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***Chick*Scope: An Interactive MRI Classroom Curriculum Innovation for K-12**

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Abstract

Researchers from several departments of the University of Illinois at Urbana-Champaign initiated *Chick*Scope, a 21-day chick embryonic development project, to demonstrate the remote control of a magnetic resonance imaging (MRI) instrument through the World Wide Web.

For 21 days, students and teachers from ten kindergarten to high school classrooms participated in this innovative project using an interactive Web lab book. From classroom computers with access to the Internet, students were able to login to the computers at the university that controlled the MRI system, manipulate experimental conditions through a simple on-line form to generate their own data, and then view resulting images of the chick embryo in real-time. Researchers answered students' questions about their MR images and other related issues.

*Chick*Scope made extraordinary hardware, software, and human resources available to the classrooms. However, it left to teachers the tasks of integrating these resources into the classroom and adapting them to the needs and abilities of the students. Thus, the implementation was teacher-based, and its meaning was realized in different ways in each setting.

This paper describes the planning, implementation, and the impact of *Chick*Scope in classrooms for facilitating learning and teaching. We provide examples from various grade levels?primary to high school. We conclude with lessons learned and the implications of advanced technologies for K-12 outreach.

Introduction

*Chick*Scope is an innovative classroom project that uses interactive, real-time Magnetic Resonance Imaging (MRI). *Chick*Scope made available many resources on the World Wide Web (WWW); it allowed for control of an advanced imaging device through the Web, and it assisted students and teachers in their collaborative construction of a Web site. *Chick*Scope was initiated by researchers at the University of Illinois as a pilot project in the use of remote instrumentation in the classroom.

The project's purpose was to enable students and teachers to control an MRI system to study the maturation of a chicken embryo during its 21 days of development. The MRI system allowed for real-time data acquisition, instrument control, and data processing through a standard WWW browser interface called NWebScope [1,2].* The study of chicken eggs is frequently used in K-12 classrooms to illustrate embryonic development. 4-H School Enrichment Programs, such as the one run by the Champaign County Extension Unit [3], often provide schools with curriculum materials for this purpose.

Our objectives were two-fold. Firstly, we sought to understand the impact of such a system on K-12 education in light of the current education reform initiatives that use the Internet for learning and teaching [4]. Secondly, we set out to 'stress-test' interactive, remote control of the MRI system for further development by scientific researchers.

*Chick*Scope Overview

Remote Instrumentation and the Web

The remote use of scientific instrumentation over the Internet offers significant potential for collaborative research and data analysis as well as dissemination of this research. In addition, it provides unique possibilities for education and outreach to different sectors of society. Using basic Internet access tools, such as a standard Web browser, researchers or educators from any place and at any time have the potential to access the latest scientific equipment available in national laboratories without having to travel or invest in such hardware. Accordingly, the World Wide Web becomes a laboratory for many fields of research and education; a World Wide Laboratory, if you will.

Use of the Web for controlling scientific instruments in addition to the MRI has already begun. For example, a transmission electron microscope has been used to acquire images [5] and telescopes can be operated remotely so that users can request images of the night sky [6].

National laboratories, such as the National Center for Supercomputing Applications at University of Illinois, are developing and implementing strategies for transferring computational tools and analytical technologies for use by all sectors of society. One strategy is to make the advanced tools and techniques that scientists use available to K-12 students and teachers [7].

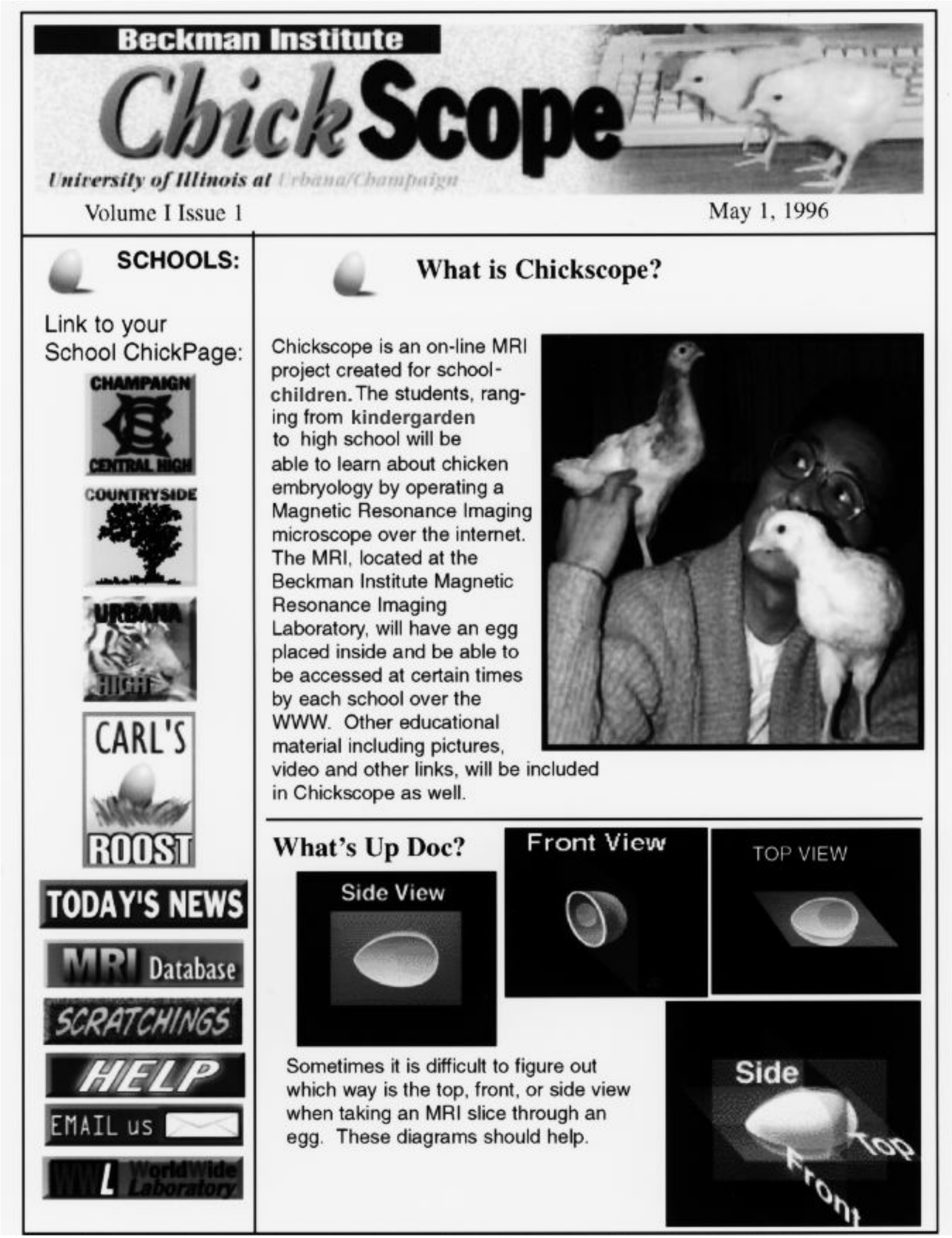
The goal of the *Chick*Scope project was not only to provide students with access to the MRI system but also to develop an underlying support structure that is useful to scientists. Furthermore, we wanted to explore how the project's concept could be tied to classroom curriculum activities.

ChickScope Planning

In simplest terms, *Chick*Scope is an interactive Web lab book created so that K-12 students and their teachers could access and control the MRI system. *Chick*Scope features (see Figure 1) included the following:

- Individual School ChickPages
- Daily News on Chick Development

- MRI Control Interface and Database
- Carl's Roost
- School ChickPage



Beckman Institute

ChickScope

University of Illinois at Urbana/Champaign

Volume I Issue 1 May 1, 1996

SCHOOLS:

Link to your School ChickPage:

CHAMPAIGN CENTRAL HIGH

COUNTRYSIDE

URBANA HIGH

CARL'S ROOST

TODAY'S NEWS

MRI Database

SCRATCHINGS

HELP

EMAIL us

WWL WorldWide Laboratory

What is Chickscope?

Chickscope is an on-line MRI project created for school-children. The students, ranging from kindergarden to high school will be able to learn about chicken embryology by operating a Magnetic Resonance Imaging microscope over the internet. The MRI, located at the Beckman Institute Magnetic Resonance Imaging Laboratory, will have an egg placed inside and be able to be accessed at certain times by each school over the WWW. Other educational material including pictures, video and other links, will be included in Chickscope as well.

What's Up Doc?

Sometimes it is difficult to figure out which way is the top, front, or side view when taking an MRI slice through an egg. These diagrams should help.

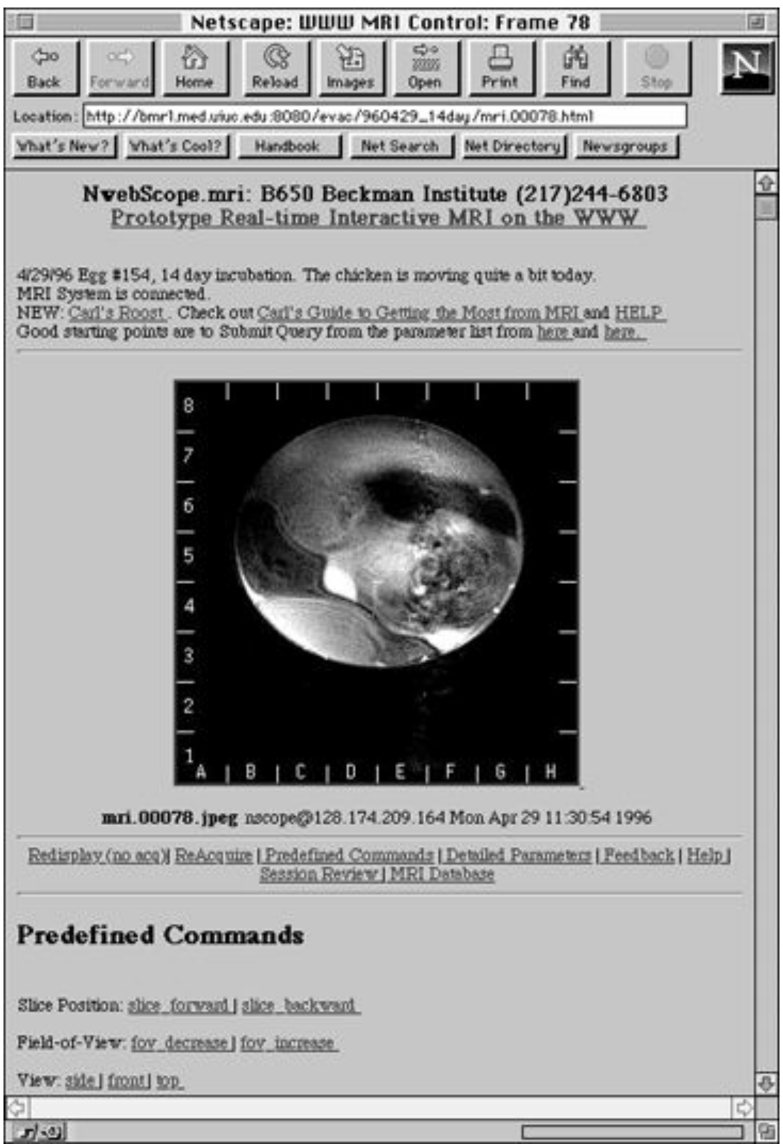
Each of the ten participating schools was provided a home page of its own. From this page the students and the teachers could access the control interface for the MRI and the database. They could also reach "chicken scratchings"?an interactive discussion space?where the students could ask questions and make observations about the chick embryo.

Today's News

This section of *Chick*Scope had daily updates on the chick embryo development for students to review, including annotated MR images acquired by the individual schools or the researchers, chick movies, and candled images. This section provided daily instructional material for the schools. Often the feedback from a 'chicken scratching' of the previous day was incorporated into the next edition of Today's News.

MRI Control Interface and Database

The MRI system is located at the Beckman Institute, but from the individual school home pages its control interface (NWebScope) could be accessed from any classroom using a standard Web browser (see Figure 2).

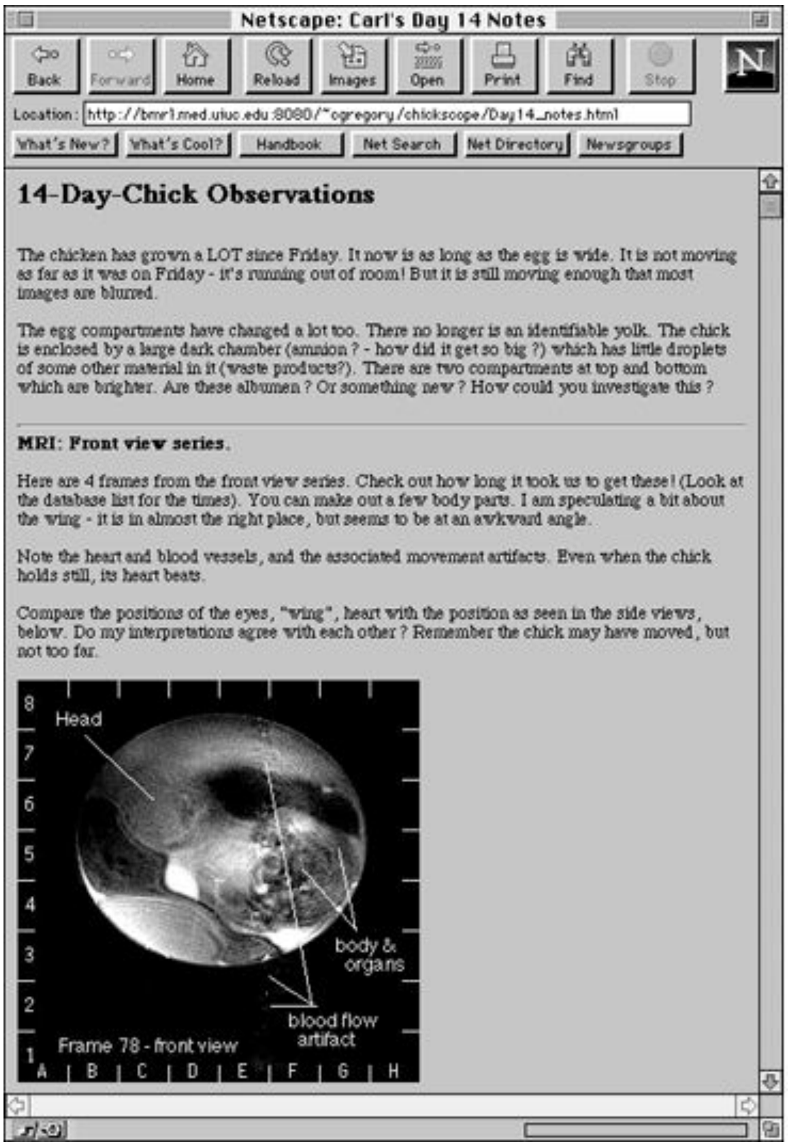


Students and teachers could manipulate experimental conditions through the simple on-line NWebScope interface to generate their own data, and then view the resulting images immediately. The control parameters, such as direction of view, slice position, slice thickness, field-of-view and image contrast, were easy to use. On-line help on any of the control parameters was available, with examples.

The MRI database archived the images along with their acquisition parameters and user information for later review. The database is accessible at all times, even when the MRI system is not available. For instance, the image in Figure 2 is stored in the directory of images of the 14th day of incubation.

Carl's Roost

This was one of the three "roosts" accessible from *Chick*Scope. Here, experts would respond to the "chicken scratchings" from students and teachers. Annotated images with notes on daily growth of the chick embryo were also here. For instance, Figure 3 shows the observations of Day 14. Often an expert would share activities or exercises that might be used in classrooms, such as a discussion of chemistry of an egg.



*Chick*Scope Implementation

Before the start of the *Chick*Scope project, the appropriate university and parental consent was obtained. The project involved the following groups:

- Schools
- One or more teachers at each of the schools
- One or more classes at each of the schools (K-12 students)
- University undergraduates, including student teachers

Prior to the start of the project, a teacher training day (April 3, 1996) was held at the University of Illinois. Incubators and resource materials were distributed, and procedures were discussed and demonstrated. A two-hour introduction to MRI, along with an overview of chicken embryo development, was given to the teachers.

During the 21-day incubation period (April 10 to May 1), each class was granted MRI access time of 20 minutes, twice a week, scheduled to accommodate classroom and school computer availability. Every morning the MRI magnet was warmed, an egg inserted, and the MRI system tuned and calibrated. All this had to be done before the first classroom could have access to the system. At the end of the day, the system was shut down and the sample egg returned to the incubator.

Much of the qualitative data presented below were collected from the surveys and interviews. Additional information gathered, included classroom observations, computer access logs, and interactive commentaries (electronic mail and "chicken scratchings").

Schools

Ten schools participated in *Chick*Scope, including public and private schools, an after-school boys and girls science club, and a home school. Classes from grades K-12 were selected, based on the teachers' interest in the project as well as classroom access to the Internet. Eight of the 10 schools were in the immediate Champaign-Urbana area. One of the high schools was in a nearby rural county, and the home school was out of state (South Carolina).

Teachers

Nine teachers participated in the project¤four high school teachers, one middle school teacher, two elementary school teachers, one primary school teacher, and one home school parent teacher. One of the elementary school teachers was also a supporting teacher for the after-school science club, and so we had nine participating teachers. All were women, except for one high school teacher. Before the start of the project, participating teachers completed a survey about their computing background and interest in the project. Participating teachers also completed a feedback survey at the end of the project. All the teachers attended the teacher training day except for the home school teacher.

On a 7-point Likert scale, the nine teachers ranged from "very comfortable" (1) to "very uncomfortable" (7) in the use of computers with an average of 3.2, meaning they felt moderately comfortable with computers. Although the dominant uses of computers by the teachers were word processing, graphics, games and simulations, and the Internet, teachers also used the computers for library access, spreadsheets, databases, and grading programs. Use of the Internet for school and personal work by the nine teachers varied from 0.1 to 5 hours per day, with an average of 1.2 hours per day for school use and an average of 0.6 hours per day for personal use. Seven of the nine participating teachers assigned their students to use computers or the Internet for classroom work. All teachers had heard about MRI before, with knowledge ranging from "very little" to "diagnostic tool." For some, the training session provided their first introduction to how MRI works.

Since the teachers represented different grade levels, their interests in the project were varied. The high school and middle school teachers were specifically interested in chicken embryology, as it could easily fit into their biology activities. For instance, a high school teacher was curious about cell development:

> *The idea of any organism developing from a simple cell fascinates me. To be able to see the progress of this development is even better.*

The primary school, home school, and elementary school teachers had more general goals; that is, providing their students an opportunity for discovery learning. For one primary school teacher, the project was seen as a way to allow her students to "look inside" an egg and learn about life cycles.

Because the project was exploratory, we expected the teachers to be innovative in integrating it into their classroom activities. We were interested in learning what strategies they used to engage their students in scientific inquiry. The high school teachers preferred an inquiry teaching and learning approach in their classrooms by encouraging their students to ask questions, and then providing them with tools for their own scientific investigations. The teachers from middle school to primary school preferred engaging their students in "hands-on" activities. For instance, the middle school teacher facilitates the process of doing science in her classroom:

> *My program is almost entirely hands-on, minds-on. We try to do relevant activities that cause students to think and apply science principles to real-world problem.*

All the teachers expected that the project would provide them and their students background in chick embryology, MRI, and the Internet. An elementary school teacher who teaches fourth-fifth grades hoped that the project would give her students and herself an opportunity to learn "about many scientific things as well as problem solving skills."

In addition to the full-time teachers, there were also three female student teachers, one each at an elementary school, the middle school, and a high school. Also, participating teachers received support from their colleagues at school. For instance, the science coordinator at an elementary school assisted a participating elementary school teacher.

Students

There was a total of about 210 students in the participating classrooms. Students were asked to complete a background survey. Surveys were received from all schools except from one second grade elementary school classroom and the after-school science club. The students in the primary school classroom were not required to do the survey. However, due to attendance problems, not all students completed the forms. Rather than a comprehensive summary, we present two classroom profiles below as representative of the participating schools.

Middle school students

On a 7-point Likert scale, the 25 students (17 girls, 8 boys) ranged from "very comfortable" (1) to "very uncomfortable" (7) in the use of computers with an average of 2.8, meaning they felt moderately comfortable with computers. More than half of the students used computers for word processing, games, and the Internet. Some students also used computers for library searches or for graphics. One student had worked with HyperCard. Fourteen students had used the Internet prior to this project, and their use of the Internet for school and personal work varied from "not very long" to a few hours per day. Sixteen students had previously used computers or the Internet in a class.

Six students had previously heard about MRI, such as its use in hospitals, and 11 students had some knowledge of the chick embryo, such as it "takes 21 days for it to hatch." In general, the students enjoyed making observations and doing scientific experiments.

High school students

On a 7-point Likert scale, the 12 sophomore, junior, and senior students (8 girls, 4 boys) in one class ranged from "very comfortable" (1) to "very uncomfortable" (7) in the use of computers with an average of 2.9, meaning they felt moderately comfortable with computers. The dominant uses of computers by all 12 students were word processing, games and simulations, and the Internet. Some students also used computers for library searches, and one student had some programming experience in Pascal and BASIC. The students did not have regular access to the lab; therefore, their use of the Internet for school and personal purposes varied greatly, from 0 to 6 hours per day. All 12 students had previously used computers or the Internet in a class.

Six students had heard about MRI before, such as it "uses magnetic field to make images," and only three students had any knowledge of chick embryology. One stated that the egg "hatches and it becomes a chicken." Since most high school students are expected to have some basic knowledge of chick embryology, it may be possible that students in this class did not share such information as they may be holding themselves to a higher standard. In general, the students enjoyed making observations and asking questions while doing scientific experiments.

Undergraduate students

Fifteen undergraduate students from the University of Illinois participated in the project by providing assistance in the classrooms. Twelve (seven women, five men) of these students were enrolled in the Project SEARCH[*] course, an undergraduate science outreach project at the university [8]. The other three students were the student teachers mentioned earlier.

Due to scheduling conflicts, only six of the 15 undergraduate students completed the background survey. On a 7-point Likert scale, these six (of which five were women) ranged from "very comfortable" (1) to "very uncomfortable" (7) in the use of computers with an average of 3.4, meaning they felt moderately comfortable with computers. The dominant uses of computers by these students were for word processing, graphics, games and simulations, library access, and the Internet. Two of the students had background in computer programming; one of them also had knowledge of spreadsheets and databases. The use of the Internet for school and personal work by the six students varied from 0.7 to 3 hours per day, with an average of 0.4 hours per day for school use and an average of 1.1 hours per day for personal use.

These undergraduate students had a general idea of MRI, mainly from their classes at the university. In general, these students were interested in chick embryology, and felt that MRI is a good way for studying growth and development. One student had not heard much about MRI. This student also was not familiar with chick embryology but wanted to learn about it through this project.

The strategies that the undergraduate students liked to use with their students included asking questions, hands-on activities, and collecting and interpreting of data. The expectations of the project by the undergraduate students ranged from giving their students a background in MRI, chicken embryology, and computers to simply developing an interest in laboratory activities. A Project SEARCH undergraduate student, who worked with students at two high schools and the after-school boys and girls club, had a wide range of expectations:

> *I expect the students at the [after-school boys and girls] club to gain an interest in the Internet and in embryology enough to ask questions and gain some knowledge. At the high school, I expect the students to understand how the pictures are being taken, and how the embryo looks at each stage of its development*.

School Facilities

Computer facilities were key ingredients in the project. Below is an overview of typical school facilities.

The middle school classroom of 25 students had one computer with access to the Internet via 128KB ISDN connection. The students in this classroom did not have any regular, formal access to the school computer lab. However, when the project started, the students spent one class period (50 minutes) per week in the computer lab working on the project. The computer lab had 25 computers, ranging from Macintosh LCII to Macintosh 580, with approximately 8MB RAM per computer.

One high school class of 12 students did not have any computer in the classroom. However, the classroom teacher reserved the computer lab twice a week for one class period (40 minutes) each day. The computer lab had 15 computers (all PowerMac 6100/60) and access to the Internet via 128KB ISDN connection.

The primary school classroom of 24 kindergarten and first grade students had two Macintosh IIsi computers, both with access to the Internet through the university.

A Sample Classroom Scenario

To illustrate how the program operated within the classroom, we have presented a sample scenario. This scenario is for the middle school classroom (7th grade). Some other approaches used by the primary school and high school classrooms are also indicated.

The 7th grade classroom was studying biology in the spring semester. Before the start of the *Chick*Scope project, the classroom teacher and her student teacher began to map out ways to integrate it into their curriculum. The classroom teacher made a list of ideas for this integration:

1. *Egg dissection.* [before the start of the project]
2. *Have students search the Web for other related sites.*
3. *Read Science World article called "From One-Cell to Full-Grown: Embryonic Development."*
4. *Relate to biology concepts like fertilization, gestation, and incubation.*
5. *Relate to vertebrate biology as far as the Ave (bird) phylum. Compare and contrast birds to other phyla of animals.*
6. *Relate MRI to what we have already learned about magnetism.*

7. *Investigate other real world applications for MRI.*

The classroom teacher and her student teacher attended the teacher training day, where they received an incubator as well as resource materials and instruction on chick incubation and embryology from the Champaign County Extension Unit. The teachers started incubating their two dozen eggs around the same time (April 10) as the eggs that were placed inside the MRI.

Before the start of the project, the students were given a presentation on the parameters for controlling the MRI. During the 21 days of the project, the students worked in four groups, with six students per group, for acquiring images through their single classroom computer. The class MRI access time was twice a week for 20 minutes. A television monitor was connected to the computer so that the rest of the class could watch while one group worked on the computer. One of the project staff members was present in the classroom to assist and answer questions. While one group of students worked on the computer, the other three groups worked on different activities planned by their teachers, such as making observations about their classroom incubator or reading about the chick embryo's progress on the bulletin board (where printed copies of *Chick*Scope pages were posted regularly). As part of the classroom activity, students also did MRI worksheets in which they identified views (front, top, side) on the images that were acquired by their class. The classroom teacher also provided them with writing assignments:

> *Explain why the air cell increases greatly during incubation*.
>
> *Read: How A Chick Emerges.* [handout distributed in class]
>
> *Hint: What happens on Day 14 of incubation?*
>
> -----
>
> *Also: Find out when the embryo's lungs start to function*.
>
> Although students worked in groups, each student would hand in her/his work individually. For instance, here is one student's response to the first question above:
>
> *So the chick can poke through the membrane easily and get accustomed to the air, and so its lungs will start working right.*

Once a week, when the entire class used the computer lab, the students had the opportunity to browse through the *Chick*Scope Web site to read Today's News, search the MRI database for acquired images, review Carl's Roost, or share a chicken joke.

An important feature of the *Chick*Scope Web site for this class was the interactive "chicken scratchings" area. If the students were unable to access the computers, they would pass their question or observation through the teacher or student teacher. The teacher and the student teacher would regularly share the scientists' responses or answers with the entire class for discussion purposes. Here are some examples of such interactions which were useful to all the students in this classroom (as well to other participating classrooms):

> *Q: Why is the MR image in black and white?*

A: Good question! Actually, the MR image has no "colors" at all - it is a radio signal. But in order to make it visible, the computer artificially colors it. Since a single image conveys only one value at each point, we choose to assign that value to "brightness". It could also be assigned to a color, however, to make a "pseudo-color image". If you have the right software in your computer, you can change the colors to suit yourself.

The black and white choice has other bases, too. MRI is often done along with X-rays in a hospital radiology department. The doctors are used to looking at black and white x-rays, so it was natural to do MRI in the same way. Often the hard-copies are made on X-ray film, which is black and white. Finally, if we have two or more images with different contrast (T1 and T2, for example), we could combine them in a computer using different colors, to make a much more informative "false color image."

Q: The eggs seem to be small. How can their big feet, eyes and body all fit in there for 21 days? Why does the embryo absorb the yolk sac?

A: The chick doesn't "eat" anything for 21 days (and a couple more after it hatches, usually). It lives off the "fat of the land", using the yolk for energy and building materials. Eventually it all gets used up, which is a good thing, since that leaves room for the chicken. Check out the Egg Chemistry page for more about the yolk.

On May 1 (hatch day), one student shared her observation through the "scratchings":

Our chicks are starting to pip already. Some of the chicks have made little holes in their eggs.

The first chick that hatched in the class was named Vivian, and the students were very excited. In fact, the entire school was excited as more eggs hatched. Because Vivian had first pipped at 4 PM (April 30), which was after school was over, the teacher had the class look at the evidence and make a hypothesis as to when the chick may have hatched. Based on the discussions of the rest period between the first and second stages of pipping, and the teacher's description of how the chick looked when she arrived at school that morning, the class decided that Vivian hatched at 6 AM (May 1). The teacher took Vivian into her hand and shared with her students:

She went from being a few cells and in 21 days she became a chicken.

Other Classroom Activities

The kindergarten and first grade students in the primary classroom were studying the egg. Some of their activities during *Chick*Scope included the following:

- Discussions on egg-related topics: life cycles, farms, animals, eggs, chickens. For instance, the students discussed "How do chickens keep eggs [at] 99_F?" as part of a topic on chickens.
- Student-initiated projects; for instance, one group was "studying eggs and all the animals that come from eggs."
- Slice hard-boiled eggs to see how MRI would "slice" the egg. Identify the three available views (front, top, and side) on their acquired images.

- Measured the circumference and weight of different sizes of eggs (large, extra large, jumbo).
- Teacher-initiated discussion among the students on acquired images or strategies for use of the MRI. For example, "Look at quadrant F3. We are looking at the top [view]. What do you think we could do next?"
- Discussion of genetics, breeds, color of feathers, or similar topics.
- Weigh one of the newly hatched chicks to keep track of his growth (and relate this activity to the math lesson).
- In a high school advanced biology class, the project was tied into a planned unit on the reproductive system and embryology. Chick embryos¤16, 24, 48 hour slides of chicks¤are already used in this unit, so the MRI visualization was a nice complement.
- Students worked in four groups with three students per group for image acquisition. Each group had two computers: on one computer the students acquired images using the MRI control interface; on another, they reviewed chick embryo news or made "chicken scratchings." Each group acquired images one at a time so that all groups were able to participate. A television monitor connected to one computer in the lab was helpful for discussions. For instance, on one occasion, the teacher involved the entire class in identifying whether the beak was in G6 or F6 [coordinate of the image]. Two students then posted the question in their scratchings portfolio so that an expert would respond.
- Worksheets on which students identified different views on the images they had acquired previously.
- Made a video on their egg candling experience for other participating schools to review.

Impact in Classrooms

As a biology project for understanding development and reproduction, the chick embryo project was clearly very interesting. The project provided the opportunity to use the Internet, to raise chicks in the classroom, and to introduce a complex scientific instrument. However, in order to understand more fully the impact of the *Chick*Scope project in the classroom, we agreed upon the following five criteria:

1. Usefulness of MRI/Web to students for understanding chick embryo development.
2. What different modalities are available to students (e.g., MRI, "hands-on" experience)?
3. What are students learning from all this experience (e.g., scratchings, MRI worksheets)?
4. What kinds of support structure are provided to teachers (e.g., resources, access help)?
5. What are some of the unexpected events (e.g., egg problem, Web access)?

All participants were queried about the impact of the project. Some sample responses are presented below.

1. Usefulness of MRI/Web to students for understanding chick embryo development.

Although the students and teachers were very excited about participating in the project, it took them some time to get used to the complex MRI system. As one high school student pointed out:

> *I could not identify the chicks that well and I had a tough time with the views. But, as I progressed along, I found that they became much easier to find out, and I learned a lot more*

about it through time.

For the primary school teacher, the project provided different activities for her unit on eggs:

> *One thing we haven't done in the past with science is really integrate the computers very much. ... And so, what I think, this does, is just add another element into the curriculum and tie in one more part of our curriculum to our unit. So, it has been fabulous. It also helps with math skills. Certainly when we say "Look at quadrant C2,"you know, or something like that. These are math skills that they are building, which certainly ties in with our unit very well.*

2. Different modalities available to students.

To one middle school student, the project provided a new way of learning science:

> *Instead of just looking, you know, at the page in a text book, we can look actually on the Internet at the pictures of the actual egg and we get to control it. And we get to send in our discoveries and have our questions answered like faster, I suppose, and more from actual, you know, people like that are specialized in what we are doing.*

The middle school student teacher summarized the objectives for her students:

> *To interact with the Web; and to try the manipulation of the MRI through the Internet and everything; and also to physically raise the chicks in our classroom.*

For a first grade student, the project provided a way to look inside an egg:

> *You get to see what is inside the egg and you get to learn a lot about how chickens develop and those kind of things.*

In the beginning of the project, students in several classrooms (from primary to high schools) participated in "hands-on" activities, such as slicing a pickle, to become familiar with MRI vocabulary and techniques. Towards the end, the chicks in the classroom became their focal point. As another first grade student pointed out:

> *It is nice in a way to have chicks in your classroom so that you can feel the experience*.

3. Student learning.

The home school teacher observed two changes as her primary student participated in different project activities:

> *Increased ability to compare and contrast different scientific data.*

> *Increased ability to write down scientific observations and data.*

This teacher expanded the project to the theme, "How Things Grow":

> *We read library books about chicks, butterflies, and tadpoles. Then using real caterpillars and tadpoles, as well as the ChickScope images we observed first hand "How Things*

Grow."These activities in turn sparked many new questions about how other types of animals grow. The questions have prompted other observations; the scientific process continues.

Students also became emotionally attached to the chicks, which often resulted in a change in their attitudes. As one high school teacher pointed out:

Some very tough kids were very gentle and caring with the newly hatched chicks.

The teachers also found the project useful. For a high school teacher, the project "made the students think in 3-D" by "visualizing slice positions." An elementary school teacher prepared an instructional booklet as a primer to MRI for her students. This booklet will be useful to her as she repeats the unit with new students. The middle school teacher summarized the benefits for her students from the project:

My students gained knowledge about embryonic development and MRI. They learned new skills in using the World Wide Web and e-mail. My students also felt as though they were a community of learners playing an integral role in a project. They felt like respected people who were given control of an expensive machine. This control of their learning in turn provides motivation and interest towards learning science.

A high school teacher frequently led his classroom through discussions on the images since his students often asked, "How can you tell what it is there?" The students initially thought that MR images were like "photographic pictures." To help the students interpret the MR images, the teacher asked them to "anticipate" embryonic features from what they knew from the previous images (in Today's News from *Chick*Scope). The teacher shared how a student would use this approach:

I understand that this is the beak that is in there because it is starting to show up and that the next thing we should start seeing in a little bit sharper detail in a couple days might be that we can see the heart developing more because the first things that have start to develop are the head and spinal regions, and you can see those things first, and then they can anticipate that next time maybe we will be able to actually see where the heart or maybe some of the vertebra are gonna start showing up in a little more detail. So there is a sort of anticipation that comes in not only from looking at the previous images or images that were acquired and they can start to understand that it does not exactly look like a picture, but I can understand how you can look at this and see what is there now.

Another high school teacher was happy that her students improved their computer and peer tutoring skills while working on the project.

4. Teacher support available.

*Chick*Scope made extraordinary hardware, software, and human resources available to the classrooms. Starting from the teachers' training day to after the hatch day, the project staff members were always available to the teachers for educational and technical support. At the eight Champaign-Urbana sites, a university student or project staff member assisted in the classrooms during their access times. The home school received regular on-line assistance. One of the project staff members visited the rural high school outside the Champaign-Urbana area before the start of the project for a class demonstration. Additionally, both these home school and high school teachers kept in contact several times a week through telephone or electronic mail.

The project incorporated teacher feedback, when appropriate. For instance, originally the three views on the MRI control interface were labelled axial, coronal, and sagittal to represent these views. The change in labelling to front, top, and side reflected a suggestion from the primary school teacher.

Yet, even with all the support available, the task of integrating these resources into the classroom and adapting their potential to the needs and abilities of the students was left to the teachers. Thus, the implementation was teacher-based, and its meaning was realized in different ways in each setting.

5. Unexpected events (and student and teacher concerns).

As with any new project, there were unexpected moments. First were problems with the schools' computer systems. The university provided a dial-up access to the Internet for the rural high school after lightning disrupted the hard-drive on its main computer. At another high school extra MRI observation time was allocated for the students, when computers in the lab kept crashing due to systems problems. Speed was also an issue at some sites, where slow display of Web information limited the use that could be made of the on-line resources.

The complexity of the MRI system caused some initial frustrations. A high school teacher suggested limiting the MRI parameters that control the system, or providing more information on what the parameters actually do. Her students learned "it is not easy to use a machine like an MRI as it seems." One of the project scientists prepared an on-line help file for students called *Guide to Getting the Most out of MRI*. It contained advice on image acquisition strategies for the students, such as the following:

Reasons for bad images:

Field of view too small. Causes "wrap-around" and "snowy" images.

Slice too thin. Causes "snowy" images. Slice position may be unexpected if offset is more than 8 times the thickness!

Motion. Causes "blurring" or vertical streaks. Repeat the image as necessary (use the "Reacquire" link for this purpose).

Conflicting commands. If two or more requests are received at the same time, the system may switch between views during the acquisition. The result can look like a "double-exposure", or like motion.

Wrong slice position. This one is obvious!

At schools where multiple computers were available, synchronization and cooperation between groups was a problem. Often all groups wanted to acquire images at the same time, resulting in blurred or bad images. Software improvements in the MRI server are needed to avoid this problem.

Another problem that a few teachers had was synchronizing the MRI egg incubation period with the classroom incubation period. For one fourth-fifth grade elementary teacher, "this was a point of great frustration and confusion for our students." There was also the lack of time for the students to concentrate on the project. For the middle school student teacher, the lack of classroom time for doing the "chicken scratchings" prevented her students from "sitting down to actually verbalize their thoughts and realize that they have to communicate with other people in this project too."

Suggestions from the classrooms

One middle school student said that "it would be kinda neat to see where the MRI is and learn a little more about how it works." A high school student suggested additional time on the project:

> *I wish we had more time outside of the actual accessing to look and go through and really see what we were seeing*.

Several teachers are hoping to use the materials created this year by their students with their students next year. As the middle school teacher pointed out:

> *I am interested in hatching chicks again! I will supplement this by using all the data I have saved ... I would also like to use the directory of MR images that exist. Lastly I am interested in my students from this year possibly coming to my room as "experts"to help teach the new seventh graders.*

The home school teacher is interested in repeating the unit. She hopes "to also explore the differences of images obtained by the MRI compared to images viewed through a microscope."

Lessons Learned and Implications for Outreach

*Chick*Scope was a learning experience for the project personnel as well as for the teachers and students. Based on student and teacher comments, the project was well received, particularly in the lower grades because this was the students' first introduction to an Internet-based collaborative science. The four main lessons we gained from *Chick*Scope are the following:

- Students working in groups can actively participate and share resources.
- Students were more involved in *Chick*Scope when it was well integrated into the classroom curriculum plans.
- MRI visualizations provided students with an opportunity to develop spatial skills [9].
- In spite of the complexity of this technology, students in all grade levels (K-12) and settings (public, private, home school, science club) were able to benefit.
- As the use of the Internet grows in K-12 classrooms, an opportunity to provide access to tools and techniques, such as *Chick*Scope, will introduce more students to science courses and careers [10]. Implications for K-12 outreach of advanced technologies include:
- Access from classrooms should use standard computer hardware and software, such as Web browsers.
- Technology should be easy to integrate into the classroom curriculum.
- The project should be adaptable to students with a variety of learning capabilities.
- On-line interactions with experts, providing "teleapprenticeships" [11], is essential to help the students participate in problem-solving activities.

Early analyses tell us that *Chick*Scope was successful in terms of immersing students and teachers in a small scientific community. They learned much about how to collect and analyze data, how to ask questions, and how to communicate findings with others. Moreover, students had the opportunity to use advanced instruments, like those used in current scientific research, but ordinarily totally inaccessible to even well-equipped classrooms.

*Chick*Scope required unusual resources. The technologies used included the World Wide Web, e-mail, remote access of scientific instrumentation, the MRI database, and classroom incubators. Even more importantly, the project enlisted the support of college students, faculty, and staff from many departments. Such an effort is clearly unsustainable day after day for all classrooms.

Giving students a meaningful encounter with scientific inquiry is enormously valuable, but natural questions arise: What does it cost? Is the project replicable? Does the learning by teachers and students carry over to other areas?

Our purpose in this study was not to devise a program that could be replicated as is, but rather to explore what the use of these new technologies might mean for learning and how they could be employed to give students a powerful learning experience. We have only begun to answer those questions, and have not looked closely at issues of cost or extensions. Nevertheless, it is worth making a few remarks on these other issues.

One is that although remote instrumentation is today an exotic and expensive technology for schools, it is clearly becoming more a part of daily practice in research and industry. That means, one, that students may need to learn more about it because it is an integral part of doing science, and two, that as with most new technologies, it is likely to become much more commonplace and less costly in the near future. Similar comments apply to the other technologies involved, although some, such as e-mail are now already an affordable component of ordinary school activities.

Although the human resources applied to this experiment were indeed substantial, they are not as prohibitive as may seem at first look. Much of the success of the project came from coordinating school and community resources that were already available in one form or another. For example, student teachers and the science coordinator in one school contributed to the overall effort by focusing the work they would do anyway on *Chick*Scope. Similarly, writing done by students, especially those in the early grades, was an existing component of the curriculum focused on *Chick*Scope. Also, the effort teachers devoted to learning about the new technologies was something they needed to do anyway; *Chick*Scope provided a center for that learning and a support community.

We are still assessing the overall impact of *Chick*Scope and related projects. But one thing that has already become clear is that the value of it cannot be assessed purely in terms of specific content learning. If that were the only goal, there would undoubtedly be simpler ways to achieve it. But *Chick*Scope appears to accomplish an array of goals that would be expensive, if not impossible to achieve in traditional ways, such as building a support community among teachers, contributing to teachers' growth in understanding technology and science, allowing students to participate in an extended activity of serious science, teaching students deeply about important new technologies, building mentoring relationships among students at various ages, and providing convenient mechanisms for scientists to support students' learning.

Future Directions

During the 21-day *Chick*Scope project, we received inquiries from teachers nationwide about participating in the project. In most cases, the teachers simply wanted information to supplement activities that they were already doing in their classroom. For instance, an elementary teacher wrote:

> *I love your project. We are hatching eggs in our third grade class and I am looking for pictures or movie clips to clarify what is happening in the eggs. I'd love any help you could give.*

In the future we hope to develop a CD-ROM with the materials from *Chick*Scope. The CD-ROM may be shared with teachers who may not have access to the Internet. We are looking for other innovative projects for bringing state-of-the-art technology into the classrooms so that we will continue to provide valuable input to the scientific community about the impact of this technology on learning and teaching.

A key question is what specific impact does a project like *Chick*Scope have on learning. The most important changes may be on the general learning environment, in areas such as teacher attitudes, student collaborations, and computer and communication skills. Nevertheless, it is important to know whether and how participation in such a project ultimately improves students' learning.

At this early stage, we can only identify some promising points of leverage that emerged from the current study. For example, these can be posed now as questions for further research:

- How does the need for precision and full specification in the use of remote instrumentation lead to a deeper understanding of measurement processes in science?
- How does the extensive use of visualization through the Web alter students' understanding of the temporal/spatial structure of embryo development?
- How does articulation of findings that are then shared in a small scientific community change students' commitment to specific hypotheses and their ability to develop evidence to support their findings?
- Although *Chick*Scope represents an unusual approach today, current trends suggest that Web use and remote instrumentation are technologies that will become increasingly common in schools and workplaces of the near future. The particular instruments and scientific domains may change, but the basic organization of collaborative, technology-supported science investigations should be generalizable. This work should lead to a better understanding of the principles underlying this mode of learning.

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