INQUIRE BIOLOGY: A TEXTBOOK THAT ANSWERS QUESTIONS

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ABSTRACT

Inquire Biology is a prototype of a new kind of intelligent textbook—one that answers students' questions, engages their interest, and improves their understanding. *Inquire* provides unique capabilities via a knowledge representation that captures conceptual knowledge from the textbook and uses inference procedures to answer students' questions. Students ask questions by typing free-form natural language queries, by entering concepts of interest, or by selecting passages of text. The system then attempts to answer the question and also generates suggested questions related to the query or selection. The questions supported by the system were chosen to be educationally useful, for example: what is the structure of X?; compare X and Y?; how does X relate to Y? In user studies, students found this question-answering capability to be extremely useful while reading and while doing problem solving. In an initial controlled experiment, community college students using the *Inquire* Biology prototype outperformed students using either a hardcopy or conventional E-book version of the same biology textbook. Additional research is needed to fully develop *Inquire*, but the initial prototype clearly demonstrates the promise of applying knowledge representation technology to electronic textbooks.

INTRODUCTION

Learning a scientific discipline such as Biology is a daunting challenge. In a typical advanced high school or introductory college biology course, a student is expected to learn about 5000 concepts and several hundred thousand new relationships amongst them[3]. Science textbooks are difficult to read and yet there are few alternative resources for study. Despite the great need for science graduates in our country, too few students are willing to study science and

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[3] This data is based on our analysis of a specific biology textbook and measuring the number of new concepts and relationships that needed to be encoded from it.

many drop out without completing their degrees. New approaches are needed to provide students with a more usable and useful resource and to accelerate their learning.

The goal of *Inquire Biology* textbook is to be useful to any student studying from this textbook, and provide better learning experiences to students, especially those students who hesitate to ask questions[4]. We wish to create an engaging learning experience for students so that more students can succeed – and specifically to engage students in more actively processing the large number of concepts and relationships described in the book. Inquire aims to achieve this by interactive features focused on the relationships among concepts, because the process of making sense of scientific concepts is strongly related to the process of understanding relationships among concepts (NRC, 1999). To encourage students' engagement in active reading, our pedagogical approach is to help a student to articulate questions about relationships among concepts and to support them in finding the answers.

Inquire Biology incorporates multiple technologies from the field of Artificial Intelligence. It includes a formal knowledge representation of the content of the textbook, reasoning methods for answering questions, natural language processing to understand a user's questions, and natural language generation to produce answers. It is based on a systematic knowledge acquisition process that educators can use to represent the textbook's knowledge in a way that the computer can reason with to answer and suggest questions. A unique aspect of our approach is the use of Human Computer Interaction design methods to create a product that combines these advanced AI technologies into a user experience that is compelling for students. *Inquire* is one of the products of Project Halo[5], a long-term research effort to develop a capability to answer questions on a wide variety of science topics.

Inquire Biology is based on *Campbell Biology* (Reece et al., 2011), which is a widely used textbook in advanced high school and introductory college courses. *Campbell Biology* is published by Pearson Education, and we are using it under a research-use license. Using a popular textbook as the basis for our research ensures that the content is pedagogically sound and the results have immediate applicability to a large group of students already using the textbook. The basic concepts in the design of *Inquire Biology* are, however, broadly applicable to other textbooks and scientific disciplines.

Exploration of the application of AI technology to electronic textbook comes at an opportune time when we are witnessing a large scale transition from paper textbooks to electronic textbooks. Electronic medium of textbooks offers tremendous opportunities to leverage a

[4] Different groups of students and courses can have varying requirements. For example, students studying for an Advanced Placement exam need to be responsive to the requirements of that exam. We have made no special effort to customize Inquire to such specific needs.

[5] See http://www.projecthalo.com

variety of AI techniques much broader than what we have considered in our work so far. For example, personalized book recommendations (Pera and Ng, 2012) and enhancing electronic textbooks with content from online resources such as images and videos (Agrawal, et. al. 2011). Our focus on the use of knowledge representation leverages the synergy between the need for precise knowledge content in an electronic textbook and the strength of knowledge representation and reasoning to facilitate that.

We begin this article with a description of *Inquire Biology,* introducing its key features and describe how a student might use *Inquire* for active reading and homework. We give an overview of the AI technology used in Inquire and then present the results of a one-day pilot experiment showing that the students studying from *Inquire Biology* received approximately 10% higher grades on homework and post-test problems as compared to students studying from the paper or electronic version of the textbook. We conclude the paper with a discussion on related work and directions for future work.

FEATURES OF *INQUIRE BIOLOGY*

Inquire Biology connects three kinds of information to meet student needs: the *Campbell Biology* textbook, Concept Summary Pages, and computer-generated answers to questions.

The *Campbell Biology* textbook contains the original content of the textbook as published by Pearson Education. The textbook content is hyperlinked to the Concept Summary Pages. These pages summarize salient facts and relationships that a student needs to know about a concept. Summary pages combine content from the glossary entries from the back of the book with automatically generated descriptions of salient properties and relationships for each of the 5000+ concepts in our knowledge base. These pages also include links to related concepts, relevant passages from the book, and follow-up questions useful for further exploration.

A student can ask questions of *Inquire* in three ways. First, a question may be typed into a free-form dialog box, from which *Inquire* computes the closest questions that it can answer and gives the user a choice for selecting the best match. Second, in response to the student's highlights in the text, *Inquire* computes the most relevant questions it can answer for the selection. Finally, *Inquire* suggests questions for further exploration on the concept summary pages and each answer page. We next illustrate how students interact with these features of *Inquire*.

TEXTBOOK

Figure 1 shows the textbook interface of *Inquire Biology.* Like most electronic textbooks, *Inquire* supports highlighting the text, taking notes in the margin, and interacting with graphics. *Inquire* leverages its knowledge base to expand on these standard features in the following three ways:

1. The toolbar provides a table of contents, index to concept summaries, and navigation history. Students can ask a question at any time by tapping the 🔍 icon .
2. Within the text, biology terms are automatically linked—students can tap to see a quick popup definition or to navigate to the full concept summary.
3. Students can highlight with a quick and easy gesture, and each highlight serves as the anchor for a notecard and a list of related questions, encouraging students to dig deeper into the material.

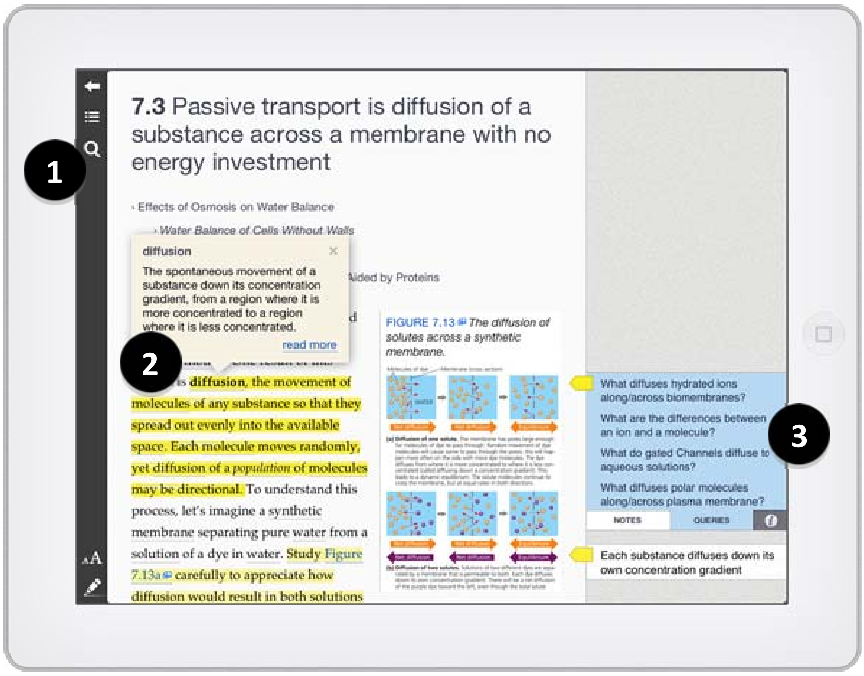

FIGURE 1: TEXTBOOK INTERFACE

CONCEPT SUMMARY PAGE

For every biology term in the book, *Inquire* presents a detailed concept summary page. Each of these pages begins with a human-authored definition of a concept (marked as 1 in Figure 2). Most of these definitions are already available at the back of *Campbell Biology,* but some were added as part of the knowledge base (KB). The text definition is followed by key facts and relationships about that concept (marked as 2 in Figure 2). These are automatically generated from the KB. Since the KB is specific

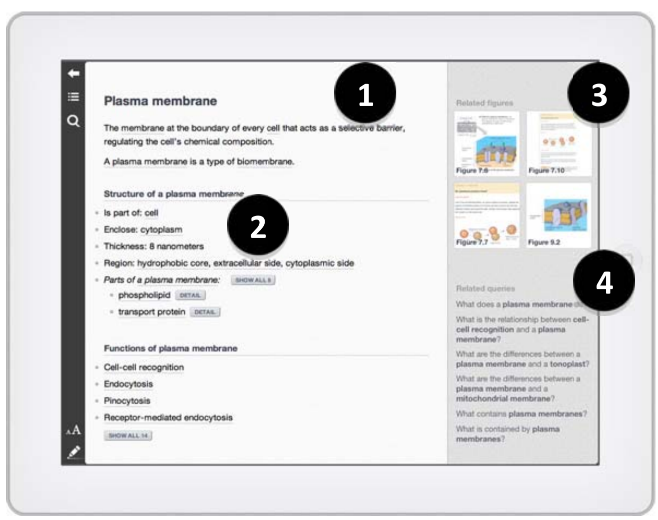

FIGURE 2: CONCEPT SUMMARY PAGE FOR *PLASMA*

to *Campbell Biology*, the concept summary never has the sort of unnecessary details students might find on Wikipedia or other general-purpose sites.

The sidebar of a concept summary page contains the figures from the textbook that are most relevant to that topic (marked as 3 on Figure 2). Finally, questions relevant for further exploration of the topic are listed (marked as 4 in Figure 2). Knowledge in a concept summary page can span multiple chapters, but the concept summaries put all the relevant facts and figures in one place. Unlike most glossaries, the *Inquire* concept summary is not a dead end but can act as a catalyst to further learning—popup definitions and follow-up questions help students explore relationships between concepts and dig deeper into the material.

Asking Questions

Students can ask questions at any time, but they may not always know what to ask. *Inquire* is proactive, suggesting questions in a variety of contexts to help illustrate the types of questions *Inquire* can answer.

The question-asking interface, shown in Figure 3, is invoked by tapping the icon. The *student* can either enter a free-form question directly, or enter a list of biology terms. *Inquire* will suggest questions related to free-form questions or key terms as the student types, helping students formulate their questions and offering alternatives for cases where *Inquire* cannot understand the free-form question directly. These suggested questions are in three main categories: definitions and reference information, comparisons between two concepts, and questions that explore relationships, such as how structure affects function. These three types provide the best overlap between the system's capabilities and the types of questions students find useful.

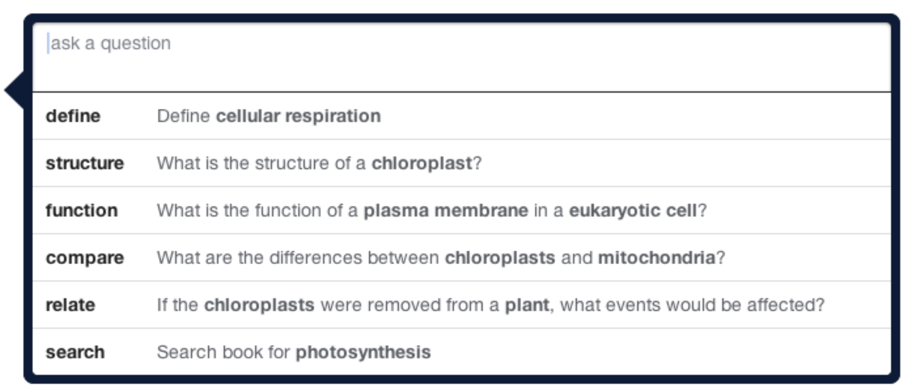

FIGURE 3: ASKING QUESTIONS WITH ASSISTANCE

In response to each question, *Inquire* returns a detailed answer with context to help students focus on what is important. Answers are designed to be concise and understandable, which means that different answers require different presentations.

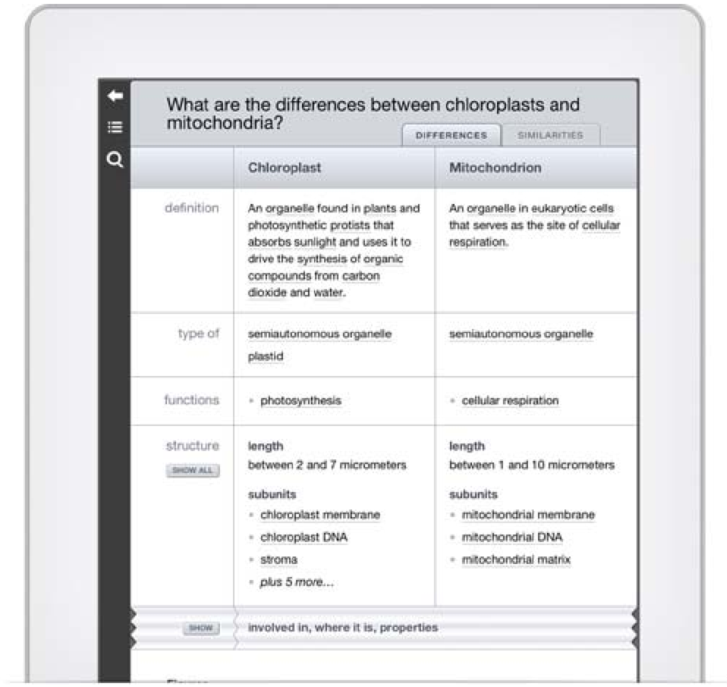

FIGURE 4: COMPARISON QUESTION

Comparison questions compute the key differences between two concepts, building on the learning principle of conceptual contrast (Ausbel, 1965). The result is displayed in a table, keeping the information well organized. Context is provided with short definitions and superclass information at the top, followed by important differences near the top. Figure 4 shows the answer to a comparison question about chloroplasts and mitochondria.

Answers to relationship questions are rendered as graphs (Figure 5), as these best highlight the connections among concepts, building on the learning principle of helping students make sense of concepts by exploring relationships among concepts (Scardamalia & Bereiter, 2006). The graph is simplified from what might exist in the underlying KB, with relations designed to be clearly understandable to a biology student. Labels alone may not be enough—brief definitions of each term appear next to the graph, plus the links to follow-up questions.

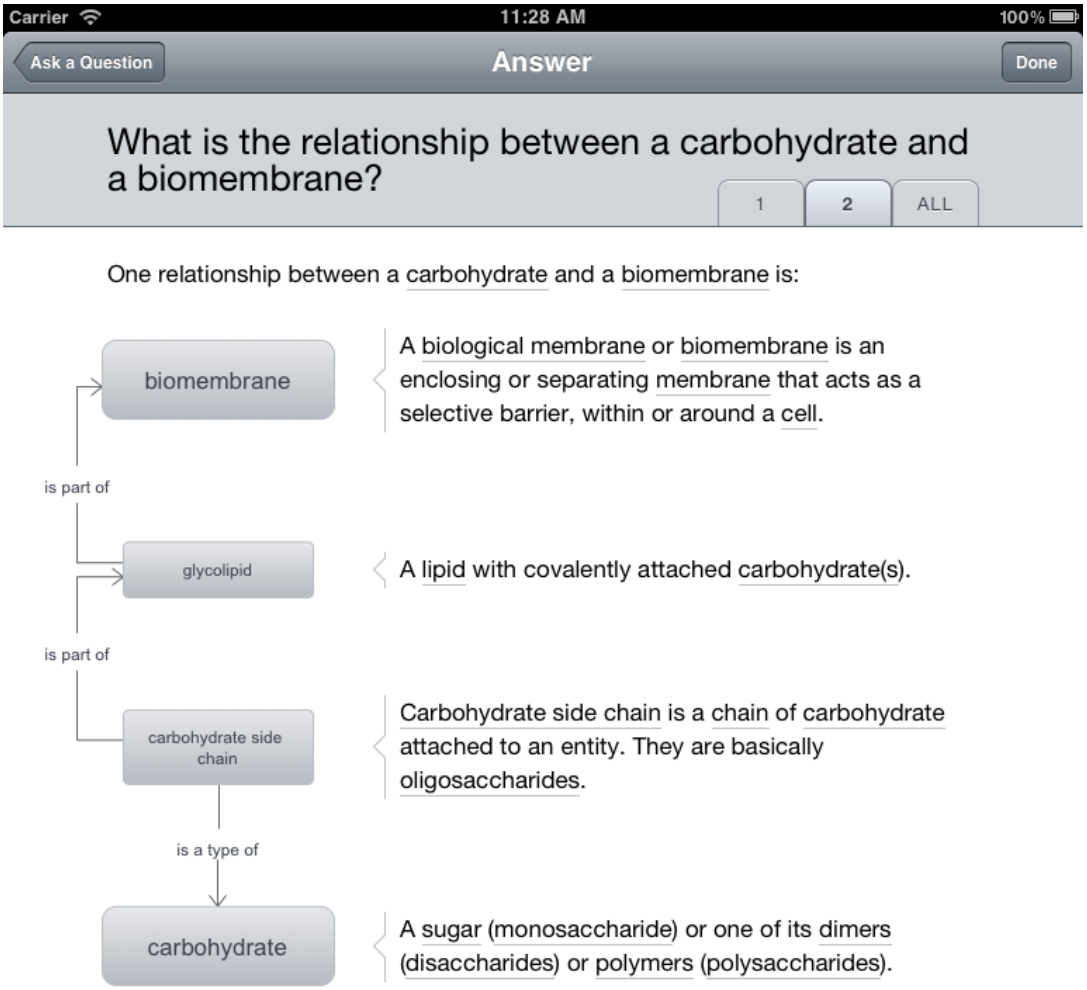

Figure 5: Relationship question

For more difficult problems, our goal is to support student investigations. In accordance with the learning principle of scaffolding (Bliss, 1996), *Inquire* links to related concepts and suggests follow-up questions, helping students ask the right questions and work their way toward a solution. By providing such scaffolding, students can make progress on more difficult investigations than they could handle unaided. In the current system, such scaffolding is always available to them. Further, by providing ready access to basic facts, *Inquire* may reduce cognitive load (Sweller, 1988) associated with information retrieval and allow students to stay focused on higher-order learning objectives.

CONCEPT OF USE

Inquire is designed to support two educational use cases: active reading and homework support. It is certainly possible to use Inquire in a classroom and for homework preparation, but we did not investigate such uses in our work. Here, we illustrate how a student might use its capabilities in the context of active reading and homework support.

Active Reading

Active reading is reading with a purpose, usually to understand a concept or to answer a question. Active reading has a strong track record in empirical learning research (Palinscar and Brown, 1984). As a learning strategy, it consists of four activities that take place before, during, and after reading a text: Predict, Ask, Connect, and Explain. The predict activity encourages students to look ahead before reading a passage. For example, students may skim a section, or look at headings, figures, and captions for organizational cues. The student combines this preview with prior knowledge to form predictions of how the topic fits into the larger themes of the domain and to anticipate the content that will follow. In the Ask phase, students make questions to reflect on what they are learning, and are encouraged to create practice test questions. In the Connect phase, students relate the new content to related knowledge, including personal experience, current events, prior knowledge, and concepts in other subjects. In the Explain phase, students restate the read content in their own words, through notes, summarizations, or diagrams, such as tables, flow charts, outlines, or concept maps. Here is a scenario to illustrate how a student might engage in active reading while using *Inquire*.

> *I'm reading Section 10.2 on Photosynthesis. I have already highlighted some sentences in this section, and I encounter a term that I do not understand: Thylakoid Membrane. I tap on this term to see more information about it and I am taken to a concept summary page. I am first shown the definition: Thylakoid Membrane is the membrane surrounding the Thylakoid. This definition is the same as the definition in the paper version of the textbook and not particularly useful. It is followed by additional information that is not directly available in the glossary of my paper textbook: that a Thylakoid Membrane is a type of double membrane. Further, I can see the parts that are unique to it: an Electron Transport Chain and ATP Synthase. I can tap on Electron Transport Chain and view detailed information about its parts such as Cytochromes. From this summary page, I can also see that the functions of a Thylakoid Membrane are Light Reaction and Photophosphorylation. But, what about the functions of its parts? I can ask a question:* What does an electron transport chain reaction do? *I get an answer:* Non Cyclic Electron Flow. *As I return to the textbook, I can see that it is the next section that I am about to read.*

In the above example, *Inquire* has supported active reading in the following ways:

- Connect: The pop-up definitions and concept summary pages help students connect to additional material and allow a quick and seamless way to refresh and review previous knowledge. In this example, they were able to review the structure and function of thylakoid membrane, and also obtained more detailed information about some of its parts — for example, electron transport chain.
- Explain: *Inquire*'s highlighting and note-taking capabilities allow students to mark passages they find particularly important and to extend and summarize the information in their own words. *Inquire* also explains the basics of a concept—for example, in this case it points out that a thylakoid membrane is a double membrane.
- Ask: *Inquire* suggests questions whenever a student makes a highlight. Related questions appear on concept summary pages and answers, and students can tap to see *Inquire*'s answer. In addition *Inquire* allows the student to ask free-form questions. In this example, the student asked a question about the function of an electron transport chain deepening, their understanding of the overall concept of a thylakoid membrane.
- Predict: Students can attempt to answer *Inquire*'s suggested questions on their own, and test their predictions by tapping through to see the generated answers. In this example, the answer to a student's question about the function of an electron transport chain leads to a preview of what is coming up next in the textbook, appropriately setting up the student's learning goals.

Homework Support

Inquire assists students in understanding and constructing answers for complex conceptual homework problems. *Inquire* generally cannot answer complex homework questions directly, but provides support in three ways: (1) Reducing the emphasis on memorization by providing a quick access to facts and relationships needed to solve a homework problem, (2) Comparing and relating concepts that may not necessarily be discussed in the same section of a textbook, and (3) Deconstructing problems by suggesting simpler questions. We illustrate this capability by considering a homework problem from Section 6.5 of *Campbell Biology*. The scenario below suggests how a student might use *Inquire* to understand and answer this problem.

CONCEPT CHECK 6.5

1. Describe two common characteristics of chloroplasts and mitochondria. Consider both function and membrane structure.

2. Do plant cells have mitochondria? Explain.

3. A classmate proposes that mitochondria and chloroplasts should be classified in the endomembrane system. Argue against the proposal.

FIGURE 6: AN EXAMPLE HOMEWORK PROBLEM

To answer the first question, I ask Inquire: What is the similarity between a chloroplast and a mitochondrion? *Inquire handles this question directly and gives me two nicely organized tables: one listing the similarities and the other the differences between a Mitochondrion and a Chloroplast. The answer to the similarity question tells me that both have a function of Energy Transformation. The similarity answer gives me little information about structure. So, I review the answer to the differences section (See Figure 4). Under the structure section of the answer, I am told that a Chloroplast has a Chloroplast Membrane and a Mitochondrion has a Mitochondrial Membrane. They are named differently, but seem similar, and since the first problem asks me to consider structure, I ask the question:* What is the similarity between a Chloroplast Membrane and a Mitochondrial Membrane? *In the answer, I am told that they are both Double Membranes. I bet that this is one of the key structural features that should be an answer to the problem.*

To answer the second question, I can directly ask Inquire factual questions such as: Is it true that Plant Cells have a Mitochondrion? *Inquire tells me that the answer is:* Yes*. This straight fact retrieval reduces the need to memorize, but developing an explanation is more challenging. I could ask the question:* What is the relationship between a Mitochondrion and a Plant Cell? *Inquire presents a graph showing the relationship between the two. This helps me develop an explanation that a Mitochondrion is a part of plant cells and functions during Cellular Respiration.*

The third question is open-ended, and Inquire helps me in de-constructing this question into simpler questions. When I highlight this question in Inquire, it suggests several questions some of which are: What is an Endomembrane System? What are elements/members of an Endomembrane System? What are the differences between a Mitochondrion and Endoplasmic Reticulum? What event results in Mitochondrial Membrane? What event results in Endoplasmic Reticulum Membrane? *None of these questions directly answers the third question, but they give me starting points for my exploration which might help me eventually construct an argument of the kind that this problem is asking for.*

In the above scenario, we can see that *Inquire* does not directly answer a homework problem, but provides answers to portions of the question, which a student must then assemble to construct an overall answer. In this process, it provides an easier access to facts and relationships, but the student is still required to develop a conceptual understanding of the material to answer a problem. By using *Inquire*'s question-answering facility, students may not necessarily be able to do their homework faster, but we do expect them to acquire a deeper understanding of material, and be more engaged in doing their homework. The fact retrieval questions as we saw in the solution of Problem 2 help the student learn basic facts, and the comparison question that we saw in Problem 1 relates pieces of information that may not be presented next to each other in the textbook. This reduces cognitive load and encourages a focus on conceptual understanding.

AI TECHNOLOGY IN *INQUIRE* BIOLOGY

Here, we give an overview of the AI technology that enables the functioning of *Inquire*. Detailed descriptions of various system components are available in previously published papers (Chaudhri, et al., 2007, Clark et al. 2007, Gunning, et al. 2010).

The overall system consists of modules for creating knowledge representation from the book, modules for performing inference and reasoning methods on the knowledge, and modules for asking questions and presenting answers to the *student*. Figure 7 illustrates the functional components of the system.

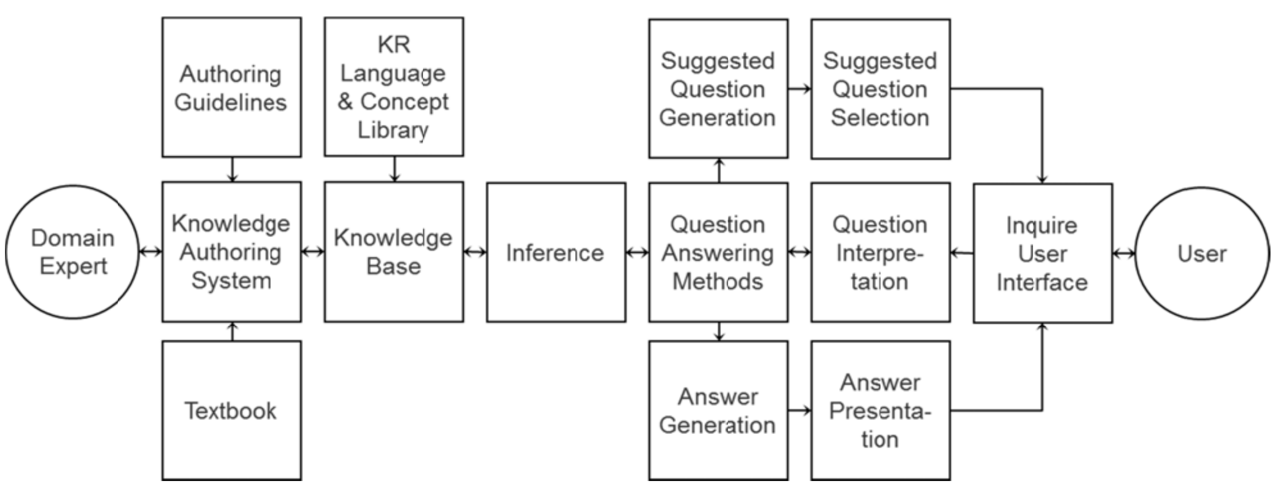

FIGURE 7: SYSTEM ARCHITECTURE

A subject matter expert (SME) is a biologist with a bachelor's degree in biology or a related discipline. The SME uses a knowledge authoring system and the authoring guidelines to represent knowledge from the textbook contributing to a growing knowledge base. *Inquire* uses AURA as its knowledge authoring system. Details on AURA have been published in *AI Magazine* (Gunning, et al. 2010). The authoring guidelines specify a process by which SMEs systematically read the textbook content, arrive at a consensus on its meaning, encode that meaning, test their encoding by posing questions, and validate the knowledge for its educational utility.

AURA uses the Knowledge Machine (KM) as its knowledge representation and reasoning system (Clark and Porter, 2012). KM is a frame-based representation language that supports a variety of representational features including a class taxonomy, a relation taxonomy, partitions (disjointness and covering axioms), rules (attached to a frame's slots), and the use of "prototypes" (canonical examples of a concept). The knowledge base itself uses an upper ontology called the Component Library or CLIB (Barker et al. 2001). The CLIB is a domain-independent concept library. The SMEs access the CLIB through AURA, and use it to create domain-specific representations for knowledge in *Campbell Biology*, resulting in a biology knowledge base. The current knowledge base has been well-tested for the questions used in Inquire for chapters 2-12.

KM also provides the core inference services for AURA. KM performs reasoning by using inheritance, description-logic style classification of individuals, backward chaining over rules, and heuristic unification (Clark and Porter, 2012). A focus of innovation in our work has been to identify these core features and to specify them in a declarative manner (Chaudhri and Tran 2012). We export the biology KB in a variety of standard declarative languages, for example, first order logic with equality (Fitting 1996), SILK (Grosof 2009), description logics (DLs) (Baader et al. 2007) and answer set programming (Gelfond and Lifschitz 1997).

In addition, AURA incorporates several special-purpose reasoning methods for answering comparison and relationship reasoning questions (Chaudhri et al. 2013). We briefly explain the computation used in these methods. For comparison questions, we first compute the description of a typical instance of each class in terms of its types, and locally asserted slot values and constraints. Next, we compute the similarities and differences between the two descriptions. The result is organized into a table. We use a variety of presentation heuristics to identify the most important similarities and differences, and to present the differences that correspond to each other in the same row of the table. As an example heuristic, the slots that indeed have a value that is different is shown before a slot in which there is a value for one class but not a value for another. The presentation heuristics also rely on input from biologists on how the slots should be organized. For example, the slots such as *has part* and *has region* are grouped together as they correspond to structural information. To compute relationship between two individuals, we first calculate all paths in the knowledge base between two individuals. Since calculating all paths is expensive, we use heuristics to control the search. As an example, we first explore only taxonomic relationships, and then relationships that can be found in a single concept graph. The computed paths are ranked in the order of importance. As in the case of comparison questions, the importance is computed using heuristics provided by the biologists. As an example, the paths involving only structural slots are preferred over paths that contain arbitrary slots.

Inquire works via an HTTP connection to an AURA server running on a Windows machine. The AURA server contains the biology knowledge base and supports the question answering and question suggestion facilities, the details of which have been previously published (Gunning et al. 2010). AURA also pre-computes all the concept summary pages, which are included in the *Inquire* application during the build process.

The question answering facility in AURA relies on a controlled natural language understanding system that was described in (Clark et al. 2007, Gunning, et al. 2010). With the direct use of that system, the students often had difficulty anticipating which questions the system can or cannot handle. To address this issue, AURA supports a suggested question facility. In response to questions entered by the *student*, AURA computes the most closely matching questions that can be answered and presents these suggestions to the student. This computation relies on a large database of questions that are automatically generated by traversing the knowledge base. For example, for two concepts that are siblings of each other in the class taxonomy, the system will generate a comparison question that asks for similarities and differences between the two concepts. Questions are generated that conform to the templates that are supported in the system. As the student types a question and even partially enters questions, the pre-computed database of questions is used to find most closely matching questions and propose them as suggestions. This approach substantially reduces the occurrence of questions that cannot be parsed by AURA, and greatly enhances the usability of the question-answering facility. Our approach to question generation is similar to the spirit of recent work on question generation[6] with one important difference: our system has an access to a detailed knowledge representation of the textbook which can be used for question generation while most other question generation systems attempt to generate questions from the surface representation of the text.

After the inference and question-answering components produce the basic content of an answer, the answer generation module constructs the full, human readable answer. Each kind of answer has a specific screen layout, and uses a mixture of presentation types that include

[6] See http://www.questiongeneration.org/

bulleted lists, graphs, and natural language statements to describe the base facts from the knowledge base. The answers leverage a natural language generation component that automatically generates English sentences from the KB (Banik et. al. 2012).

EVALUATION OF *INQUIRE* BIOLOGY

The goal of evaluating *Inquire* was to assess the extent to which the AI enhancements to *Campbell Biology* were useful to students for the active reading and homework support tasks, and to determine if *Inquire* leads to better learning. The formal evaluation of *Inquire* was preceded by a series of user studies, which we used to refine *Inquire*'s capabilities and ensure that the system was usable. In discussing the evaluation, we describe the experimental design, participant profile, procedure used, and both qualitative and quantitative results.

EXPERIMENTAL DESIGN

Our evaluation used a between-subjects research design, with students randomly assigned to one of three conditions. The ***Full Inquire group*** (N=25) used the system version that had all the AI-enabled features that we discussed earlier in this paper. The ***Textbook group*** (N=23) used a standard print copy of *Campbell Biology*. The ***Ablated Inquire group*** (N=24) used a version of *Inquire* that lacked the concept summaries and question answering capabilities but included all the other E-book features such as highlighting and annotation.

The purpose of these three groups was to compare studying with *Inquire* to two forms of existing practice: studying with a paper textbook and studying with a conventional e-book reader version of a textbook. We wished to control for unexpected effects that may arise from the iPad platform, or idiosyncrasies with the *Inquire* interface. Specifically, we wanted to avoid criticisms that any improvements observed by using *Inquire* were simply due to the excitement of using an iPad, and that use of an un-enhanced electronic textbook lowers student performance as compared to using a paper textbook.

In actual practice, the students might use lecture notes, Wikipedia, and other teacher-provided resources during active reading and homework problem solving. However, we did not incorporate these into our study because of the huge variation in available supplementary resources.

PARTICIPANTS

We recruited 72 participants from a local community college. The number of subjects was chosen to ensure that the study had sufficient power to detect expected differences. All the participating students were enrolled in an introductory biology course that used the same edition of the *Campbell Biology* textbook that is contained within *Inquire*. The students were pre-screened to ensure that they had not previously covered the sections of the text used in the evaluation. Based on the student background variables, such as grade point average, age, gender, educational background, native language, and familiarity with iOS devices, the three groups were comparable at the onset of the study. All students were financially compensated for their time; they did not receive any academic credit for their participation; and, there was no attrition of the participants during the exercise.

PROCEDURE

All groups performed an identical learning task: they were asked to study a unit on cellular membrane structure and function. We chose this topic as it is fundamental to cell biology, and students frequently have difficulty understanding the material. Students' specific learning objectives were to (1) understand specific components of membranes and their functions, (2) understand what specific components of membranes contribute to their selective permeability, and (3) explore how structure influences function at molecular and macromolecular levels.

The evaluation took place outside of the classroom to ensure that study conditions were the same for each group. Each session took place on a single day and lasted between four and six hours depending on the group. The evaluation consisted of four primary components: introduction and training, active reading task, homework support task, and a post-test. In addition, a researcher interviewed students in the *Inquire* groups afterwards, to better understand their experience.

The introduction and training consisted of an orientation to the study and a 30-minute training exercise designed to familiarize participants with the process of *active reading* and how they could use *Inquire* for *homework problem solving*. The training on active reading and homework problem solving was conducted by a biology teacher affiliated with the team.

The active reading training introduced the students to habits of active reading (predict, ask, connect and explain), and illustrated these habits using an example. The example used for this training was Gravitation, and was specifically chosen to be un-related to the topic of the actual evaluation. After a lecture on active reading, students were given a scripted tutorial on active reading. This tutorial used a section from Chapter 6 of *Campbell Biology* that concerned Cell Structure, and provided step-by-step instructions on how a student could engage in active reading using the features of *Inquire*, Ablated *Inquire*, or the print version of the text.

The training segment for problem solving focused on understanding homework problems, different question types, understanding answers, and constructing follow-up questions. The training also covered question formulation for questions that contain "how" and "why" in the question statement. Many such questions can be rephrased as questions that are supported in *Inquire* ("How" and "Why" questions are not directly supported). The training segment also included a five-minute video illustrating how a student can use *Inquire* for solving a non-trivial homework problem.

Most of the active reading training was administered to all three groups. However, only the full *Inquire* group received training on using *Inquire* features for active reading and homework problem solving.

The problem sets used for homework and the post-test were designed by a Biology instructor. The homework problem set had six problems (with several sub-parts), and the post-test had five problems. Both problem sets included problems that the instructor would normally use during the teaching of the course, and were not specifically aligned to the capabilities of *Inquire*. The problem sets were tested for any obviously confusing information by first trying them with a few students. This ensured that any confusing information about the problem statement would not confound the results. Students were able to use their book while doing the homework exercises, but not during the final post-test.

Students were asked to read the first two sections of Chapter 7 from *Campbell Biology* in 60 minutes, do homework in 90 minutes, and then take a post-test in 20 minutes (Table 1). The exercise was followed by an informal discussion session in which the students completed usability and technology readiness surveys and provided qualitative feedback. The students' homework and post-test were each scored by two teachers, and score discrepancies were resolved. All student work was coded such that the teachers had no knowledge of which student or condition they were scoring.

		1 hour	2	3	4	5
intro	Training	Active reading task (60 minutes)	Lunch	Homework support task (90 minutes)	Post-test (20 min)	Debrief

TABLE 1 TYPICAL STRUCTURE FOR EACH CONDITION

QUANTITATIVE RESULTS FROM THE POST-TEST

Figure 8 shows the quantitative post-test results. Both the homework and post-test tasks had a maximum score of 100. The scores in Figure 8 show the mean score of students in each group.

Our primary interest is in the effect on the post-test score of *Inquire* as compared to the two contrasting, more typical conditions. The mean post-test score of 88 for the *Inquire* group was higher than both the corresponding score of 75 for the ablated *Inquire* group and the score of 81 for the textbook group. The difference between the *Inquire* group and the Ablated *Inquire* group was statistically significant (p value=0.002). The difference between the *Inquire* group and the Textbook group was also significant (p value=0.05). These differences suggest that students who used *Inquire* learned more.

The mean homework score of 81 for the *Inquire* group was higher than both the corresponding score of 74 for the ablated *Inquire* group and a score of 71 for the textbook group. The difference between the *Inquire* group and the Ablated *Inquire* group was not statistically significant (p value=0.12), but the difference between the *Inquire* group and the textbook group was significant (p value=0.02). The observed trend is consistent with our hypothesis that *Inquire* enhances learning by helping students perform better on homework.

The comparison between the paper textbook and the ablated version of *Inquire* is also interesting. Although the mean homework score of 74 for Ablated *Inquire* and a mean score of 71 for the paper textbook differ, there was no statistical difference between these conditions. Similarly, there was no statistical difference between the homework scores of the two conditions (p value=0.18). This result is consistent with the prior research that simply changing the medium of presentation has no impact on student learning (Means et al. 2009).

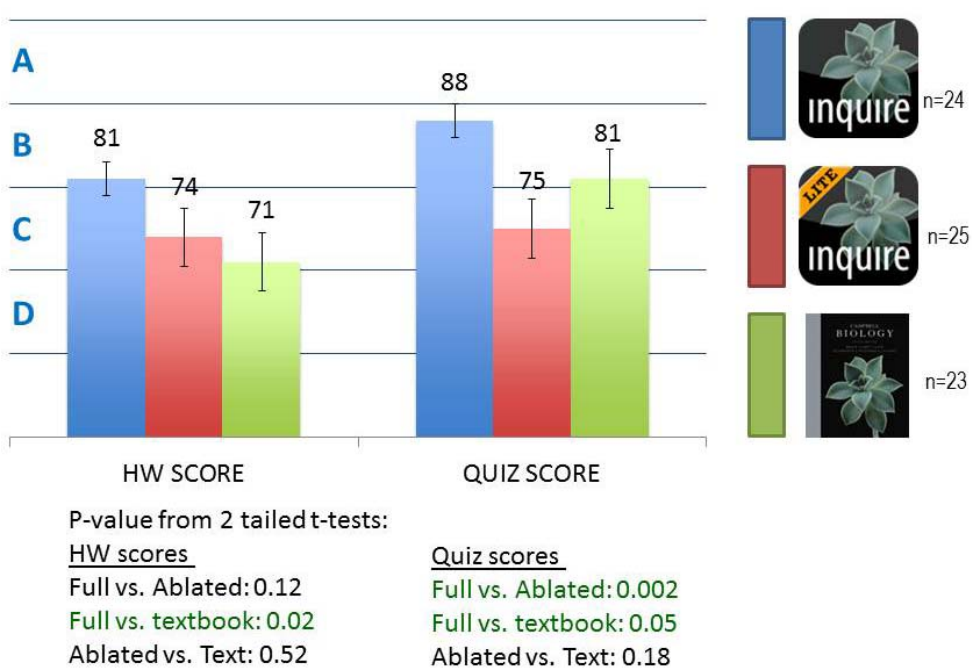

FIGURE 8: QUANTIATIVE POST TEST RESULTS

We gathered extensive data on how the different features of *Inquire* were used but did not discover any significant correlation between the usage of a particular feature and the improvement on post-test performance.

We did not explicitly measure to what extent students followed the specific steps of active reading, or to what extent they acquired deeper understanding of knowledge, or whether they were more engaged with the material. The post-test scores are a measure of depth of understanding, and increased engagement was apparent in their qualitative feedback that we discuss next. Additional analysis could be done by analyzing their note taking behavior, but since it was orthogonal to the core AI features that were the subject of the study, we left it open for future work.

Qualitative Results

We gathered three forms of qualitative data to assess the usefulness of *Inquire*. The data included the usage of *Inquire* features as well as results from a usability survey and a technology readiness survey.

We tracked the questions asked by students and the concept summary pages visited by them. All students in the Full *Inquire* group asked questions and visited concept summary pages. Students viewed a total of 81 concept summary pages during the exercise; 38 of these were viewed by at least two students. Approximately 30% of the questions were of the form "What is X?", another 30% were factual questions and the remaining 40% were evenly split between comparison questions and relationship questions. This usage data is suggestive of the usefulness of these features to students.

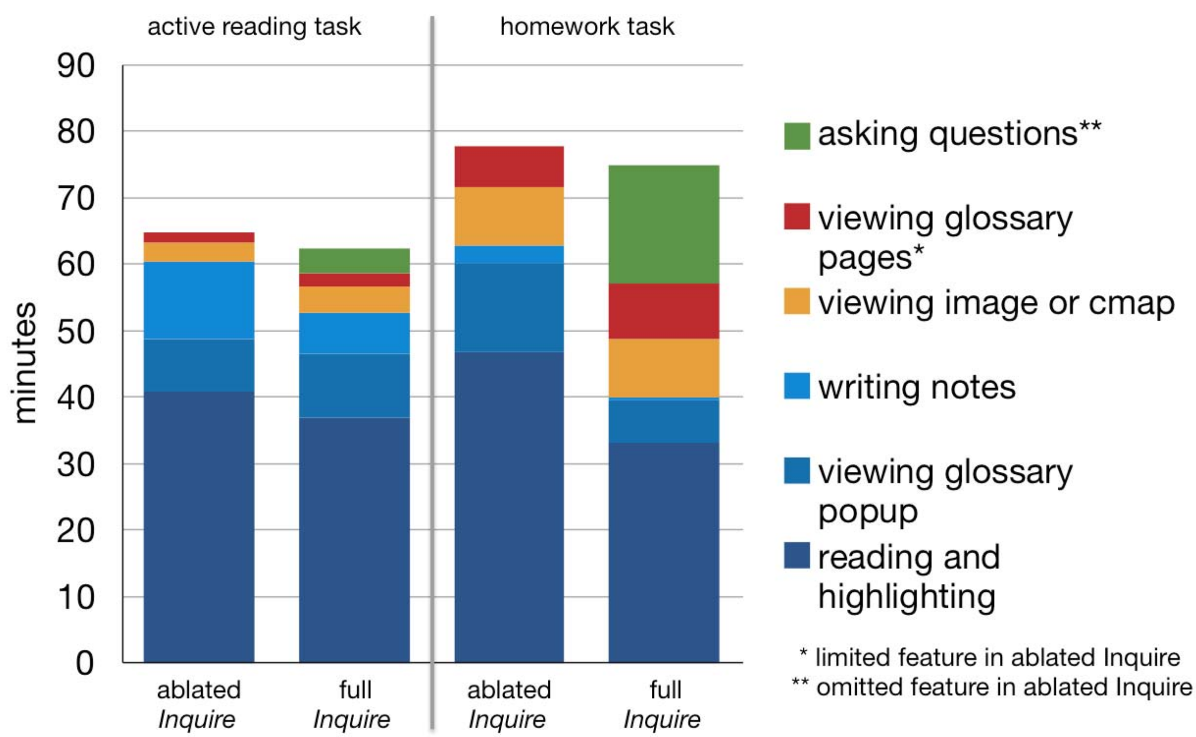

FIGURE 9: AVERAGE STUDENT USAGE TIME BY ACTIVITY

During the active reading task, students cumulatively asked 120 questions, and during the homework task they asked a total of 400 questions. This difference is expected, as students naturally have a greater need for asking questions during the homework task. During active reading, the question asking predominantly came from students clicking on questions suggested in response to their highlighting of text. During homework problem solving, however, students were more prone to use *Inquire*'s question-asking dialog. A total of 194 unique questions were asked by the students, out of which only 59 questions were asked by two or more students. The variety of questions would make it very difficult to anticipate all questions in the textbook itself. This suggests that automatic question answering can be a useful addition to a textbook.

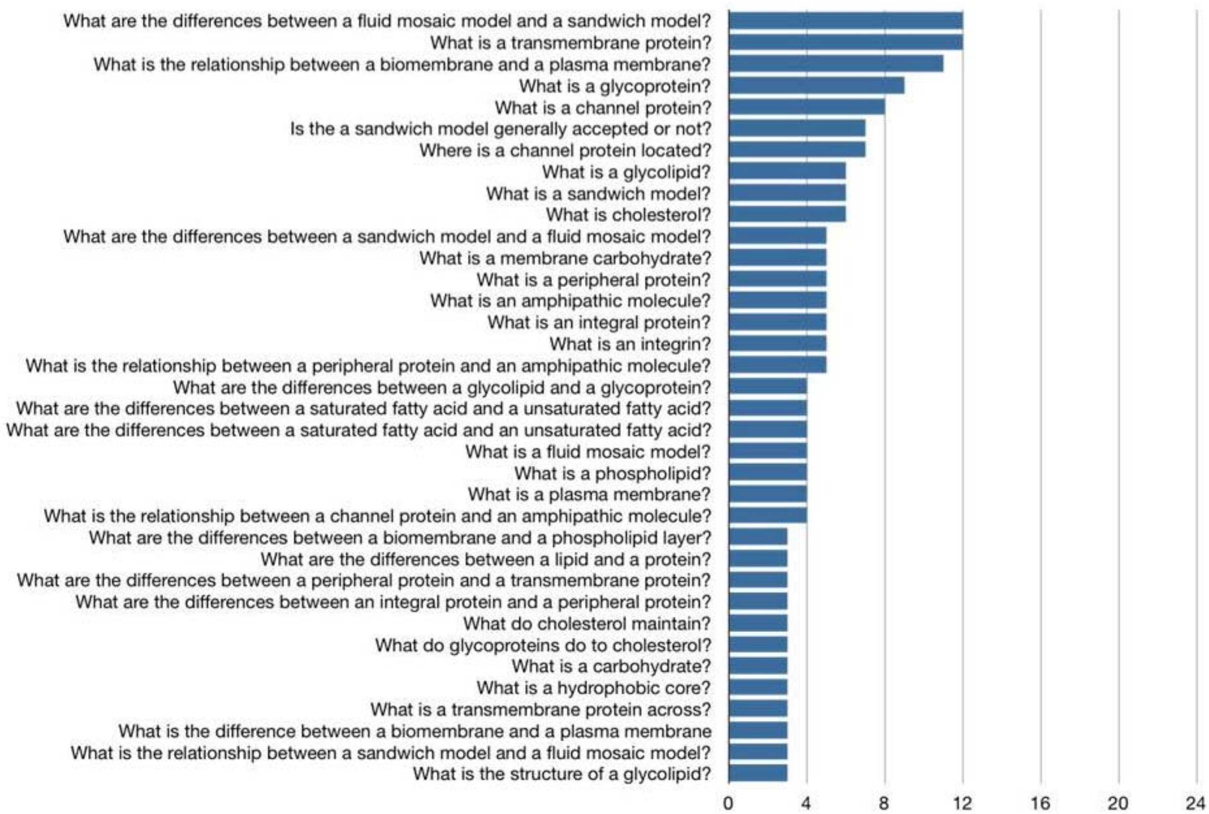

Figure 10. Number of students who asked a question (X-axis denotes number of students)

In Figure 10, we show the actual questions that the students asked and how many different students asked each question. As we can see there is a good spread of different question types even though the questions of the form ``What is X" predominated the mix. There were some questions that were more popular than the others.

After use, the students rated the usability of *Inquire* using the SUS scale (Brooke 1996). The SUS score for Ablated *Inquire* was 84.79 with a standard deviation of 11.82, whereas the score for full *Inquire* was 84.4 with a standard deviation of 9.02. This suggests a high degree of subjective satisfaction in using *Inquire* as well as no degradation in usability from the addition of AI-based features.

The students also completed a survey to provide subjective ratings of various features of *Inquire.* The students were asked to indicate whether a particular feature was ready for use, ready for use with some improvements, or required major improvements. The concept summary pages had the highest score with 76% of students rating them as ready to use in the present form, 16% rating them as requiring minor improvement, and 8% rating them as requiring major improvements. For the question answering facility, 51% of the students rated it as ready to use in present form, 37% rated it as requiring minor improvement, and 12% rated it as requiring major improvements.

In the post-task debrief, students in the *Inquire* group unanimously reported that they would like to use the system for their class. They reported that *Inquire* "motivates you to learn more" and "helps you stay focused." Students also reported that they felt less distracted as they could use *Inquire* to get additional information without losing context. Usage logs show students made use of questions answering and concept summary pages during the active reading task, which suggests that they were engaged in the content, and actively seeking out related and supporting information. A more extensive evaluation of how *Inquire* improves engagement is open for future work.

Overall, the qualitative assessment of the *Inquire* features was positive, but also indicated some areas for improvement. Students reported that the comparison answers were "well organized" and "to the point" but, also commented that the range of questions supported needs to be expanded, and the answer quality, still needs to be improved.

GENERALIZABILTIY AND SCALABILITY

Let us now consider how this approach generalizes and scales potentially to textbooks other than biology. Our most substantial experience in using AURA is with Campbell Biology. In addition to Biology, we have prior experience in using AURA for Physics and Chemistry (Gunning, et al. 2010). We have also performed a design-level analysis for the domains of Government and Politics, Micro Economics, and Environmental Science. Within the domain of Biology, we have considered AURA's applicability to a middle-school textbook and to advanced textbooks on Cell Biology and Neuroscience. We can draw the following conclusions from these studiess

Conceptual knowledge (ability to define classes, subclasses, stating disjointness, defining slot values and rules), mathematical equations and qualitative knowledge (e.g., directly or inversely proportional) cuts across all domains and are widely applicable. Such knowledge can account for at least half of the knowledge that needs to be captured in a textbook. Inquire Biology demonstrates that a useful enhancement to an electronic textbook can be built using these core forms of knowledge. The approach is directly applicable with little changes to any textbook that is comparable in scope to Campbell such as (Mason et. al. 2011) or a middle school textbook (Miller and Levine 2010). The conceptual knowledge, qualitative knowledge and mathematical equation features of AURA generalize to any of the domains mentioned above.

Outside the context of an AI research project, one possible approach to achieve scalability of the approach in practice is for the knowledge representation of the content of the book to become an integral part of the book authoring process. This new requirement is no different than the preparation of table of contents, index, or glossary that is typically found in standard textbooks. The books of the future could include knowledge representation for the most salient portions of the content which could enable numerous pedagogical features some of which are illustrated in Inquire Biology.

AURA and Inquire, however, do not cover all forms of knowledge found across multiple domains. Some domains are more mathematical than others, for example, Physics, Algebra or Economics. For such domains, the reasoning capability of the system needs to include mathematical problem solving. The domains such as Chemistry and Algebra also require capturing procedural knowledge. A typical example of such knowledge in Chemistry involves steps for computing pH of a buffer solution. While solutions exist for mathematical problem solving and capturing procedural knowledge, but their combination with conceptual knowledge requires novel AI research. The background knowledge provided in CLIB needs to be extended for each domain requiring some research in conceptual modeling and application of this research by the domain experts in the respective domain. New domains also require developing new question types and answer presentation methods.

RELATED WORK

The work presented here directly overlaps with three related areas of research: electronic textbooks, question answering systems, and reading for comprehension. In this section, we briefly situate our work in these three areas of related research.

ELECTRONIC TEXTBOOKS

To inform the initial design of *Inquire*, in early 2010 we evaluated existing E-book apps and electronic textbooks to develop a list of key features and solutions to common problems. Based on this analysis, we determined that students would expect *Inquire* to save their places in the book and make it easy to take notes, highlight text, zoom in on images, and search the concept summaries. We also saw many approaches to displaying the highly structured content of textbooks, from scaled-down images of actual pages (Kno[7]) to entirely custom iPad-optimized layouts (Apple iBooks textbooks). We chose to render the book content as a vertically-scrolling HTML page, as that gave us an optimal combination of readable text, flexible layouts, good performance, and a reasonable level of effort.

Standing apart from the other iPad textbook apps is Inkling[8], an app released in August 2010, around the time we built the first alpha versions of *Inquire*. Inkling 1.0 had all the major features discussed above and, like *Inquire*, rendered content as speedy HTML rather than the slower scans of book pages. Since 2010, Inkling has added several features that may address some of the specific needs we target with *Inquire*: providing definitions of key terms through integrating Wikipedia into the app's search feature, and shared notes that allow students to communicate with their classmates and ask *each other* questions about the material. Because AURA's answers never stray from the content of *Campbell Biology*, they are more accurate and better scoped than what one might get from Wikipedia or from one's peers. Inkling's work is however an important step forward for students and an indication of the degree of rapid improvement that is occurring in the electronic textbook domain.

Question Answering Systems

A survey of recent question answering systems has been published in *AI Magazine* (Gunning, Chaudhri and Welty, 2010). For the present discussion, we will compare AURA to Watson and Wolfram Alpha.

Watson is a recent question answering system from IBM that outperformed humans in the game of Jeopardy (Ferrucci 2012). Watson is an impressive system that showed performance over a broad domain of question answering. One of the primary characteristics of the Jeopardy problem is that 94.7% of the answers to questions are titles of some Wikipedia page (Chu-Carroll and Fan, 2011). The remaining 5.3% of the answers that are not the titles of the Wikipedia pages include multiple entities such as *red, white & blue*, or even sentences or phrases, such as *make a scare cow*. Since there are more than three million Wikipedia pages and a huge variety of questions, this is not an easy task, yet it is constrained in a way that makes it amenable to solution by machine learning techniques. In contrast, the answers returned by AURA can be fairly complex—especially the answers to the comparison and relationship reasoning questions. Furthermore, these answers are not always stated in the textbook, and even if they are, they may be stated in different parts of the textbook. In

[7] See http://www.kno.com
[8] See http://www.inkling.com

addition, *Inquire* is an interactive user-centered application and has much higher usability demands.

Wolfram Alpha is a question answering system based on Mathematica, a computational reasoning engine[9]. Wolfram Alpha relies on well-defined computations over curated data sets. For example, when given a question such as "orange and banana nutrition?", it looks up the nutritional information for both orange and banana, adds them, and presents the net result. When given an equation such as g(n+1)=n^2+g(n), Wolfram Alpha gives its solution and presents a plot showing the value of the solution as a function of n. Wolfram Alpha is similar in spirit to AURA in the sense that it provides well-defined computations over curated data, but very different in terms of the curated data and the specific computation. For AURA, the knowledge is curated from a biology textbook, and the computations are based on logical reasoning rather than mathematics.

Reading Comprehension

Achieving the potential offered by e-book technology will depend on a rich understanding of how students learn from college-level science textbooks. Past research indicates that as the information complexity of such textbooks increases, the explanatory clarity, or text cohesion, declines (Graesser, McNamara, Louwerse, & Cai, 2004). To succeed, science students must move from decoding to sense-making, which involves making connections between prior knowledge and new information (Kintsch, 1988; Palinscar & Brown, 1984; Scardamalia, Bereiter, Hewitt, & Webb, 1996), yet research indicates that many college students find it difficult to read science textbooks because of gaps in their understanding of science concepts (diSessa, 1993; Driver & Easley, 1978; Ozuru, Dempsey, & McNamara, 2009).

Inquire features promote active reading, strategies that can help readers construct better models of the concepts they are learning. Priming readers to focus on their goals or the text structure before reading can serve as a form of advance organizer that cues existing knowledge, supports strategic reading, and permits readers to mentally record new knowledge more effectively (Ausubel & Youssef, 1963; Mayer, 1979). Providing readers with opportunities to check their knowledge as they read supports active self-regulation of learning (Bransford, 2000; Brint, 2010). Prompting readers to pose questions as they read is also useful for meta-cognitive monitoring, improving comprehension, and making connections among ideas (Novak, 1998; Pressley & Afflerbach, 1995; Udeani & Okafor, 2012). In addition, coupling visual elements in textbooks, such as diagrams, with text can also have quite robust effects on student learning (Mayer, 2003a), especially for students who prefer visual information (Mayer, 2003b).

[9] See http://www.wolframalpha.com/about.html

FUTURE WORK

Inquire is an early prototype of an intelligent textbook and our results show the promise of applying AI technology to electronic textbooks to enhance learning. To fully realize this promise, more work needs to be done in at least three categories: improving the representation, improving question answering capability, conducting more extensive education studies, and improving the learning gains. We discuss each of these directions in more detail.

IMPROVING REPRESENTATION AND QUESTION ANSWERING

Currently, *Inquire* provides very good coverage of Chapters 2-12 of *Campbell Biology,* and some coverage of Chapters 13-21, 36, and 55. It currently handles factual, comparison, and relationship reasoning questions. The knowledge representation needs to be both deepened and expanded to cover the remaining chapters. The current representation handles knowledge about structure and function, process regulation and energy transfer. Additional representation constructs are needed in CLIB for representing experiments, evolution, continuity and change, and interdependence in nature. Expanding the knowledge base to the full textbook requires ensuring the scalability of the knowledge authoring system in AURA. Additional work also needs to be done on developing new reasoning methods such as for process interruption reasoning, and to expand the range of questions that the system currently suggests. The usability of the system will also improve substantially by expanding the range of English that can be accepted as input questions.

MORE EXTENSIVE EDUCATIONAL STUDIES

The evaluation considered in this chapter lasted for only a few hours over a single day. It remains to be shown if similar improvements in student learning can be obtained if the students are allowed to take *Inquire* home, and study from it over a period of several weeks. The current study suggested that *Inquire* may be especially useful for lower-performing students; additional students need to be tested to validate this trend. We also need to better understand which specific features of *Inquire* contributed to the improvement in learning that we observed.

IMPROVING LEARNING GAINS

Current results show that the use of *Inquire* improved the post-test scores by approximately 10%. A natural question is whether this is the maximum improvement possible. Several new educational supports can be included in *Inquire* to support a better model of student comprehension, identifying student-specific problem areas to provide targeted support, and incorporating better problem solving dialog capabilities. In the long term it could have a full-fledged intelligent tutoring system.

SUMMARY AND CONCLUSIONS

Inquire Biology is an innovative application of AI technology to an electronic textbook. The key ideas in *Inquire* are to provide automatically generated concept summary sages, suggested questions and to provide answers to comparison and relationship questions. This is enabled by taking advanced AI technologies and blending them into an E-book to provide a seamless user experience. Most natural language question-asking interfaces suffer from the problem that the *student* does not have a clear sense of what kind of questions the system can handle. *Inquire* addresses this by the use of suggested questions. The evaluation results show that students find *Inquire* usable and engaging, and that they learned more. Although the result is from a preliminary evaluation study, it is an important and significant result as it is one of the first to conclusively demonstrate the usefulness of explicitly represented knowledge as students study from their assigned science textbook.

When students transition from print textbooks to electronic textbooks, they will learn more only if the new media better supports their learning process. To date, most work with electronic textbooks reproduces only capabilities such as highlighting and annotation, which are already available for paper textbooks. By using knowledge representation, question answering and natural language generation techniques from AI, we have shown that an electronic textbook can go beyond what is possible in paper books. Specifically, knowledge representation can support students in asking and answering questions about the relationships among the large number of concepts that are newly introduced in challenging science courses. By helping students understand the relationships among concepts, an AI-enriched textbook has the potential to increase students' conceptual understanding as well as their satisfaction with study materials. Even though the focus of our work has been on a specific subset of AI techniques, we hope that Inquire Biology will provide inspiration for a variety of AI methods to provide pedagogical supports for personalization and leveraging online resources in electronic textbooks that facilitate the development of inquisitive scientists and engineers that are much needed today.

ACKNOWLEDGMENT

This work has been funded by Vulcan Inc.

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