk	**0.48**	**0.41**	**0.14**	**2.50**	**0.45**
Housekeeping	0.11	0.05	0.00	0.50	0.08
Clarification about Clicker Question	0.26	0.23	0.07	2.00	0.26
Answer to Clicker Question	0.11	0.14	0.07	0.00	0.11
Model Talk	4.67	4.00	2.64	8.50	4.12
Model-based reasoning	**2.07**	**0.86**	**0.71**	**3.50**	**1.42**
Question about Model Logic	1.59	0.55	0.57	3.00	1.06
Causal Explanation	0.48	0.32	0.14	0.50	0.35
Other model talk	**2.59**	**3.14**	**1.93**	**5.00**	**2.71**
Question about Model Content	1.93	1.91	1.14	4.50	1.83
Statement about Model	0.67	1.23	0.79	0.50	0.88
Insufficient Data	0.11	0.00	0.00	0.00	0.05
Total ST per QC Type	5.26	4.41	2.79	11.00	4.62
Total # CQ	27	22	14	2	65

Subtotals of model talk suggestive of model-based reasoning, other model talk, and non-model talk are shown in bold. Red indicates differences question conditions that are most interesting to the researcher. Yellow indicates other areas of smaller difference and interest.

Examination of the number and type of student utterances that occurred following the three main clicker question diagram conditions revealed some potential areas of interest. The instructional method focuses on learning biology through reasoning with models. Therefore, the areas of interest to the researcher were the student talk categories that suggested engagement with the model and especially those that suggested engagement in reasoning with the model.

Areas of Greatest Differences and Interest (Shown In Red)

The ratio of total student utterances per clicker question was larger for both main clicker question conditions that had diagrams directly associated with them than for the no-diagram clicker question condition. The model-representation diagram clicker question condition had the largest ratio, and at 5.26, it was nearly double that of non-diagram clicker questions (having a ratio of 2.79). The data diagram clicker questions had a ratio of 4.41, which was slightly more than 1.5 times that of the no-diagram clicker question condition.

Talk Suggestive of Engagement with the Model

The total student utterances per clicker question that were suggestive of engagement with the model was also larger for both of the main clicker question conditions that had diagrams directly associated with them than for the no-diagram clicker question condition. The model-representation diagram clicker question condition had the largest ratio, and at 4.67, it was nearly double that of non-diagram clicker questions (having a ratio of 2. 64). The data diagram clicker questions had a ratio of 4.00, which was again slightly more than 1.5 times that of the no-diagram clicker question condition.

Talk Suggestive of Engagement in Model-based Reasoning

The total student utterances per clicker question for model-representation clicker questions was more than double that of either of the other two clicker question conditions

at a ratio of 2.07. The data diagram and no-diagram clicker questions had more comparable ratios at .86 and .71, respectively.

Student Questions About the Model Logic

The largest difference between ratios of student utterances per clicker question across the three main clicker question groups was found in the student questions about the model logic category of student talk. In this category, model-representation diagram clicker questions had 1.59, which was almost three times the amount of either data diagram or no-diagram clicker questions, at .55 and .57, respectively.

Student Causal Explanations

The ratios of student utterances per clicker question across the three main clicker question conditions was found to be notably different in the student causal explanations category of student talk. In this category, model-representation diagram clicker questions had a slightly higher ratio than data diagram clicker questions, at .48 to .32, respectively. No-diagram clicker questions had a notably lower ratio at .14.

Combined with the student questions about the model logic, this resulted in the larger ratio of "model talk suggestive of model-based reasoning" in the model-representation diagram clicker question condition.

Areas of Smaller Differences (Shown in Yellow)

Clarification About Clicker Question and Student Questions About the Model Content

The ratio of student utterances to clicker questions in the student talk categories Clarification about clicker question and Questions about the model content for the non-diagram condition was close to half the amount of the data diagram and model-representation diagram clicker question conditions.

Student Statements About the Model

The ratio of student utterances to clicker questions in statements about the model following data diagram clicker questions was slightly greater than 1.5 times the other two main clicker question conditions.

Areas of Little Difference

Housekeeping and Answers to the Clicker Questions

The ratios of student utterances to clicker questions in student talk categories housekeeping and answers to the clicker questions were very similar among the different clicker question conditions.

Summary

Comparisons of the total number of student utterances and ratio of student utterances to clicker questions within the student talk categories across the clicker questions in the different instructional phases and diagram conditions revealed potential areas of interest for future exploration.

As expected based on observations discussed in Chapter 7, the majority of the clicker questions were used in the Lesson phase of instruction; therefore, the majority of the student utterances also occurred in the Lesson phase. In looking at the differences in the ratio of student utterances to clicker questions among the Topic, Unit, and Lesson phases, the ratios increase across the phases, with Lesson having the highest ratio of student utterances per clicker question. The most interesting difference to the researcher was that there were notably more student model talk utterances, especially talk suggestive of model-based reasoning, in the Lesson phase than in either the Topic or Unit phases. However, because the clicker question style differed among these categories (as discussed in Chapter 7) differences were expected across the instructional phases.

In focusing on the Lesson phase, there were differences noted in student talk frequencies between the clicker question diagram conditions[7].

1. Model-representation and data diagram clicker questions both had notably higher ratios than the no-diagram clicker questions of student utterances to clicker question in total talk as well as in categories of model related talk.

2. Model-representation diagram clicker questions had a ratio of student utterances to clicker question in categories of student talk suggestive of model-based reasoning that was more than double either the data diagram clicker questions or no-diagram clicker questions, with a higher ratio in both student questions about the logic and causal explanations.

3. The ratio for student questions about the model logic was three times greater for model-representation diagram clicker questions than in either data diagram clicker questions or no-diagram clicker questions.

4. The ratio for student causal explanations was only slightly higher for model-representation diagrams clicker questions than for data diagram clicker questions, but these were both more than double the ratio for no-diagram clicker questions.

[7] Both diagrams type clicker question condition was excluded from the analysis because of the small size of two clicker questions.

It should be noted that model diagrams were handed out to students, while data diagrams were projected in front of the class. Although students could point to parts of data diagrams projected in front of the class, being able to draw on and point to model diagrams in front of them at their seats may possibly have contributed somewhat to the effect of more whole class discussion here.

In summary, looking at the student utterances within the student talk categories among the clicker question diagram conditions and across the instructional phases indicated that class-wide discussions were impacted by the different conditions. Gaining a deeper understanding of the differences might aid in the enhancement of the GAMBR instructional approach as well as other applications of clicker questions. In the conclusion chapter, I will summarize and discuss the findings of the four research questions, present hypotheses grounded in these findings and instructional implications.

CHAPTER 11

CONCLUSION: SUMMARY OF FINDINGS, MODEL OF INSTRUCTION, LIMITATIONS AND IMPLICATIONS

> I didn't learn much about Biochemistry until I started taking my introductory biology class in the University of Massachusetts Amherst. The first day I learned about signal transduction pathways. It wasn't like any other Biology class I took. It was focused less on memorizing terms and more on understanding and critically thinking about the pathway as a whole. My professor presented us with different scenarios and challenged us to critically think about them and come up with a solution. I see a similar approach with the way researchers approach a problem. (Student)

Introduction

This chapter summarizes the findings of the research project and the support for them. It discusses the limitations of the study and the theoretical and instructional implications. It is a little unusual as a final chapter because in the middle I attempt to develop a hypothesized model of the instruction capable of explaining some of the quantitative findings. This could have been a chapter on its own, but it made sense logically to put it after the summary of findings.

Broader Questions Addressed

This case study examined the Guided Application of Model based Reasoning (GAMBR) instructional approach being implemented in large-lecture biology courses at the University of Massachusetts Amherst by Professor Randall Phillis. The research aimed to address some of the gaps in the large-lecture biology personal response system (clicker) literature (see "Case for a Case Study" at the end of Chapter 4 for more details). I list these here not as my specific research questions but as broader long range questions motivating this study. The literature is missing or is very sparse on:

Examples of courses with a heavy focus on inquiry/process/skills-based learning objectives.

- Could student engagement in any of these processes be detected during courses?
- How would such a course be structured?

Model-based educational approaches

- Can a course that is deeply model-based be designed and implemented in college biology?

Strategies for designing complex and provocative clicker questions

- In particular, what are some strategies for creating clicker questions designed to promote model based reasoning?

Examinations of students' talk during [peer or] class discussions

- In particular, can any of the model-based reasoning skills mentioned above be detected in classroom discussions?

Strategies for using visual aids to support learning on different levels

- In addition, can the use of visual aids have an effect on model-based reasoning during class discussions?

GAMBR is a unique method of teaching biology that includes a focus on learning model-based content and process goals through application of model-based reasoning using existing biological models. Clicker questions are designed as tools for facilitating student engagement in model-based reasoning and are used to generate student talk during class-wide discussions. Clicker questions are often associated with model-representation diagrams that are partial depictions of the model students are being asked to reason with.

Qualitative case study analyses of the course structure and instruction were conducted to develop a rich and detailed description of GAMBR. Quantitative analyses

of some of the most important course features (clicker questions, diagrams, and student talk during class-wide discussion) were conducted. These findings are summarized in this chapter. Using them as a base, I then go beyond the data-based findings to generate the beginnings of a hypothesized model for GAMBR instruction, as shown in Figure 11-1.

Summary of Findings

This section summarizes the findings for each research question. As a highlight, among the quantitative findings, three of most interest to the researcher are presented in Table 11-1, underneath the main hypotheses grounded in these findings.

Table 11-1: Main hypotheses generated and qualitative findings of most interest to the researcher.

GAMBR engages students with biological models **Support: 89% of student talk during class-wide discussion was about the model**
GAMBR engages students in model-based reasoning **Support: 30% of student talk during class-wide discussion was suggestive of model-based reasoning**
Model-representation diagrams facilitate model-based reasoning and related student talk in GAMBR **Support: Clicker questions with model-representation diagrams had greater amounts of student talk suggestive of model-based reasoning than clicker questions with data diagrams or without diagrams.**

It is important to recognize in presenting these results and the perceived significance of them, that a limitation of this study was that there was no control classroom available or in the literature with which to compare the findings. Nevertheless, in my opinion, the first two percentages above appear to be very high and would pose a challenge to other instructors to emulate, especially in a traditionally-focused large-lecture biology course, with or without the use of clickers.

A description of the methods used in this study can be found in Chapter 5, but Figure 11-1 provides a visual representation of the research questions and highlighted findings for this case study and the status of the hypothesized model of instruction for the course that will appear later in this chapter.

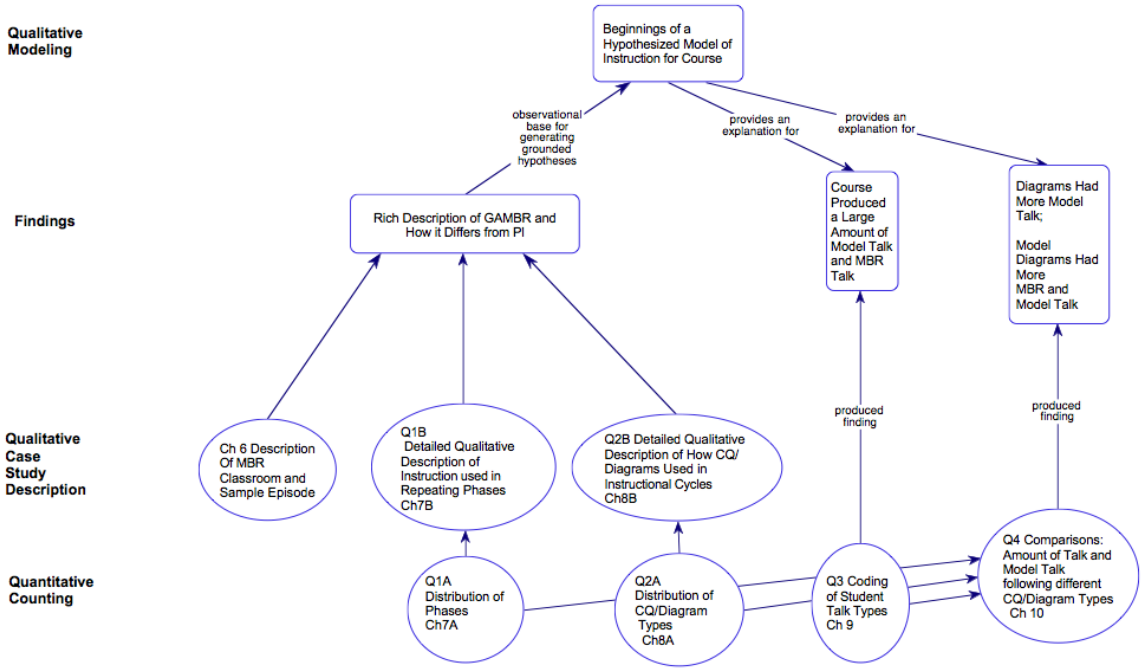


Figure 11-1: Research questions and inference structure for dissertation.

This figure will be referred to throughout this chapter to help the reader follow the logic of the thesis.

Summary of Findings for Each Research Question

This section reports the overall findings for each research question set forth in the methods section. Referring to Figure 11-1, this section addresses the findings generated from the bottom two rows: Qualitative Case Study Description and Quantitative

Counting. See Chapter 5 for details on the research methodologies used to generate these findings.

Description of the Course (Chapter 6)

Chapter 6 presents a detailed description of the typical course content and activities as well as a case description of a Day in the GAMBR Classroom. There are three levels of nested content: big real-world topics, such as cancer; focused content units, such as gene expression; and lesson models, such as stem cell self-renewal. The instruction includes out of class activities, such as pre-class readings and quizzes; as well as in-class activities, such as clicker questions and Friday quizzes. The course website is the primary source of course information to students, while the textbook is used as a reference book. The clicker questions are closely aligned with the summative assessments and both aim to engage students in model-based reasoning. The information within the description provided a context for the remainder of the study.

Overall Findings for Research Question 1: Patterns/Cycles of Instruction (Chapter 7)

What major patterns/cycles of instruction took place during the course?

(A) How is the course broken down into sections such as topics and units, and where do models occur? How many instances of each type of section occurred and how are they distributed over the semester?

(B) What is the qualitative structure of the instruction within the sections? Are there patterns or cycles in the instruction that utilize models?

Through analysis of the course field notes and materials and discussions with the instructor, three phases of the instruction were identified based on the pre-determined content structure of the course. Counts of the total instances of the phases and

corresponding clicker questions were made. The phases were then examined to provide detailed descriptions of the instructor's goals and activities (including the role of clicker questions) at each stage.

Quantitative (B) and Qualitative (A) Findings on the Three Phases of Instruction

Nested Cycle of Instruction, Consisting of 3 Phases. A nested cycle of instruction based on three levels of content was identified in the course (Figures 7-1 and 7-2 are important to review here). The cycle started with the Topic phase, followed by the Unit phase, and then the Lesson Phase. Within the Lesson phase, several models were covered by the course, and eventually the instruction returned to the Unit phase with the introduction of a new unit, which would lead back into the Lesson phase. After a few cycles between Unit and Lesson, the instruction would return all the way to the Topic phase with the introduction of a new motivating topic, starting the instructional cycle over (for a visual see Figure 7-1 in Chapter 7).

The three instructional phases are described below. Table 11-2 shows the distribution of clicker questions across the instructional phases.

Table 11-2: Clicker questions across the phases.

Total Clicker Questions per Instructional Phases

	Total # CQ	% Total
Topic Phase	3	4%
Unit Phase	9	12%
Lesson Phase	65	84%
Total Clicker Questions	77	100%

Topic phase was the initial phase of instruction at the highest organization level and occurred four times over the course of the semester. The goal of this phase was to motivate student engagement by situating the content unit and associated models in a biologically relevant and socially engaging real-world topic, for example, cancer. A clicker question was sometimes used in this phase to get students motivated with a total of 3 clicker question used in this phase over the semester. The main format of the instruction was a PowerPoint presentation, using images and visuals to help students recognize the significance of the topic.

Unit phase was the second phase of instruction and occurred 6 times over the course of the semester. The goal of this phase was to introduce content and to scaffold the initial associated models that the students would be asked to reason with in the Lesson phase. A few clicker questions were sometimes used in this phase to get students thinking and reasoning about the general causes of biological phenomenon related to the unit; a total of 9 clicker questions were used in this phase over the semester. The clicker questions appeared to aim at helping students see the importance of learning the minute details and logic of the associated models, for example, "What is the mechanism that

controls what type of cell a stem cell turns into?" as well as scaffold their knowledge of the model. The main format of the instruction was an instructional lecture.

Lesson phase is the third and main phase of instruction. Within this phase were several lessons on different models, with a total of 18 models being taught. There was also a pattern within each lesson. The lesson pattern included the modes of: Introduce the model; Extend, comprehend, and revise the model; and Connect the model to other models. The model in one lesson would often be nested within the model in the following lesson, where the first model became part of the second model, and so on. At the end of a unit, the models were connected to models in previous units.

The goal of the Lesson phase was to increase students' content knowledge and reasoning skills to engage them in model-based reasoning with biological models. An additional way to think about the lessons was to move students from an initial model to a more complex target model as well as to support the building of connections among the different models. The main quantitative finding on this question was that many clicker questions were used in this phase, a total of 65 (84% of all clicker questions for the semester), and they were the tools used to engage students in reasoning with the model and guide them from the initial model to the target model. The clicker questions led into many instructor and student activities, including peer discussions, class-wide discussions, and micro-lectures (focusing on application). See Chapter 7 for more details.

Overall Findings for Research Question 2: Clicker-Questions and Diagrams in the Lesson Phase (Chapter 8)

For the above reasons, this question focused on the Lesson phase of instruction only.

How are diagrams used in the course in association with clicker questions?

(A) For different types of diagrams that appear in association with the clicker questions used over the course of a typical semester, how often is each type used?

(B) How are these diagram/clicker questions used within the instructional design?

Two types of diagrams were used in conjunction with clicker questions, ones that depicted a scientific model and ones that depicted data. These two diagram categories were used to sort the clicker questions in the Lesson phase of instruction into four categories related to diagrams:

Model Representation Diagram Clicker Questions: Clicker questions associated with diagrams that depicted a scientific model (model representation diagram)

Data Diagram Clicker Questions: Clicker questions that had a diagram depicting data (data diagram) related to the model

No-Diagram Clicker Questions: Clicker questions that did not have associated diagrams

Both-Diagram Clicker Questions: Diagrams that had both a model-representation diagram and data diagram associated with them

Main Quantitative and Qualitative Findings Related to Clicker Questions and Diagrams

(A and B1-3 below refer to the specific sub-research question the finding pertains to)

(A) A high proportion of the clicker questions used in the Lesson phase of instruction had some type of diagram directly related to them, and often it was a model-representation diagram. Eighty-seven percent of the clicker questions

in the Lesson phase had a diagram associated with them; 48% of the clicker questions had a model-representation diagram.

(B) Eleven unique aspects of the clicker questions used in the Lesson phase were identified (very few of these were found in other biology courses reviewed in the literature):

- Goal of the clicker questions is to engage students in practice applying and perturbing the model rather than measuring correct responses
- Clicker questions were based on existing biological models.
- Clicker questions asked students about possible manipulations of the model.
- Clicker questions used multiple True/False format.
- Clicker questions were sometime ambiguous.
- Clicker questions introduced new model elements.
- Clicker questions were not connected to points for correctness.
- Clicker questions allowed space for creative scientific thought.
- Clicker questions aligned with the summative assessments.
- Clicker questions were designed in progressive clusters.
- Clicker questions included diagrams.

Overall Findings for Research Question 3: Categorization of Student Talk[8] During Class-Wide Discussion Following Clicker Questions (Chapter 9)

What kinds of student talk were elicited during class-wide discussions following clicker questions?

[8] Student talk refers to a student utterance during class-wide discussion, corresponding to a full turn. "More student talk" then means more utterances or turns of student verbalizations, not "more minutes of talk time" (although the two may very well correlate).

(A) What categories can be formulated to describe student talk occurring during the class-wide discussions following clicker questions in the instruction? Can any be considered to be model-related or indicative of model based reasoning?

(B) How many instances of each type occurred during the course?

See Chapter 9 for more details.

Through open coding of the course field notes, followed by repeated cycles of comparison and revision, the study converged on eight categories of student talk during class-wide discussions. A second iterative process of refining the coding rubric to reach and acceptable IRR between two coders followed. (See Chapter 5 for complete description of IRR protocol.) An IRR kappa of 0.81 was achieved on a randomly selected subset of the data prior to the coding of the entire dataset, comparing well to the *a priori* value of .60.

Main Qualitative and Quantitative Findings on Student Talk

The student talk categories were generated using open coding. Once categories were stabilized a second coder was trained using randomly selected sets of student utterance data until an IRR of 84.9% agreement was reached. Both coders then coded the entire data set individually, and joint determinations about the non-matching codes were made. Below are the findings (A and B1-3 below refer to the specific sub-research question the finding pertains to):

(A) Eight categories of student talk were defined which were divided into 2 groups and two subgroups.

Group 1: Non-model Related Talk – student talk not suggestive of engagement with the model

- Housekeeping - Student utterances related to information about the course, but not content (e.g., exams, course website, etc.)
- Clarification about Clicker Question – Student questions about the format or content of the clicker question pertaining to functionality (e.g., how to enter the response using the clicker, or if the wording is incorrect)
- Answer without Explanation – Student utterances providing only a possible answer to the clicker question (e.g., what number or letter they picked)

Group 2: Model Related Talk – student talk suggestive of engagement with the model

Subgroup 1: Model-based Reasoning Talk – talk suggestive of model-based reasoning

- Question about Model Logic – Student questions about the causal logic of the model (e.g., seeking to understand the interaction between two components)
- Causal Explanation – Student utterances explanation their reasoning using causal links between items (e.g., one component acting on another resulting in a change of state).

Subgroup 2: Other Model Related Talk

- Question about Model Content – Student questions about content related to the model (e.g., seeking the definition of a term)
- Statement about Model – Student statement related to the model (e.g., the current state of a component or end result without an explanation).

Not grouped

- Insufficient Data – Student utterances that did not have enough information to be categorized.

(B) A high percentage of student talk suggested engagement with the model

- 89% of the total student talk is model talk—it suggests students are engaged with the model
- 30% of the model talk is suggestive of students being engaged with model-based reasoning (questions about model logic and causal explanations)

Note that these are highlighted findings, other percentages for specific student talk types can be found in Chapter 9.

Overall Findings for Research Question 4: Exploration of Patterns Among Instructional Phases, Clicker Question Diagram Conditions, and Student Talk During Class-wide Discussion (Chapter 10)

Are there patterns among student talk, clicker question diagram conditions and instructional sections?

(A) Are there patterns of student utterances in the different student talk categories (from Research Question 3) across the different instructional sections (from Research Question 1)? In particular, does model-related talk vary across the different course phases?

(B) Are there patterns of student utterances in the different student talk categories (from Research Question 3) that appear within the different clicker question diagram conditions (from Research Question 2)? In particular, does model-related talk vary across the different question/diagram conditions?

See Chapter 10 for more details.

Differences in total student utterances and student utterances per clicker question in the eight student talk categories (defined in response to Research Question 3) were compared across the instructional phases (identified in response to Research Question 1) and across the clicker question categories (defined in response to Research Question 2) through generating comparison tables. Note: there were only two items in the both diagram type clicker question category so it was not included for this analysis. The key findings were (A and B1-3 below refer to the specific sub-research question the finding pertains to):

Main Findings (Quantitative)

(A) Not surprisingly, more student talk occurs following clicker questions that ask them to reason with specific models that have been introduced, and more of the talk is suggestive of model based reasoning.

Support: Ratio of student utterances per clicker question was highest in the Lesson phase where clicker questions ask students to reason about a specific model, as opposed to the Topic or Unit phases, where clicker questions were found to ask students to think/reasoning on a more general level.

(B-1) More student talk occurred when there was a diagram associated with the clicker question.

Support: Compared to the no-diagram condition, the two diagram conditions (data diagram and model diagram) had a higher overall ratio of student utterance per clicker question

(B-2) More student talk related to the model and more talk suggestive of model based reasoning occurred when there was a diagram associated with the clicker question.

Support: Compared to the no-diagram condition, the two diagram conditions (data diagram and model diagram) had a higher ratio of student utterances per clicker question in the subtotal of category of model related talk

(B-3) More student talk related to the model and more talk suggestive of model based reasoning occurred following clicker questions associated with model-representation diagrams, than when the associated diagram depicts data or there is not accompanying diagram.

Support: Compared to the no-diagram condition and the data diagram condition, the model-representation diagram condition had an overall higher ratio of student utterance per clicker question, and higher ratios were found in the categories of student talk related to the model and suggestive model-based reasoning, especially in the student talk category of "questions about the model logic."

Many other differences were reported in the student talk categories across the instructional phases and across the clicker question diagram conditions. These were

presented in Chapter 10, but the differences or sample sizes were smaller and of less interest to the researcher given the focus of the study on model-based reasoning.

Why was There a High Percentage of Model Talk?

As stated at the start of this chapter, the researcher is strongly interested in the high percentage of model talk and model-based reasoning talk generated by GAMBR. As an extension of Research Question 4 we can ask: Why did this occur? At a surface level, one might give a quick answer: the whole course was focused on models. In particular the instructor:

1. Presented many explanatory models and model elements
2. Asked students to apply and work with models through clicker questions

Even so, it was not a given, however, that young college students would be able to learn to think in terms of dynamic models, given that explanatory models are perhaps the most difficult conceptual ideas in biology, and the instructor was unsure in setting out on this path that he would be able to get these young undergraduates to think with and about abstract models, such as engaging them in model revision and extension, especially in the setting of a lecture hall with up to 480 individuals. As we all know, just asking students to do something does not mean they will be capable of doing it. And a theme of this study is that the instructor went to some extraordinary lengths to support students in the sophisticated "reasoning to learn" he was asking them to do. There is a difference between asking students to do something and documenting through observations that they are actually able to do it.

For those reasons, I ask the reader to assume for the sake of argument in the remainder of this chapter that the findings for the course of 89% of the total talk being model talk and 30% of the total talk being model-based reasoning talk are noteworthy findings, and that it is worth examining in detail the aspects of the course that may have produced them. I begin by summarizing discerned, distinctive features of the course that separate it from previous approaches, including details about how the instructor asked students to apply and work with models in item 2 above. Once this has placed key features of the course into relief, they will be gathered into a more speculative hypothesized model of how the course produces model talk. An overview of that model can be obtained by scanning the rest of the figures and tables in this chapter.

Discussion on the Differences Between GAMBR and Peer Instruction

Returning to Figure 11-1, this section connects to the box to the left just above the Qualitative Case Study description, reading "Rich Description of GAMBR and How it Differs from PI." The detailed description of GAMBR will continue through the next two main sections of this chapter, with a focus on differences between GAMBR and Peer Instruction (PI).

This case study has used both quantitative and qualitative approaches to look at the GAMBR instructional approach being implemented at the University of Massachusetts Amherst in large-lecture biology courses. GAMBR is a unique method of teaching biology that includes a focus on model-based reasoning skills. These process learning goals, along with goals addressing specific course content knowledge are learned through the continuous application of existing biological models. This is one of several

distinctive qualities this course has from other large-lecture biology courses that appear in the literature. The researcher has found PI to be the dominating application of clickers as classroom tools in the large lecture biology literature. This approach to clicker use focuses on providing "time to engage in active learning" and "students learning from students" but was not seen to drastically impact the course focus on what type of content students learn, nor include a heavy focus on scientific process goals. Question Driven Instruction, the other most well studied use of clickers, only appeared in the large-lecture biology literature as "support and ideas for using clickers and designing questions" rather than the approach being sited as the one used in the course. No examples of QDI being used in the ways described by Beatty et al. (2006b) were found.

GAMBR differs from PI in many ways, but the key distinctions are:

- Content Learning Goals: Rich, deep, and dynamic biological models as a learning goal vs. traditional biology content goals
- Inquiry/Process learning Goals: Model-based reasoning skills as a learning goal vs. no articulated inquiry/process goals
- Instructional Format: Application-based learning in biology vs. "active" lecture-based learning
- Classroom format: Peer discussion and class-wide discussion vs. only peer discussion (or class-wide discussion, when included used mainly for students explaining their response rather than dynamic instructor and student interactions)
- Summative assessments: Test students understanding of the model as well as model based reasoning ability vs. testing content knowledge
- Textbook use: Textbook used as a reference book (out of sequence and chapter structure) vs. textbook used in traditional chapter-by-chapter structure
- The Clicker Question Design*: I do apply my previous and current knowledge prior and new to reason with the model* clicker questions versus *I am here, prepared and paying attention* or *I do learn, understand, apply what you just lecture about* - Woelk (2008) found that most uses of clickers fell into two categories: "I am" (I am here, I am prepared, I am paying attention) and "I do" (I

learn, I understand, I apply) (p. 1400). There are at least 10 features of Clicker question design that are unusual in this course (detailed in Chapter 8 under Part B, Fine-grained Description of MBR Clicker Question Features). The most notable of these would arguably be that the purpose of the clicker questions is to engage students in practice applying and perturbing the model rather than measuring correct responses.

Disclosure

A direct and controlled comparison of GAMBR and PI would be needed to support any claim to an improvement of effectiveness resulting from the differences suggested above. It should be noted that PI is not considered to be an ineffective use of clicker questions, just a different, more common approach with more ease in maintaining traditional large lecture biology learning goals (and perhaps outcomes).

Hypothesized Course-grained Model of GAMBR Instruction

In this section I begin to pose theories for how the course could produce high percentages of model talk based on the qualitative and quantitative findings summarized in the earlier Summarized Findings section.

The hypotheses generated here, though generated in response to the findings of this case study, are not considered to be heavily supported or evaluated; however, one of the important roles of case studies is to generate theoretical models as well as description. Such theoretical models are grounded in initial observations from the case study and pose hypotheses that can be evaluated in future research.

In the next two main sections, I develop a theoretical model of instruction in GAMBR. In the spirit of theory construction, I will on occasion be implying or stating that students have engaged or would engage in a particular activity. However, this is

meant in the frame of theoretical hypothesizing, that is to say, there will often be no specific evidence that the students engaged in said activities (though findings will be used as support whenever possible). Rather, the text below presents a model of what students may be doing during GAMBR instruction that can explain high frequency of model-engaged statements observed. Further research on student behaviors (as well as instructor's in some cases) would be needed to provide a stronger statement of what students activities are occurring.

Returning to Figure 11-1, as shown there this section will present a hypothesized model for course instruction based in the qualitative case study descriptions from Chapters 6 to 8 to (Research Questions 1B and 2B) as well as Chapter 6.

There are many materials, activities, and interactions the student experiences during GAMBR that may support them in progressing from their prior model of the biological process to the target model goal of the instructor. Students are provided instruction related to the content and model by the instructor. The students have the opportunity to get information from their peers during peer discussions. Students are provided with material to support and further their understanding, such as handouts, drawings on the board, and clicker questions. This study only examined student behaviors during class-wide discussions, but inferences can be made related to their activities during group discussions and initial reasoning with clicker questions based on what they said during class-wide discussions; in doing this, the discussion that follows is theoretical in that way as well.

Figure 11-2 shows the initial theoretical model of student progression from prior model to target model I will use as a starting point. As shown in Figure 11-2, the students

are presumed to come from previous lessons with a model; through this knowledge the students have what I will call the *existing prior model.* (This includes knowledge about the model gained through pervious courses and life experiences, a well as information related to the model presented during the Topic and Unit phases of instruction.) This can be seen in Figure 11-2 all the way to the left. The brief introduction at the start of a lesson results in an *initial model for the lesson* that includes both their prior knowledge and the new elements that they have learned from the instructor's micro-lecture. (This can be seen in Figure 11-2 as the second model to the left.) The instructor then uses clicker question clusters to ask the students to apply the initial model. Each clicker question introduces new elements to the model, guiding the students toward making a revision or extension of their initial course model. Therefore, each clicker question may help develop a slightly more complex, correct, and complete model; these are considered to be *intermediate models*, as they are between the initial and the *target model* for the lesson. (These can be seen in Figure 11-2 as the models that progress toward the right.)

In Figure 11-2, the activities in the course that generate new model elements are represented by the stacked boxes at the bottom. These boxes depict the clicker question cluster and associated student and teacher activities that occur surrounding each clicker question. These activities and the hypothesized results of them are discussed below, but first it is important to point out again that much of what is said to be happening in this section is hypothetical, as the data were not sufficient to make stronger statements. The students asked questions, and provided answers and explanations during class-wide discussions. The questions and comments made by the students during this time suggest that prior to class-wide discussion, during the time the clicker question is posted and

students are encouraged to talk with their peers, they are engaged with reasoning about the model. From an observational stand point, the researcher can verify that students talked to each other during peer discussion times and that they generally appeared engaged with the clicker question, often gesturing or pointing at time as they talked. The instructor responded to the student comments and questions. These responses included micro-lectures. These instructor activities were observed but not recorded in detailed.

The instructor used the clicker questions and diagrams to introduce new elements of the model into the classroom. The clicker questions thereby acted as a vesicle for new model information and a stimulant for the generation of new model ideas. New model elements were, therefore, not necessarily confined to the clicker questions but were generated by students during class-wide (and likely peer) discussion. There is evidence that supports that at times students brought up new ideas about the model during class-wide discussions, inferences that they made based on new elements introduced by the clicker questions, diagrams, and/or their peers. For example, the student utterance that appears in Chapter 6 Case Description of a Day in GAMBR on Day 3, "Maybe, the signal might not still be there –it must be originally but might not be now," provides a new element to the model. Note that these were complicated to code for systematically, given the data available; complete transcripts would be needed to confirm that ideas had not been previously mentioned or covered by the instructor or during class discussions. Often, such as in the case above, the clicker question is specifically designed by the instructor to support students in generating such inferences. These inferences may contribute to the classroom knowledge of the model and help move the model toward the target model. The instructor uses the class-wide discussion to address issues that the

students are having with new elements introduced by the clicker question and diagrams, as well as to draw out their inferences. For example, the statement above is followed (indirectly) by two student questions seeking further clarification about the model and new model element of time: "How long do these things last?" and "By present, do you mean attached to the receptor?" This instructor's response to these questions as well as to the previous students' statements led to a new intermediate model (see Figure 11-2 below).

The inferences are used to move the lesson to the next clicker question in the cluster, which has been pre-designed to address it. The complexity of the target model and depth to which the instructor desires the students to know and be able to reason with it impacts the number of clicker questions used in the related cluster. (It would appear that the experience of the instructor is key to successfully orchestrating the sequence and design of the clicker questions.)

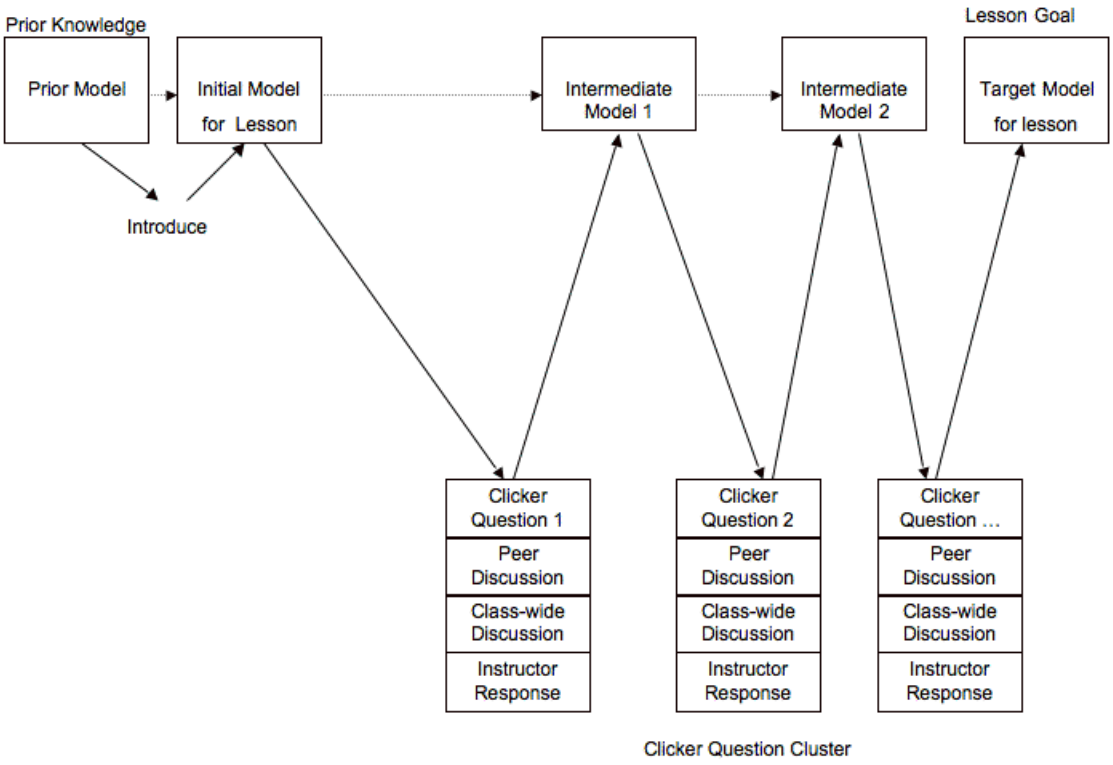


Figure 11-2: Theoretical model of student progression from prior model to target model.

Theoretically, the students start with a prior model based on their prior knowledge from outside and inside the course. The student develops an initial lesson model based on the brief introduction at the start of the lesson, which includes their prior knowledge. The instructor then uses a clicker question cluster to guide the students to the target model. Each clicker question in the cluster is used to support the student in generating an intermediate model until the target model is reached. New model elements are introduced to the students from the clicker question text and diagram (when applicable), discussion with peers, and the class-wide discussion, including instructor responses to student questions and comments.

Thinking about the learning that occurs in GAMBR in this vein puts it in alignment with, though a variation on, the approach of model co-construction as described by Clement and Rea-Ramirez (2008). Model co-construction is an instructional strategy whereby the students and teacher work together to build a model. The model evolves through student generated model elements and elements introduced by the teacher (Clement & Rea-Ramirez, 2008; Rea-Ramirez, 1999; Steinberg & Clement, 2001). In co-construction, the central feature is considered to be model evolution, where students are able to build on knowledge that they had developed in earlier sections (Clement & Rea-Ramirez, 2008; Clement & Steinberg, 2002). One of the main differences of model co-construction provided previously in the literature, however, is that GAMBR has the students starting from biological models that are somewhat well constructed already, in that the students are presented with a basic version of the model prior to the lesson. Another difference is that there appear to be more teacher-generated model elements in GAMBR, as the clicker questions often directly introduce new elements, which are intended to be used to revise or extend the existing model that is then expanded as they work through the lesson. Another difference is that the students are asked to read prior to class and, therefore, are expected to have a solid basis of prior knowledge about some of the "new elements" before learning about them in class. It seems that the focus in GAMBR is on application of the model in ways that are consistent with how scientists use models to explain and or to generate extended to revised versions of existing models rather than how they generate more purely original models. This last contrast may be important for faculty considering implementing a model-based approach in their large-lecture course, especially if the course is geared toward majors at a research

intensive university, such as UMass Amherst. At such schools, it may be more appealing to move toward model-based learning if instructors can see the parallels between the skills and content they are trying to teach their students and the skills and content they look for in future graduate students. Further examination of how GAMBR can contribute to the literature on model-based education at the undergraduate biology level as well as in a more general sense may be a worthy endeavor.

More Detailed Model of GAMBR Instruction: Why does GAMBR Result in High Percentage of Student Talk About the Model During Class-Wide Discussion, Including Talk Suggestive Model-based Reasoning?

This section discusses the researchers' hypotheses on why GAMBR generated a high percentage of student model talk and model-based reasoning talk, grounded in the main qualitative findings for Research Questions 1 and 2, that is, the detailed course description that was generated will be used as a foundation for some of the hypotheses.

Some terms I will use:

1. Increased student talk—increased number of student utterance turns that occur during class-wide discussions following clicker questions.

2. Model talk—sub-category of student talk that was identified as talk that was related to the model (see Table 11-1 and Research Question 3(A)).

3. Model-based reasoning talk—sub-category of model talk that was identified as talk suggestive of model based reasoning (see Table 11-1 and Research Question 3(A)).

Important pre-assumptions of the researcher:

In the following analysis, I include in my model the impact on various instructional and clicker question conditions on peer discussion. It is important to note that no data were collected on student talk during peer discussion but that the facilitation of peer discussion is hypothesized by the researcher to indirectly support students in talking more during class-wide discussion because it provides an opportunity for students to talk in a small group of peers, thereby gaining comfort, ability, and confidence in talking about the models prior to class-wide discussion.

This section is broken down by the individual research questions, posing hypotheses for how the various course aspects could produce such high percentages of model talk based on the qualitative and quantitative findings. Figure 11-3 provides a visual representation of the top level hypotheses on how GAMBR generated a high percentage of student model related talk. The model includes 6 levels of processes in the instruction, the first 5 of which are shown in this diagram from topic to clicker question characteristics. The hypothesized model described in this section moves from the left of this diagram to the right.

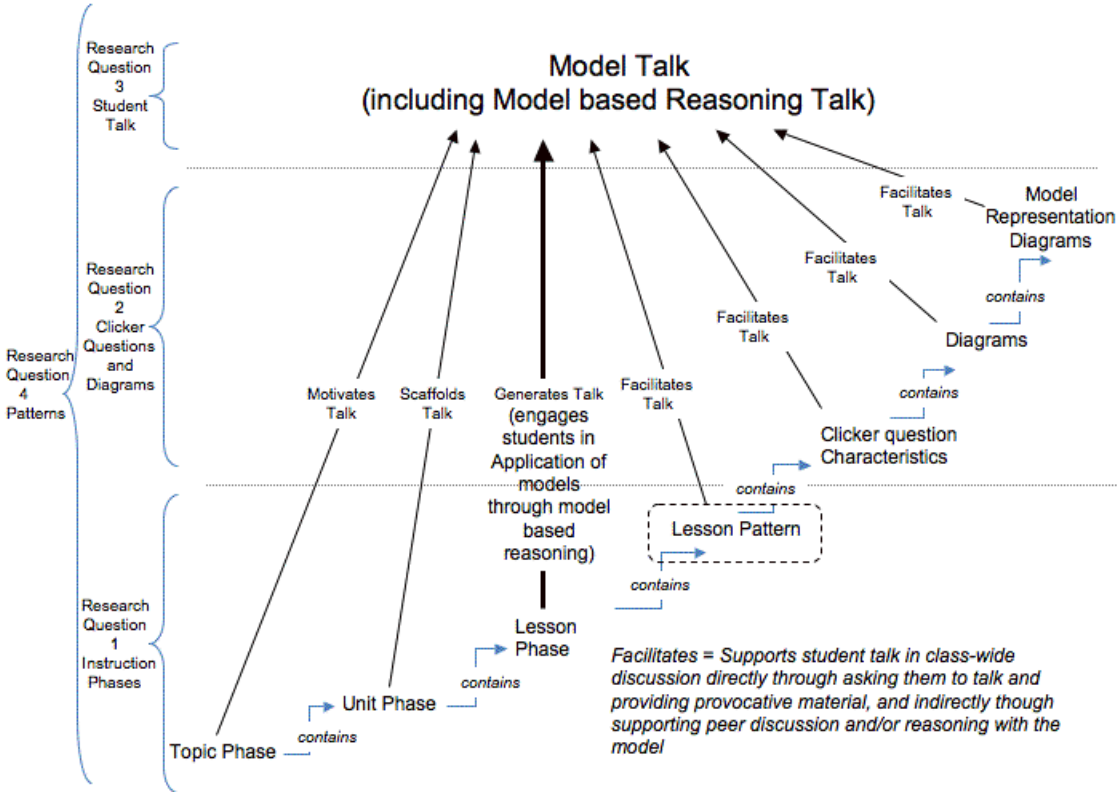


Figure 11-3: Hypotheses on how GAMBR generated a high percentage of student model-related talk.

The line from Lesson phase to model talk is bold because this phase of instruction was found to be where the main instructional activities aiming at generating model talk occurred, and it had the highest amount of model talk across the phases. The instructional phases to its left are hypothesized to support model talk by preparing the students for engagement during the Lesson phase. Course components to the right are contained within the Lesson phase and are viewed as parts of the Lesson phase that facilitate model talk in various ways. The dotted box around Lesson pattern will be expanded in Figure 11-4.

Instructional Phases: Hypotheses on How GAMBR Generated a High Percentage of Student Model and Model-based Reasoning Talk Grounded in Findings from Research Question 1: Course Segmentation and Phases

The quantitative findings of Research Question 1 reveal that most of the active learning times in the class are spent having students apply models by asking them to reason with models. In brief, the majority of active learning, meaning learning that involved the use of clicker questions and allowed time for students to talk with peers and interact with the instructor, fell during the Lesson phase of instruction (84% of all clicker questions were used in this phase). Referring to the left hand side of Figure 11-3, we see the phases are all hypothesized to play a role in the high percentage of model talk found.

Motivating and Scaffolding Student Engagement

However, the Topic and Unit phases that occur prior to the Lesson phase are considered to be important in generating high rates of student talk. The Topic and Lesson phases may support student talk by motivating engagement with the model and scaffolding their content knowledge. Student motivation/interest is important when trying to get students to engage in complex reasoning; the more motivated they are to engage with the model, the more likely they are to talk about the model. Scaffolding the students' knowledge so they have some prior knowledge of the model (including some relevant concepts and vocabulary) provides a basis for their reasoning and talking about the model.

Concentrated Student Engagement with the Model Through Application

The Lesson phase of instruction accounts for most of the classroom time and focuses on engaging students in learning the models through application. Figure 7-2 provides a visual distribution of the clicker questions in the course and hypothetical timeline for the phases. The researcher is calling this course structure that is highly model focused (in both content and process learning goals, and instructional structure): model-centric.

Lesson Pattern

The Lesson phase consists of multiple lessons on models associated with the unit. There are three parts of a lesson identified that I call the lesson pattern: *Introduce* the model; *Extend, comprehend, and revise* the model; and *Connect* the model. As 91% of all model talk occurred in this phase, I will focus on it in the rest of this section.

More Detailed Model of Lesson Pattern Effects on Talk

The researcher's hypotheses on how each of part of the lesson pattern facilitates student talk is presented in Figure 11-4 and discussed below. Obviously, the hypotheses represented in this and the diagrams to follow are not put forward as complete; rather, it is hoped that they will provide an initial model that may be improved over time by criticism and revision.

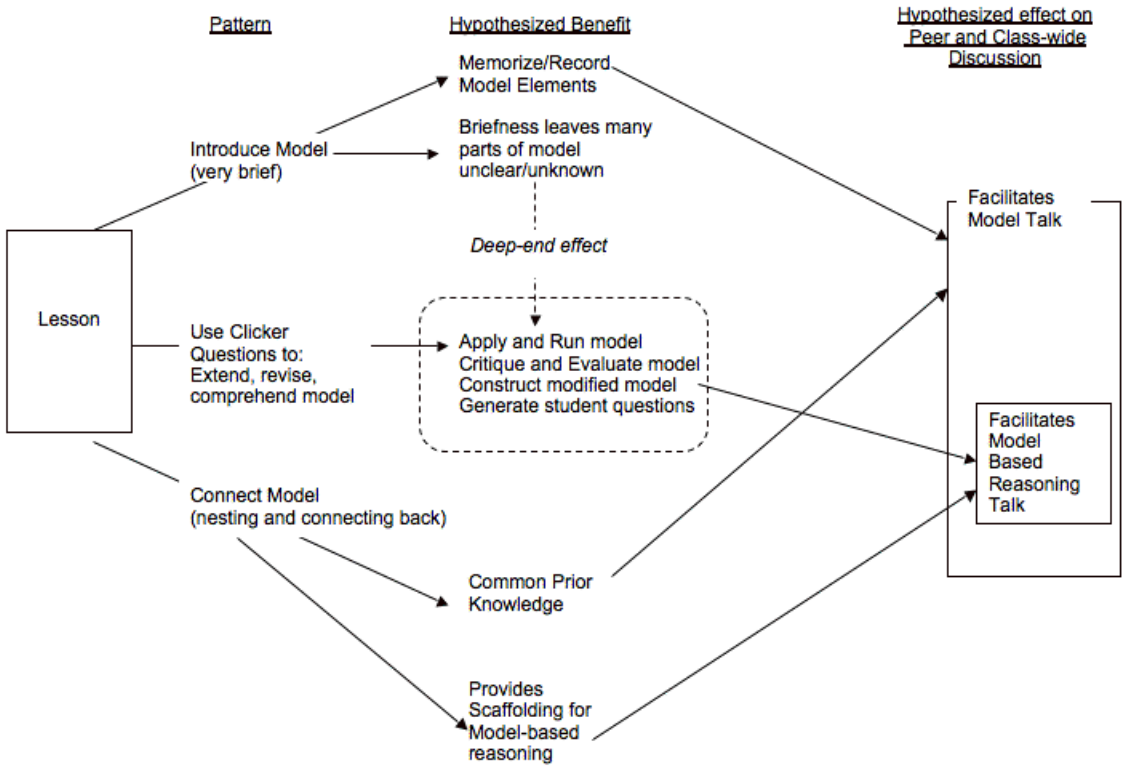


Figure 11-4: Hypotheses on how the lesson pattern facilitates model talk .

This diagram is an expansion of the area enclosed in the dotted line in Figure 11-3. The dotted item in this diagram will be expanded in Figure 11-5.

Introduce the Model. The first step in a lesson is a brief introduction to the model given by the instructor in the form of a micro-lecture. The introduction provides minimal information about the model to the students, including basic logic and components. The students are then immediately asked to apply the model through a clicker question. Students may memorize or record some of the information related to the model during the introduction that, in turn, could facilitate model talk. In addition, and perhaps more important, the briefness of the introduction of the model generates student

questions when combined with the request to apply the model to answer clicker questions posed immediately following the introduction. One way to think about this is as a *deep end effect* that is created by the briefness of the model introduction. (In Figure 11-4 this is represented by the downward dashed arrow from "briefness leaves many parts of model unclear/unknown" to "Apply and run model.")

Extend, Comprehend, and Revise the Model. The majority of a lesson is spent having the students work through clicker questions that ask them to reason with the model (see "Use clicker questions to: extend, revise, and comprehend model" to left in Figure 11-4 under Pattern). The clicker questions are designed to stimulate peer discussions, class-wide discussions, and instructor responses (including micro-lectures). Throughout the lesson, the intention is that new model elements will be introduced by the students as they reason with the model. With each clicker question, students have the opportunity to apply the model. The clicker questions are designed to ask the students to reason with the model in ways that engage them in running the model and, therefore, challenge students' incomplete or vague knowledge of both the model content and model logic. Actively running the model may facilitate comprehension of the model content and logic and may also reveal gaps in student understanding, generating student questions. Applying the model may also lead to critiquing or evaluating the model, resulting in model revisions that may result in them making a statement or posing a question about their new understanding of the model. New model elements are introduced throughout the lesson (commonly via clicker questions) and these "model extensions" are likely to generate student questions and inferences about the model as they attempt to apply and

run it and construct a modified model. Looking back to the example of classroom activities presented in Day 3 under Case Description of a Day in the Classroom in Chapter 6, examples of student questions and comments generated during class-wide discussions support that the lessons generate the types of talk described here.

Connect the Model. Lessons commonly involve the lesson model being connected to previous models. (See "Connect model" to the left under Pattern in Figure 11-4.) There are two ways this was seen to occur, that were described as: nesting and connecting back. (See Figure 7-4 for a visual representation of nesting and connecting back.) In nesting, the new lesson model contains the previous lesson model. The previous model nested within the new model provides a foundation for the students' understanding that can scaffold model-based reasoning. This may facilitate model comprehension, revision, or extension, leading to more student questions and/or comments about the model during peer and class-wide discussions. Also the old model is a point of common prior knowledge for the students facilitating communication.

Connecting models back to previous models has the same benefits as nesting: the students have familiarity with both models that can facilitate reasoning and supply common knowledge to support student discussions.

Hypotheses on How GAMBR-Generated High Percentage of Student Model and Model-Based Reasoning Talk Grounded in Findings from Research Question 2: Clicker Questions Characteristics (Including Diagrams)

The qualitative and quantitative findings of Research Question 2 both provide a foundation for theories on why there were high percentages of model talk, grounded in the observations pertaining to the clicker questions and diagrams. As stated above, the quantitative findings of Research Question 2 reveal that the clicker questions in the Lesson phase were predominantly associated with one of two diagram types (48% were associated with model-representation diagrams, and 34% with data diagrams). The diagram conditions were found to be associated with a different ratio of student utterances per clicker question. The use of diagrams, however, was only one of several unique characteristics of the Lesson phase clicker questions identified by the researcher. This section focuses on the researcher's hypotheses on how the characteristics of the Lesson phase clicker questions may facilitate student model talk during class-wide discussion.

The clicker questions used during the lessons aim to *engage students in applying and perturbing the model*, rather than measuring correct responses. The researcher's hypotheses on how clicker questions facilitate student model talk are discussed below, and Figure 11-5 offers a visual representation of the hypotheses. The various clicker question characteristics identified in Research Question 2 and appearing on the left side of the figure are hypothesized to facilitate student talk in various ways. I discuss each of the benefits in column 2 of Figure 11-5 below.

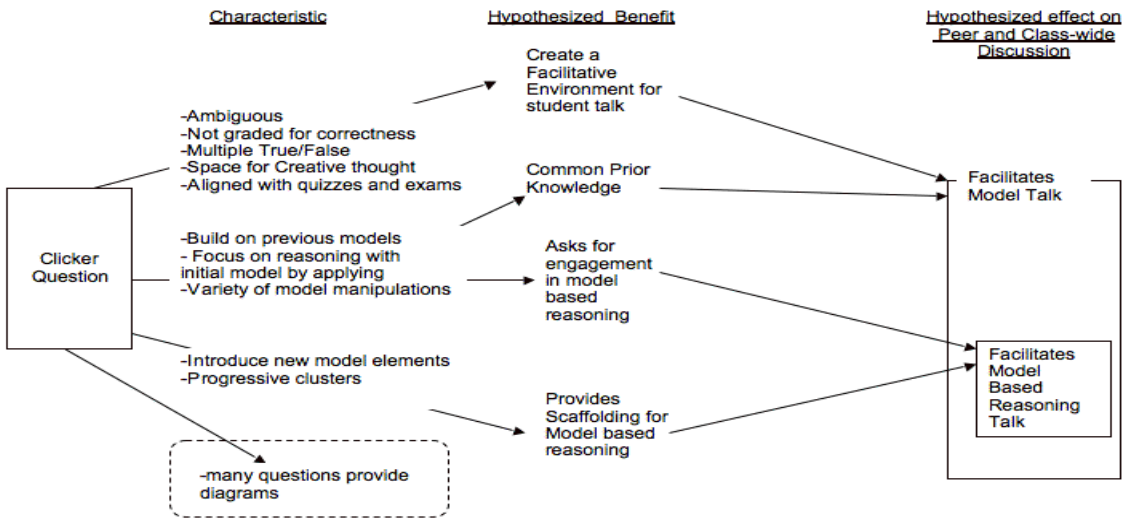


Figure 11-5: Hypotheses on how clicker questions facilitate model talk.

This diagram is an enlargement of the area enclosed by a dotted line in Figure 11-4. The area enclosed by a dotted line in this figure will be expanded and connected in Figure 11-6.

Create a facilitative environment for student talk:

- Sometimes ambiguous
- Not graded for correctness
- Multiple True/False format
- Space for creative scientific thought
- Aligned with the summative assessments

The characteristics listed above are hypothesized to help create a classroom environment that is facilitative to student talk in both peer and class-wide discussions. Not connecting the clicker questions to grades allows for students to focus on reasoning

and discussing the model without worrying about correctness. Clicker questions are often ambiguous, aiming to generate student questions and ideas, and providing points to haggle over during peer discussion. By asking somewhat open-ended questions, the clicker questions also provide space for creative scientific thought; thereby, students might generate ideas they want to share with peers and the class. Multiple true/false questions provide more opportunities for students to run the model and talk about that, and alignment with summative assessments motivates engagement in both peer and class discussion to ensure correct and complete understanding.

Engagement in model-based reasoning:

1. Build on previous models
2. Focus on reasoning with initial model by applying
3. Variety of model manipulations

The clicker questions also engage the students with thinking about the model in complex ways centered on manipulating the model, which beg for discussion with peers and the instructor to sort out what is happening in the model. Some of the unusual and more complex attributes of clicker questions generated by the manipulations of the models are:

- Deep ended: For example, the students are asked to reason with the complex model right from the start, prior to having much exposure to how it works.
- Model Revising: For example, clicker questions introduce new model features and ask the students to reason about their effects on the model.
- Model Incomplete: For example, clicker questions are used to expose that the model currently being used is incomplete and in need of extension to explain new data or model components.

All of the above features of manipulating the model may result in the clicker questions being Question Generating, meaning that they are provocative and often *create an explanatory need.* (These clicker question attributes are exemplified in the course episode analysis in the section on hypotheses of how model representation diagrams support reasoning below.)

Because the models build on each other, they provide points of prior common knowledge among students that may facilitate communication about the model during peer and class-wide discussion.

Provides scaffolding for model-based reasoning:

4. Introduce new model elements
5. Progressive clusters

The clicker questions provide scaffolding through the use of diagrams and progressive introduction of new model elements. The progressive design of the clicker question cluster, with new model elements introduced in successive questions, may help students to talk about the model, and their reasoning (as their knowledge and confidence in the model content and logic) grows over the course of the lesson. The deep end effect is also in play; however, the instructor often uses the clicker questions to introduce new model elements prior to teaching the class about them (via lecture), which likely generates peer discussion and class-wide questions.

Diagrams

The clicker questions often uses diagrams, and there are several hypotheses about how diagrams may have supported student talk. These will be discussed below in relation

to Research Question 4, where student talk during the different clicker question diagram conditions was compared quantitatively.

Hypotheses on How GAMBR-Generated High Percentage of Student Model and Model-Based Reasoning Talk Grounded in Findings from Research Question 4: Patterns of Student Talk in Different Clicker Question Conditions

Research Question 4 looked at patterns of student talk across the instructional phases and among the clicker question diagram conditions.

Clicker Questions Across Instructional Phases

In relation to instructional phases, clicker questions in the Lesson phase were found to have the highest amount of student talk, including talk about the model, with an especially large discrepancy in model-based reasoning talk in comparison to the Topic and Unit phases. This finding was additional support for the hypotheses discussed above on how the Lesson phase and characteristics of the clicker questions within that phase may have supported student talk in the form that clicker questions used in the Lesson phase were followed by more student model talk and especially model-based reasoning talk than the clicker questions in the other phases (see Table 11-3). Put simply, something happened during the Lesson phase to produce higher ratios. The researcher hypothesizes that the clicker questions in the Lesson phase successfully engaged students in model-based reasoning, as intended. The bold line from the Lesson phase to model talk in Figure 11-3 is meant to represent that this is the main phase that generated student model talk.

Table 11-3: Ratio of student utterances per clicker question across instructional phases for model talk and talk suggestive of model-based reasoning.

	Topic Phase	Unit Phase	Lesson Phase	Total Student Utterances
Model Talk				
Model-based reasoning talk Utterances per clicker question	0.33	2.67	4.12	3.81
Total Student Utterances per Clicker Question	0.33	0.44	1.42	1.26
Total No. Clicker Questions	0.33 3	3.00 9	4.62 65	4.26 77

In red are the ratios in the Lesson phase that are notably higher than those of the Topic or Unit phases.

Clicker Question Diagram Conditions

Examining patterns of student talk among the different clicker question diagram conditions reveals more instances of model talk (during the Lesson phase) when there was a diagram associated with the clicker question. Clicker questions with model representation diagrams were found to have the highest amount of model talk, with an especially high rate of model based reasoning talk in comparison to the data diagram and no diagram conditions (see Table 11-4).

Table 11-4: Ratio of student utterances per clicker question for the main clicker question diagram conditions for model talk and talk suggestive of model-based reasoning.

(Lesson Phase Only)	**Model-Representation Diagram**	**Data Diagram**	**No Diagram**	**Total Student Utterances**
Model Talk	4.67	4.00	2.64	4.12
Model-based reasoning	**2.07**	**0.86**	**0.71**	**1.42**
Total Student Utterances per Clicker Question	5.26	4.41	2.79	4.62
Total # CQ	27	22	12	65

The ratio shown in red in the model-representation condition that is notably higher than those of the data diagram and no diagram condition. In yellow are the ratios that were notably higher for both diagram conditions compared to no diagram.

It should be noted that model diagrams were handed out to students, while data diagrams were projected in front of the class. Being able to draw on and point to model representation diagrams in front of them at their seats may possibly have contributed somewhat to the effect of more whole-class discussion here. That said, students were observed pointing to parts of data diagrams projected in front of the class, and students in all conditions had the option to draw and point to abbreviated diagrams in their personal notebooks.

This section presents hypothesis one, why diagrams support model talk. Figure 11-6 provides a visual representation of the hypotheses.

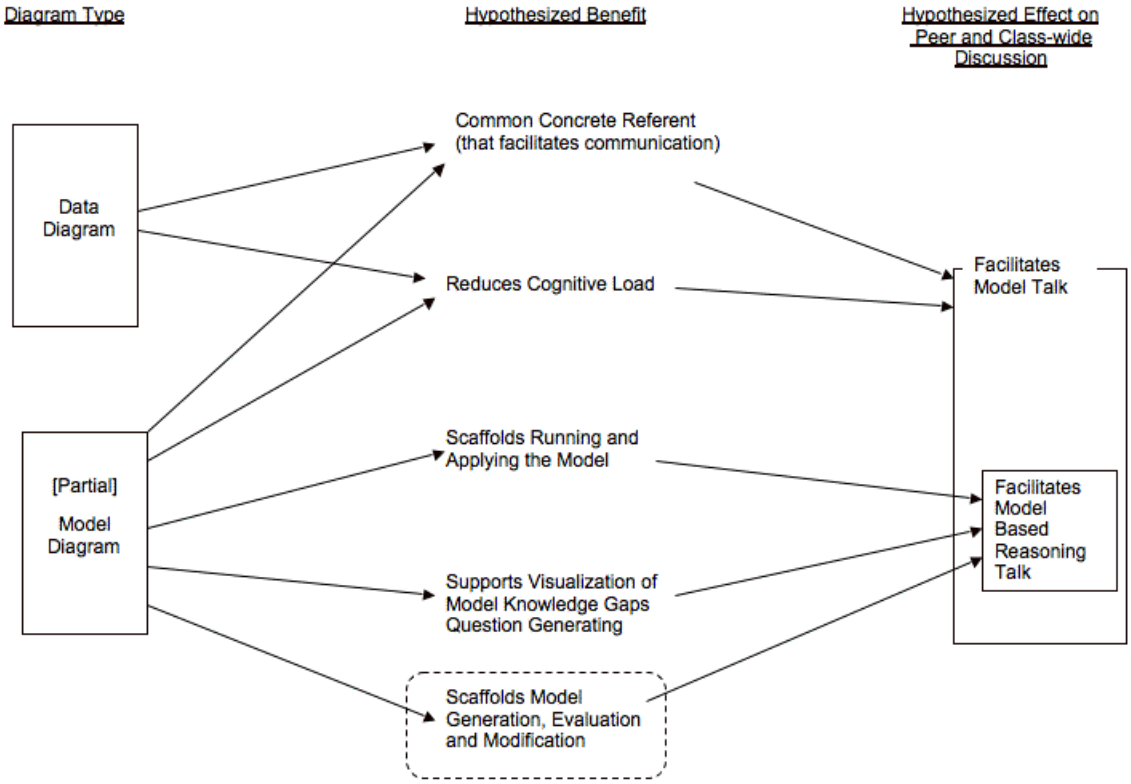


Figure 11-6: Hypotheses on how diagrams facilitate model talk.

This diagram is an enlargement of the area enclosed in a dotted line in Figure 11-5. The area enclosed in the dotted line will be referred to as the GEM cycle in the following sections.

Hypothesized Benefits of Both Types of Diagrams: Using Data Diagrams or Model Representation Diagrams with Clicker Questions

Common Concrete Referent that Supports Student Talk

The diagram may function as a common concrete referent that supports students in communicating with each other and the instructor in peer and class-wide discussion. When the diagram is handed out, this effect may be even greater than if it is a projected

diagram because students can more easily point to it and draw on it as they talk with each other, which may further facilitate peer communication.

Reducing Extraneous Cognitive Load

The ability of diagrams to reduce cognitive load is well documented in the literature (see Chapter 3). It is argued by the researcher that there is much intrinsic cognitive load in the GAMBR instructional approach that comes with engaging students in model-based reasoning. The diagrams may reduce some of this load. In considering the possibility of the instructor attempting to provide the same information provided in both the data and the model-representation diagrams to the students without the use of diagrams, one can argue that the cognitive load would be greater without the diagram. For example, interpreting the data from an electrophoreses gel would likely be more difficult if the data were presented as a text description of the placement of the bands in on the gel than looking at a gel diagram that shows the placement of the bands. Likewise, reading a text description of the model would likely make the model more difficult to understand and visualize than looking at a diagram of the model. By reducing the cognitive load that would be generated through extraneous text descriptions of data or model, the diagrams may facilitate the ability to think about the clicker question. It should be noted that clicker questions with a data diagram were still centered on applying a model; therefore, the diagram's effect on reducing cognitive load and providing a common referent for communication could still facilitate model talk.

Hypothesized Benefits of Using Model-representation Diagrams with Clicker Questions

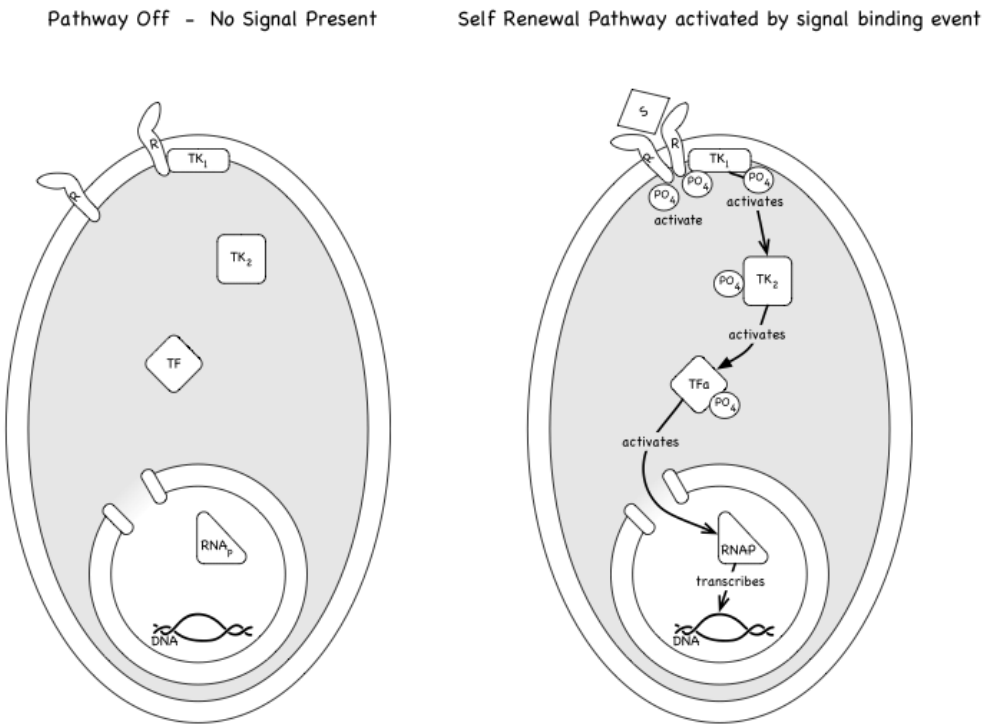
The researcher suspects that the model representation diagrams facilitate student reasoning about the model in additional ways, beyond that of the data diagrams. This hypothesis is supported by the finding in Research Question 4 that more student model talk occurred following clicker questions with model-representation questions, especially model talk suggestive of model-based reasoning. More specifically, the largest values of the ratios of student utterances per clicker question was found in "student questions about the model logic" when model-representation diagrams were used, and this also engendered the highest ratio of causal explanations (to a lesser degree). So why might model-representations diagrams be more effective at generating student questions about the model logic and causal explanations?

The model-representation diagram in this course is a depiction of the model that the students are being asked to apply and run. These diagrams, therefore, may support the students in visualizing and animating the model internally as well as externally (through pointing and drawing). The researcher hypothesizes several ways that supporting visualization of the model facilitates student reasoning (that would likely result in more student talk suggestive of model-based reasoning). The example provided in Chapter 6 of classroom activities will be used to provide some initial support for the hypotheses, specifically by looking at the clicker questions and student talk that occurred on Day 3.

Scaffolds Running and Applying the Model

The model diagram contains some of the key components and logic that are needed to run the model. For example, looking at the stem cell self-renewal signaling

pathway diagram even a novice who had had high school biology could likely understand the basic operations of the model without a great deal of introduction. Recalling that the instructor provides a brief introduction to the model component and logic prior to the first clicker question used in the lesson, one can imagine how the diagram would scaffold the student in running and applying the model. The reader can try to answer the clicker question below using the diagram shown, given this basic information S= signal, R= Receptor, PO4= Phosphate, TK = an enzyme that can be activated with a phosphate, RNAP = enzyme that turns on a gene.



If this cell is analyzed and TK2 is found to be phosphorylated, is the signal present?

1. Yes
2. No
3. Maybe

This question can be answered almost entirely by reading the diagram that represented the model. When S is present, TK2 has a PO4 attached, so students can say the answer, Yes. The initial student comment below following this clicker question supports that the student ran the model, the term "activates" suggests that the student is visualizing the model in action:

Student 1: The signal activates the TK to phosphorylate it.

Remembering that the students are not given much more than the brief introduction that the reader got, the importance of having a diagram of the model in order to run it in this case is evident. This is an example of how a model diagram can *Scaffold running and applying the model.*

Support in Visualization of Model Knowledge Gaps and Scaffold Model Generation, Evaluation, and Modification

The diagram is also hypothesized to support students in recognizing where there are gaps in their understanding of the model and scaffold the generation of new model elements and criticisms of the current model.

In revisiting the question above, one might argue that this question is so simple it might not even require the student to run the model, but the Maybe option introduces an ambiguity that asks the student to consider the model beyond what is shown in diagram. To think about Maybe, the student may animate the model piece by piece to figure out if it is possible for the TK2 is phosphorylated when the signal is not present. This clicker

question is used to perturb the students' model and introduce the new element of "time" to the model. In animating the diagram, the student may realize that the signal, while needed to start the chain reaction, might not have to stay attached for the activation sequence to continue down the chain. The student may generate a new inference about the model. Indeed, the second student comment generated by this clicker question illustrates this:

> Student 2: Maybe the signal might not still be there –it must be originally but might not be now.

In the diagram, the signal is present when the pathway is activated, but the student seems to have *evaluated* the current model and made the realization that the depiction in the diagram is not representative of everything that is and can happen in reality. It just represents a single moment in time. The student's internal model (which is likely very similar to the diagram representation at this point because this is the first question in the cluster) is *perturbed* and now *in need of being modified* to account for the possibility that the signal may not be present when the pathway is on. Thus, the possibility of recognition of a knowledge gap in the model has been created by the clicker question because the model first introduced to the student did not include the possibility of the signal not being present while the pathway is on. It is possible that the diagram facilitates this recognition of a knowledge gap, as indicated in Figure 11-6 because the diagram does not explain or account for this phenomenon.

Another example of this is when a new component of the model is introduced by a clicker question. The absence of the new component in the diagram can help the students to evaluate the current model and recognize that the model needs to be modified

to account for the new component and perhaps be extended to account for where that component comes from or what effect it has on the model.

Consider the second clicker question in the cluster:

Problem 2 of clicker question cluster on stem cell self-renewal signaling:

The self-renewal signaling pathway in a particular stem cell type has an additional kinase, TK3 that targets TK1. TK3 is produced from the expression of a gene activated by TFa. How would TK3 change the behavior of the pathway?

1. It would become a temporary circuit, even when signal is still present.
2. It would become a permanent circuit, even when signal is absent.
3. It would not change.

The clicker question adds a new element to the model (an additional kinase) that is not represented in the diagram. In trying to map the new component onto the diagram, the students may more easily recognize that they do not know where the model elements are coming from because the diagram set only shows the kinases as already present and also does not explain where the kinases come from. The students needs to extend their internal model (which may at this point still consist mainly of a mental picture of the diagram, as this is the second question in the cluster) to include the new model element as well as to *generate*/recognize a "black box" for where such elements come from. The student comment below could be considered an *evaluation* of, or exposure of a gap in the current model, which can lead to a model *modification*:

Student 3: Where are the tyrosine kinases coming from?

In these several ways, the model diagram may support model generation, evaluation, and modification processes, as indicated at the bottom of Figure 11-6. In returning to the model of learning presented in the proceeding section of this chapter, one way to think

about the process of model-based learning described here is that students' models evolve through successive modifications (simulated and facilitated by clicker questions that perturb the model). This corresponds to the model construction cycles of generation, evaluation, and modification or GEM cycles that are described to occur in the model-based learning literature (see Clement & Rea-Ramirez, 2008; Clement & Steinberg, 2002; Nunez-Oviedo et al., 2008; Williams & Clement, 2007). Thus, it is possible that the model-representation diagrams may play a role in supporting student GEM cycles.

The hypothesized presence of the GEM cycle in GAMBR is shown in Figure 11-6 within the dotted line.

Why Model-representation Diagrams may be Important to GAMBR and Student Model Talk

In thinking back to the list of attributes of clicker questions generated by manipulating the model, we can see Deep-endedness, Model Revising, and Model Incompleteness in the clicker question examples above. One can imagine the importance of having a diagram to support students in navigating the type of model-based reasoning the clicker questions are asking them to engage in and to support them in *talking about their reasoning*.

Status of the Model of Diagram Effects in Figure 11-6. Referring back to Figure 11-6, we see that on the left the model-representation diagram box has more arrows proceeding from it than the data diagrams (five versus three). This is to say there are similar hypothesized general benefits from both types of diagrams for model talk; but there are additional benefits from model-representation diagrams for facilitating model

based reasoning talk. This model can explain the findings that clicker questions that had model-based reasoning diagrams had a notably higher rate of student utterances suggestive of model-based reasoning than clicker questions with data diagrams did and two other major differences visible in Table 11-3. Thus, although still quite speculative, the theory represented in Figure 11-6 obtains a bit of support by being able to explain that the model diagram condition obtained a much higher rate of MBR talk than the no-diagram condition, whereas the data diagram condition did not; and both diagram conditions obtained a higher rate of model talk than the no-diagram condition.

Reflecting Back on the Course Content and Structure

The organization of the course content and instructional structure was presented in Chapter 7 as a hierarchy of nested cycles, including Topic, Unit, and Lesson models. This structure was based on the most visible levels of content taught to the students. However, in examining the components of the instruction and content in greater detail, the following six nested cycles are hypothesized to be implemented at six levels, as shown in Figure 11-3:

Topic Phase: Motivate Topics 1-n

At the highest level is the topical cycle described in the NSF grant (Phillis & Stillings, 2005) whereby the instruction cycles through real-word topics that motivate student interest - Topic 1, Topic 2, Topic n.

Unit Phase: Scaffold Units 1-n

Within each topic there are several units: Unit 1, Unit 3, Unit n. The Unit level provides content that scaffolds the models to be taught through application in the lesson phase.

Lesson Phase: Apply Model n in Lessons 1-n

Within each unit there are several lessons covering different models that are nested and connected to each other: Lesson 1, Lesson 2, Lesson n.

Lesson Pattern, Parts 1-3

Within each lesson is a pattern of content and instruction: part 1-introduce model, part 2 extend, revise, and comprehend model, part 3 -connect model.

Apply and Discuss Clicker Questions 1-n

Within each lesson pattern, clicker questions are used to engage students in Applying and Discussing the models: clicker question1, clicker question, clicker question n. The clicker questions have various characteristics that are hypothesized to facilitate discussion and reasoning.

GEM cycle within a Clicker Question

Within each clicker question students have the opportunity to Generate new ideas about the model, evaluate the model, and modify the model. (This process is hypothesized to be supported by model representation diagrams when present.)

Returning again to Figure 11-3, we can see the above hierarchy represented as moving from left to right, though the GEM cycle is not included. In the diagram, we can consider the possibility of viewing the use of diagrams as a seventh nested strategy; however, this is strategy was not always used. One can also see the progression of the hierarchy by looking through Figures 11-3 to 11-6 and focusing on the areas enclosed in each dotted box. If there is some truth to this model with six nested levels of instructional processes, it reveals a striking degree of complex structure within the strategies the instructor was using.

Reflecting Back on the Hypothesized Model of Instruction

Returning to Figures 11-2 through 11-6 and the accompanying sections, one should now be able to see how the observed course structure and use of clicker questions and diagrams might feed into and implement the hypothesized model of instruction, explaining how this form of instruction could result in a high percentage of biological model talk and model-based reasoning talk, summarized as follows.

Each part of the course appears to be centered on the learning and application of models. The Topics and Units provide motivation and scaffolding for the Lessons, and the Lessons engage the students with models. The structure of the lesson pattern and strong focus on application of the model facilitate student talk and reasoning. The student enters a lesson with an *a prior* model of a biological process (that is based on content learned prior to the course and in the course during previous Topics, Units, and Lessons). The brief introduction of the model (which is hypothesized to lead to an initial model) followed immediately by requests for application and introduction of new model elements via the clicker questions, generate student questions and ideas. The shift in focus of clicker questions in this course from an opportunity to check for correct understanding to an opportunity to apply, extend, and talk about the model (aided by the various characteristics of the clicker questions) may facilitate students in generating questions and ideas. Further, the information within the clicker question may help to stimulate a model generation, evaluation, and modification (GEM) cycle, by generating new ideas either directly through the introduction of a new model element or indirectly by supporting student inferences. The peer and class discussions support students in

evaluating and modifying their model and are used by the instructor to help guide the students to an intermediate model and eventually a target model.

Because the instructor appears to use the student talk during class-wide discussion to guide the learning and application of the model, student model talk and model-based reasoning talk is not just a product of the instructional process but is an integral part of the GAMBR teaching method. The researcher used the types of course segments and talk types identified as starting points for this model. The high percentage of model talk and model-based reasoning talk is an indication that the instructional approach is "successful" in its goal of engaging students with models and model-based reasoning skills. The hypothesized model of instruction provides an explanation for those high percentages and for several relationships between the ratios shown in Table 11-3, as described earlier. The model was constructed certainly not as a finished theory, but as an initial model that can be evaluated and improved in future studies.

Limitations of the Study and Recommendations for Future Research

There are several limitations of the study due to the nature of the data available. The accuracy of observations may have been impacted by the fact that the data were recorded by hand in real-time. The lack of video and audio data prevented checking for accuracy at a later point. However, the researcher endeavored to record as accurately as possible every student utterance made in class-wide discussion during the semester.

Video and audio data would have also likely generated a more detailed and richer description of the course and allowed for the researcher to more closely examine instructor and student practices and behaviors and that suggests an important direction for

future research. The wealth of the data in terms of number of student utterances collected (328) and classes observed (32 classes) as well as the uniformity of only having one recorder hopefully provide some consistency and breadth.

Outcome Testing and Control Group

This case study aimed to explore and describe the course rather than to report or compare results of traditional student learning success rates, such as on content-based exams. No direct and controlled comparison of GAMBR was made to any other course. A controlled comparative study would need to be conducted for any claim to a difference or improvement in learning or engagement resulting from GAMBR. Such a comparison would be best designed using a pre-/post-test for both traditional content knowledge and model-based reasoning skills learning in a GAMBR course and a clicker course with similar populations. However, such a study would not provide insight into what specific aspects of GAMBR result in any significant difference found. To isolate the impact of features in the hypothesized model of instruction presented in this study, other instructional features, such as frequency of clicker questions as well as peer and class-wide discussion use would have to be controlled for.

No Statistical Comparisons

Statistical comparisons relating to the student talk categories could not be made because the student utterance data did not fit the assumption of independence. Though student names were not attached to the data, there was known to be more than one student utterance per student in the data set. However, this study is meant to be an

exploratory case study, and there were some very strong patterns visible in the data tables.

Looking for Evidence of Engagement with the Model

The researcher had a predisposed interest in exploring student engagement with the model through the student talk occurring in class-wide discussion. There are many directions that the development of the student talk codes could have gone in. However, the interest to the researcher was engagement with the model, as this was a major instructional goal that the class-wide discussions aimed to accomplish. Using a different lens to explore the student talk would likely result in a different set of student talk codes. That said, the researcher was not attending to the difference between questions with data diagrams and model diagrams when she collected the data, and it had not occurred to her as a factor of interest at that time.

Alternative Hypotheses for Quantitative Results

Other limitations concern the relationships between the instructional phases, student talk, and clicker question diagram conditions. While there were marked differences in the ratios of student utterances to clicker questions in some of the student talk categories among the 3 instructional phases (Topic, Unit, and Lesson phases) and 3 main clicker question diagram conditions (no diagram, model-representation diagram, and data diagram), there are possible alternative hypotheses to those results.

Differences in Complexity of the Content Covered

For example, though all the clicker questions in the Lesson phase were related to a model, they covered a wide variety of content areas. The difficulty of the various content areas was not controlled for. It is likely that some models were more complex than others. Some of the models concerned biological processes that the students likely had familiarity with, such as transcription and translation. Though it is unlikely that the material was previously taught to them as models to reason with, having prior knowledge of the process (including familiarity with terms and concepts) might have made it easier for students to talk about these models. Other models were more likely to be genuinely novel to the students, such as stem cell self-renewal, which may have impacted the students' ability (and comfort) to talk about the models in class-wide discussions.

Differences in Instructor Behaviors

The instructor's actions during class-wide discussions were not controlled for or recorded to a level of detail that they could be compared between different discussions, days, or weeks. The instructional phases had different objectives. For example, during the Topic phase, the goal was to motivate student engagement using a real-world topic. The instructor may, therefore, not have allowed for discussion time after the clicker questions because it was not deemed necessary for reaching the objective of "motivation." In relation to the clicker question diagram conditions used within the Lesson phase, the instructor may have allowed for more or less talk at particular times based on what was said during class discussion or time pressure.

Differences in the Presentation of the Diagrams to the Students

The model diagrams were handed out to students, while data diagrams were projected in front of the class. Being able to draw on and point to model diagrams in front of them at their seats may possibly have contributed somewhat to the effect of more class-wide discussion. That said, students were observed pointing to parts of data diagrams projected in front of the class while talking, and they had the option to draw on blank paper in both conditions.

Hypothetical Model of Instruction

The previous two main sections in this chapter developed a hypothetical model of instruction in GAMBR and numerous hypotheses on why there was so much model talk. In the mode of theory construction, I occasionally implied or stated that students had engaged or would engage in a particular (sometimes mental) activity. As stated prior to that section, this was theoretical hypothesizing on the part of the researcher (though findings were used to support ideas whenever possible). Further research on student behaviors (as well as instructors in some cases) would be needed to provide evidence for evaluating and supporting or improving the proposed hypothetical model of instruction and hypotheses related to student talk.

To this end, it is inappropriate to draw more than hypotheses from the findings of this study without further research, and the quantitative findings about the effect of diagrams, for example, were stated as hypotheses.

Instructional Implications

This case study of GAMBR suggests a number of big and small ideas for large-lecture biology course design. Within the study can be found ideas for:

(1) instructors seeking to design clicker question that can support class-wide discussions in their biology course, such as handing out a diagram to facilitate students thinking and exchanging ideas and using multiple true/false to provide more possibilities for students to think and talk about. The clicker question design ideas should be especially useful to instructors looking to engage students in model based reasoning or other skills based learning goals that are best learned and refined through a high level of application.

(2) More broadly, the findings may support instructors in moving their large-lecture classes more toward inquiry- or process-focused learning goals, especially if their interest is in developing a model-based teaching approach. Specifically, guidelines could be generated out of this case study for other instructors interested in thinking about how to design and structure a model-centric courses for large-lecture biology.

(3) Even more broadly, extending the application of this course into other universities may help to move the focus of undergraduate science education from a content knowledge-based practice toward learning environments with practices and goals that more closely mirror real scientific research.

Below, I attempt to provide a guide to innovation in these directions that could apply to a broader range of large-lecture courses using clickers, possibly including those outside biology (the range of courses in which these techniques could be used is a compelling question for future development and research). The starred items indicate those that are the most unusual techniques based on my review of the large-lecture biology literature; thus, they may be less obvious to many instructors.

Ideas for Innovative Large-Lecture Instructional Design:

- Focus on application, and structure your course around application of knowledge (using clicker questions to engage the students in application)

- *Design progressive or “deep-end” instruction were students learn as they go, and/or do not have all the necessary information prior to being asked to think about it

Ideas for Clicker Question Design that will Promote Student Talk:

- *Use multiple True/False format to provide more opportunities for student engagement with the material per clicker question.
- *Include ambiguous response possibilities to generate student debates.
- *Use clicker questions to include new model elements that the students have not yet learned about.
- Do not focus clicker questions on correctness—remove point values.
- Provide openings for creative scientific thought.
- If you change your clicker question design to be more inquiry/process/skills-oriented, you might want to consider also changing your summative assessment questions to align. (This may result in /require an overall change in the course learning goals.)
- Include diagrams that represent data or a model, perhaps providing the diagrams as handouts.
- Design clicker questions that build off each other, scaffolding student learning of more and more complex ideas, and aiming to bring the students to a specific knowledge set.

For Instructors Specifically Interested in Making Their Course More Model-based

It is highly recommended that they:

- As starting points, where possible, use existing models of dynamic processes that are already present in textbooks or models that you are most familiar with reasoning about in your own research. It is recommended to look for models that can be easily thought of in terms of having a causal chain of events that one can follow and perturb.

- Generate a diagram of the model that represents basic components and logic. Use this diagram to generate your clicker questions.

- Generate clicker questions that ask students to practice applying and perturbing the model. Use a deep end approach and specifically emphasize thinking about model revisions and extensions. Idea for expansion: try using GAMBR-type clicker questions to engage students with model simulations and animations.
- Engage students in the process of model evolution by introducing an initial model and using clicker questions and model-representation diagrams as tools to help them reach a target model via intermediate models.

- Use class-wide discussion as part of your learning format so you can both assess and contribute to the model evolution process – *it's fun!*

- To go all the way to a model-based learning environment, make it "model-centric" by structuring the course entirely around the application of models.

Gaps in the Literature Addressed in this Case Study

At the end of Chapter 4, five gaps in the large-lecture biology literature were identified that supported this case study on the Guided Application of Model-based Reasoning (GAMBR) instructional approach. These gaps and the manners in which they were addressed through this study are revisited below in Table 11-5. The researcher's initial attempts at responding to the gap sub-questions are presented.

Table 11-5: How gaps in the literature were approached and relevant findings.

Gaps in the Large-Lecture Biology Literature
• **Examples of courses with a heavy focus on inquiry/process/skills based learning objectives** • ***How would such a course be structured?*** Approach: The content and instructional structure of a large-lecture biology course in which GAMBR was implemented was examined and described (Research Question 1). Relevant finding: (1) Detailed description of an exemplary course including the structure of content and instruction. Researcher's Response: A large-lecture biology course with heavy focus on inquiry/process/skills- based learning objectives can be structured by *learning through active application* of model-based reasoning skills. • ***Can student engagement in any of these processes be detected during courses?*** Approach: Student engagement in model-related activities during the large-lecture, class-wide discussions were categorized, coded for, and documented (Research Question 2). Relevant finding: (1) 89% of student talk displayed engagement with scientific models (2) 30% of the student talk suggested engagement in model-based reasoning Researcher's Response: This finding demonstrates that it is possible to design a large-lecture course in which students are engaged in inquiry/process/skills, namely model-based reasoning.
• **Model based educational approaches** • ***Can a course that is deeply model-based be designed and implemented in college biology?***

Approach:

Aspects of GAMBER were examined in relation to the current model-based learning literature on instructional activities to find correlations that would suggest/confirm that the course was, indeed, an example of model-based instruction in the commonly used sense of the term.

Student talk was examined for evidence of model-related activities (Research Questions 1-3).

Relevant finding:

(1) As shown in Figure 11-3 and 11-4, the course structure was a complex array of nested and interconnected content and instruction all centered on learning and reasoning with biological models.
(2) One key design element was the use of clicker questions (and the surrounding student and teacher activities) during the Lesson phase of instruction to teach models. This process had many parallels to the activities described as "model co-construction" in the model-based learning literature, including the suggested presence of the GEM cycle within each clicker question.
(3) Six categories and subcategories of student talk relating to models were defined.
(4) The high percent of instances of talk related to the model and specifically the talk that suggested model-based reasoning supported that students were engaged with models during the classroom activities.

Researcher's Response:

GABMR is an example of a model-centric large-lecture undergraduate biology course that is designed and implemented to be deeply model-based.

- **Strategies for designing complex and provocative clicker questions**
    - ***In particular, what are some strategies for creating clicker questions designed to promote model-based reasoning?***

Approach:

The unique aspects of the clicker questions were examined and described. Different clicker question conditions relating to diagrams were analyzed. (Research Questions 1 and 2).

Relevant finding:

(1) Several characteristics of the clicker questions were described and summarized on the left side of Figure 11-5. This includes using progressive clusters, focusing on engaging students in reasoning with models, and asking questions that make the students both apply and perturb their current model (through the introduction of new model elements). These were framed as general design ideas for facilitating class-wide discussions.
(2) Including a diagram depicting a model or data was an additional strategy that appeared to support student talk, especially if the diagram was a depiction of the

model. (Note that another factor of this diagram condition may be an important factor, such as that the diagram was given as a handout that students could draw on and gesture over while reasoning and talking.)

Researcher's Response:

Designing clicker questions with model-representation diagrams is an effective way to support and promote student engagement in model-based reasoning in large-lecture undergraduate biology courses.

- **Examinations of students' talk during [peer or] class discussions**
    - ***In particular, can any of the model-based reasoning skills mentioned above be detected in classroom discussions?***

Approach:

Student talk during class-wide discussions was examined, categorized, and coded in relation to models (Research Question 3).

Relevant finding:

(1) 30% of the student talk occurring during class-wide discussions suggested engagement in model-based reasoning.
(2) Allowing for class discussion is an important aspect in the implementation of GAMBR. This time allows for students and the instructor to consider and voice questions and inferences about the models and was indicative of an active model co-construction environment.

Researcher's Response:

Student engagement, model-based reasoning can be detected during class-wide discussion in large-lecture undergraduate biology courses.

- **Strategies for using visual aids to support learning on different levels**
    - ***Can the use of visual aids have an effect on model-based reasoning during class discussions?***

Approach:

Four different diagram conditions relating to clicker questions were examined and analyzed in relation to student talk (Research Questions 2 and 4).

Relevant finding:

(1) Findings suggested that diagrams increased student talk during class-wide discussions, specifically talk related to models.
(2) Findings suggested that diagrams depicting models had the greatest impact on student talk during class-wide discussions, especially talk suggestive of model-based

reasoning.

Researcher's Response:

(1) Findings suggested that using diagrams with clicker questions can support students in engaging with and discussing models in large-lecture undergraduate biology courses.
(2) Findings suggested that model-representation diagrams are effective aids in supporting model-based reasoning during class discussions in large-lecture undergraduate biology courses
(3) These findings may have implications for the use of model simulations and animations in large lecture halls.

Closing Statement

This analysis of GAMBR, using both qualitative and quantitative approaches, offers a picture of this unique instructional approach. The findings provide the beginnings of guidelines for the structure of such a course for other instructors, such as how clicker questions and diagrams can be used as effective tools for engaging students in reasoning with models and facilitating student model talk during class-wide discussions. Through this study, it is suggested that the GAMBR instructional approach contains interesting alternatives to the more commonly used approach of peer instruction in large-lecture biology courses using clickers, especially for other science instructors interested in process-learning goals and the learning of complex, nested models in science.

GLOSSARY

Both-diagram type clicker questions (BD-CQ)

Clicker question diagram category describing clicker questions that has both a model representation and a data diagram associated with it

Categories of Student Talk

Answer without explanation

Subcategory of non-model talk describing student utterances that suggests student is providing an answer to the clicker question, but does not provide an explanation or any further information (e.g., I chose C)

Causal explanation

Subcategory of model-related talk describing student utterances that suggests the student is providing a causal explanation, and thereby has reasoned with the model (e.g., When it hits a stop codon, the release factor binds and the process stops.)

Clarification about clicker question

Subcategory of non-model talk describing student utterances that suggest the student is asking a question about the logistics of the clicker question (i.e., asking about the wording of text or diagram or method of entering response –e.g., Do we enter the response as letters or numbers?)

Housekeeping

Subcategory of non-model talk describing student utterances that suggest the student is talking about course related business but not related to the course content (e.g., When is the next exam?)

Insufficient data

Subcategory of student talk describing student utterances that was not complete enough to code or missed.

Model-related talk

Subcategory describing student utterances that suggest the student is engaging with a model in some manner

Model-based reasoning talk

Subcategory of model-related talk describing student utterances that suggest the student is engaged in reasoning about a model

Non-model talk

Subcategory of student utterance describing student utterances that suggest the student is not talking about the model

Question about model content

Subcategory of model-related talk describing student utterances that suggest the student is asking a question about content related to the model (i.e.. questions about the definition of a model component, e.g., Can you say what the Krebs cycle is again?)

Question about model logic

Subcategory of model-related talk describing student utterances that suggest the student is asking a question related to the causal relationships between components of the model, and thereby attempting to reason with the model (e.g., When chaperone binds to the thing does it cause it to bend correctly?)

Statement about the model

Subcategory of model-related talk describing student utterances that suggest the student is making a statement about the model, but does not provide support of reasoning (e.g., It ends up as oxygen.)

Clicker question (CQ)

Question posed by the instructor using a personal response system

Clicker question cluster

Set of clicker questions that build on each other—intended to move a student from an initial model to a target model for the lesson. Each question in the cluster introduces new elements to the model.

Clicker question diagram conditions

Different clicker question conditions relating to types of associated diagrams or lack thereof

Connect model

Part of the instructional pattern that occurs within a lesson. The instructor nests previous models within newer models and connects new models back to older models.

Connecting back

Current lesson model is connected back to previous lesson model/s

Data diagram

Diagram depicting observations assumed to have been collected from a clinical test, or instrument

Data diagram clicker questions (DD-CQ)

Clicker question diagram category describing clicker questions that has a data diagram associated with it, usually embedded in the question

Extend model (extend, comprehend, and revise model)

Middle and primary part of the instructional pattern that occurs within a lesson. Instructor uses clicker questions and associated student and instructor activities to facilitate student learning of content and model based reasoning skills by progressing the classroom knowledge from an initial model to a target model.

Formative assessments

1. Assessment tool used to monitor student learning to provide the instructor feedback on their instruction and provide students feedback on their learning progress.
2. In the GAMBR instructional method:
    - clicker questions, peer and class discussions

GAMBR Guided Application Model-based Reasoning in Biology Instructional Approach

1. Instructional approach developed by a professor at the University of Massachusetts Amherst to teach large-lecture introductory biology courses
2. A major goal of GAMBR is to create an environment in which students construct an understanding of biology by reasoning about well-established scientific models of biological systems through peer discussion

3. Classroom format: Nested cycles of instruction aiming to engage students with reasoning about models, including instructor-posed questions (in this case using a personal response system) that initiate peer discussion and class-wide discussion and that can be proceeded or followed by mini-lectures.

Initial model for lesson (or initial lesson model)

Model that is assumed to evolve from the student's prior model after preliminary concepts and components of the initial model has been introduced by the instructor at the beginning of the lesson

Instructional phases

Instructional segments that were pre-determined by the content structure of the course

Intermediate model

An incomplete version of the model that is assumed to evolve through revision or extension of the initial model, prior to reaching the target model. It is presumed to be generated by the student from the clicker questions and corresponding peer and class discussions during a lesson. Several intermediate models may be generated between the initial model and the target model for a lesson.

Introduce model

Initial part of the instructional pattern that occurs within a lesson. Instructor introduces the initial model with a micro-lecture to.

Lesson

1. Refers to a small sized section (phase) of the course, lasting from 1 to 3 class days.
2. A model (or *associated model)* of a biological process is associated with each lesson

Lesson pattern

Series of instruction activities within a lesson that aim to teach a model— *Introduce model, extend model, connect model*

Model

My use of the term model is consistent with Cartier et al. (2002) who describes a model as: "...a set of ideas that describe a natural process that can be mentally run to explain or predict natural phenomena" (Cartier et al., 2002, page 3). To elaborate, she uses the term model to mean a relatively small set of interacting causal mechanisms that a scientist can reason with to generate predictions or

interpret and explain data. Others in the literature refer to this idea as an explanatory model (Clement, 2008), but here I use just model for this idea.

Model co-construction

Model-based instructional strategy whereby the students and teacher work together to build a model. Model evolves through student-generated model elements and elements introduced by the teacher (Clement & Rea-Ramirez, 2008; Rea-Ramirez, 1999; Steinberg & Clement, 2001).

Model element

A component or process within a model, such as a new enzyme or a concept related to degradation over time.

Model evolution

Central feature of some model-based instruction, such as model co-construction, by which students are able to build on knowledge that they had developed in earlier sections by evaluating various possible model modifications (Clement, 2002; Clement & Rea-Ramirez, 2008).

Model-based reasoning

1. Actively using the concepts and vocabulary in a model to understand how the components work collectively to predict the outcome of the process
2. Skill of extending or revising the model when the presented model does not explain newly revealed aspects of the system. Sometimes this subcategory of model-based reasoning is called model-based learning.
3. Skills employed by expert scientists: generation of predictions, interpretation of data, and revision or elaboration of the original model. Learning to reason with the key explanatory models in a science promotes, indeed largely constitutes, the understanding of the science.

Model-representation diagram

Diagram depicting a theoretical model, such as a flow chart or schematic representing a biological structure or process

Model-representation diagram clicker question (MRD-CQ)

Clicker question diagram category describing clicker questions that has a model-representation diagram associated with it, usually as a handout.

Nesting models

One model that has already been taught through a lesson becomes one small part of the next model.

Non-diagram clicker questions (ND-CQ)

Clicker question diagram category describing clicker questions that does not have either a model-representation or data diagram associated with it.

Peer Instruction (PI)

1. Instructional method described by Mazur (1997) to improve large lecture undergraduate physics education through helping to make lectures more interactive and to get students intellectually engaged with what is going on.
2. Mazur's website description: "Peer Instruction actively engages the students in their own learning. Carefully chosen questions (*ConcepTests* give students the opportunity to discover and correct their misunderstandings of the material, and, in the process, learn the key ideas of physics from one another" (Mazur Group, 2014, para. 2 Sidebar).
3. Classroom format: Interjection of questions into lecture (commonly using a personal response system). The instructor-posed questions initiate an instructional cycle where students first respond individually to the question and then discuss with peers and re-respond.

Prior model

Model that a student is assumed to have before the lesson. This includes all their knowledge gained prior to the course as well as all the information they have learned in the course up until the initial lesson model is introduced.

Question driven instruction (QDI)

1. Instructional method described by Beatty et al. (2006b) to improve large-lecture undergraduate physics education through a constructivist approach to learning.
2. Scientific Reasoning Research Institute's (2014) website description: "Having students wrestle with rich, meaty, meaningful questions and problems as a context for sense-making and a vehicle for learning, not just as assessments" (para. 1).
3. Classroom format: cycle of questions is used to guide/drive instruction based on the needs of the students, in place of lecture (commonly using a personal response system). The instructor-posed questions initiate an instructional cycle that includes periods of peer discussion, class-wide discussion, and mini-lectures.

Student talk categories

Categories developed in this study to describe student utterances made during class-wide discussions

Student utterance, student talk

A verbalization made by a student during class that corresponds to a full turn. "More student talk" then means "More utterances or turns of student verbalizations," not "more minutes of talk time" (although the two may very well correlate).

Summative assessments

a. Assessment tool used to evaluate student learning, usually occurs at the end of a learning unit or at specific intervals with in the course.
b. In the GAMBR instructional method: Friday quizzes, unit exams, and a final exam

Target model for lesson (or target lesson model)

Complete model that includes all the revisions and extensions that the instructor intended by the end of the lesson

Topic

1. A large section (phase) of the course, lasting from 2 to 4 weeks. (See Figure 7-1.) Each topic contains several content Units, each of which contain several Lessons.
2. Real-world topic of interest to the common public, such as breast cancer.

Unit

a. Refers to a medium sized section (phase) of the course, lasting from 3 to 8 class days.
b. Body of information related to a specific area of biology, such as gene regulation, including terms, facts, concepts, and the relationships between them as well as specific (associated) models. Comprised of 2 to 5 Lessons

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