Creating a New Physics Education Learning Environment

at

Joliet Junior College

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Reader’s Guide

Special terms appear in the Glossary. The first time one of these terms occurs in a major section, it appears double-underlined and the definition is available in a mouse-over box. (In the print version, these definitions appear as lettered footnotes.)

All citations to which the case study refers are listed in the References.

Technical asides are indicated by a numbered footnote marker and available to the reader in a mouse-over box. (In the print version, these asides can be found in the Endnotes.)

Lengthy quotes from participants that illustrate a point often are available in mouse-over boxes (lettered footnotes in the print version), for the benefit of the reader who prefers to read the participants’ own words.

Various topics introduced in the study are developed at greater length in Discussions (specified by number in the print version) to which the reader is referred via links at relevant points.

The reader is referred via links at relevant points to various other Resources (specified by letter in the print version). Among these is a short description of the Methods Used to Produce this Case Study (Resource G in the print version).

We use pseudonyms for the students who appear in the quoted material. To help avoid confusion, the researchers are identified as “interviewer” the first time their voice appears an interview segment. Lengthier quotes appear in italics.

The instructors and administrators who are identified in the case study read the document and gave us permission to use the quotes we attribute to them. These Joliet readers also affirmed that this case study conveys the essence of what they were doing in the fall of 1999.
Introduction

“We’re serving these students by teaching them physics. But more than that, we’re teaching them how to think, developing their ability to analyze complex sets of data, and developing the unique skill of separating the irrelevant from the relevant. We’re teaching in context—in a context where they try to do physics.”

Who is Curt Hieggelke?
Dr. Curt Hieggelke teaches physics at Joliet Junior College in Joliet, Illinois. He is a national leader in the development, use and dissemination of innovative computer-enhanced introductory physics teaching methods. In the last ten years, he has received nine NSF grants to pursue his work in this area. His current projects include “Two-Year College Physics Workshops for the 21st Century” (see http://tycphysics.org) and “Tools for Learning and Assessment.”

What’s he done?
A “tekkie” from way back, physicist Curt Hieggelke has transformed his introductory physics courses at Joliet Junior College into meaningful and exciting learning experiences for his students—whether they are aspiring engineers, scientists, health professionals, or non-science majors. Key to his success is the use of computer-based labs that actively engage his students through real-time acquisition and analysis of data, connections to real-world events, visualization and simulation.
Why?
For some time, Curt had been aware—and concerned—that despite the care he took to present material to his students, they were just not grasping the concepts and ideas he was trying to teach. First, he tried refining his lectures—to no avail. Gradually he came to realize that “lecture doesn’t necessarily transmit any information.”

…I became convinced that no matter how much I told them the right answer, they still didn’t pick it up; that becoming a better lecturer doesn’t have a better impact on them.

What his students needed, Curt decided, was a more active learning environment, one that encouraged—no, demanded—student participation in the learning process. Teaching in a lecture format simply was not accomplishing this. So, what would?

Well, for years Curt had been using computers in the classroom to aid in the analysis of data. In the late 1980s, however, it dawned on him that he might go beyond using computers merely for analysis and instead use them to transform the way his students learn physics. In particular, he was excited about the possibilities of using electronic probes that interface with a computer; such devices would enable his students to actually collect and analyze data themselves, fostering a predict-observe-explain learning process that Curt felt was essential to getting his students to understand—not just memorize and regurgitate—important physics concepts.

So first, Curt set about getting computers for his students (no easy task in itself). Then he searched for—and helped develop—a “second generation” of software tools that would enable the active learning environment that Curt sought for his students.

1. **Predict**—Students are given a situation or problem and are asked to predict what will happen when something is done to change that situation.
2. **Observe**—Once the change has been made, students carefully observe what happens.
3. **Explain**—They compare their predictions with what happened and explain their findings, giving reasons, particularly, for any differences between predictions and results.

More specifically, these software tools allow students to

- visualize patterns of data.
- use graphical representations in ways that enable them to avoid getting lost in the data setup and collection details that accompany most lab activities.
- experiment easily with different parameters in the same lab setup.

The first generation of computer technology was ‘do the old lab experiment and hook a computer to it and the computer would do graphing or fitting.’ The second generation demands the active engagement of students. It’s predict and observe and explain…

Students are really engaged with the experiments. After they set them up, they can interact with them and see exactly how things changed.

These tools are expressly designed to help students understand relationships between data and concepts and to engage their interest in physics.

**But it’s not just the technology…**
Along with—and equally as important as—his computer-enhanced teaching strategies, Curt has implemented other active-learning techniques such as guided group work and formative assessment activities. These activities are not computer-dependent *per se*; however, in his teaching, Curt blends computer-dependent and computer-independent activities into a synergistic framework for learning.

*The hope is that [the computer work] will feed nicely into how I am interacting with the students and how the students are interacting with each other, even when we are not in lab…*

*Now, I’m not sure if the technology in and of itself is essential to start doing this ‘elicit-confront-resolve’ approach [a variation of the predict-observe-explain approach], but it might be essential. It’s not the only reason [this approach] works, but the technology allows us to do it. And this new way carries over into the rest of our class.*

The result is a set of learning activities that reinforce each other, providing students with challenging, engaging and effective science learning experiences.

**What happens on a typical day in Curt’s classroom?**

*Curt:* What I do in the classroom is quite different because I’m not preparing a lecture. It’s very intense, because I have to be listening all the time and also thinking about the next question I want to pose to them that moves them from that point to the next point. That’s the challenging thing—trying to think ahead at the same time I’m trying to listen to what they’re saying.
Sounds great, but are the students really learning better?
In a word—yes. Posttests show that when tested on conceptual understanding, Curt’s students perform significantly better than their counterparts in traditional physics courses, as indicated by the Force Concept Inventory (FCI) results presented in Table 1, below.

The FCI, designed by David Hestenes and colleagues, is widely used in the physics community to assess student understanding of the basic issues and concepts in Newtonian dynamics (Hestenes, Wells & Swackhamer 1992). Questions are multiple-choice and are written in non-technical language, but included correct answers are attractive distracters that specifically address common-sense misconceptions about physics.

To enable consistent comparison of performance on the FCI of students from diverse institutions (from the most to the least selective), Richard Hake of Indiana University introduced an “average normalized gain” factor (Hake 1998). Hake developed what has become known in the physics community as the “Hake factor” while researching the difference between traditional physics classes and what he calls “interactive engagement” classes in terms of students' pre-instruction and post-instruction performance on the Force Concept Inventory test. The significance of the Hake factor is that it adjusts for the fact that percentage improvement is normally easier for those who start with lower pretest scores than for those who initially score quite high.

\[
\text{Hake factor} \ (h) = \frac{\text{actual gain}}{\text{maximum possible gain}}, \text{ or } h = \frac{(\text{average posttest score} - \text{average pretest score})}{(100 - \text{average pretest score})}
\]

In his study, Hake reported that 14 “traditional” courses that “made little or no use of interactive-engagement (IE) methods” achieved an average gain of 0.23±0.04 (SD), whereas 48 courses that made “substantial use of IE methods” achieved an average gain of 0.48±0.14 (SD). These numbers provide a kind of benchmark for other faculty nationally who use the FCI.

| Table 1. Joliet Junior College Physics 201, Fall 1997 – Spr 2000 (N = 68) |
|-------------------------------|-------------------------------|
| **Average Adjusted Pre/Posttest Gains on FCI** |
| **Pretest Score** | **Posttest Score** |
| Mean score | 49% | 73% |
| SD | 16 pts. | 15 pts. |
| JJC Hake gain | .47 |
| National Hake gain, *traditional* courses | .23 |
| National Hake gain, *interactive* courses | .48 |

SD=Standard deviation; N=number of students.

According to Alan Van Heuvelen, a nationally recognized physics educator at the Ohio State University’s Department of Physics, Curt’s two-year college physics students are performing as well as Harvard students in similarly taught courses.
When you plot Hieggelke’s students’ posttest results on the Force Concept Inventory along with the results of students taught by other faculty who use the interactive engagement approach to physics, his students’ outcomes compare favorably with those of students taught by Eric Mazur at Harvard University.

That’s impressive. But how do students respond to a new learning environment? Of course, tests are only one side of the achievement story. Are students willing, for example, to take charge in an interactive environment, to accept that the responsibility to learn is theirs? If Curt’s students are any indication—and we think they are—the answer is yes, many will. As a student in Curt’s Engineering Physics course put it,

A teacher may be a spoon feeder—giving you plenty of examples—but that doesn’t do it for me. I’ve got to do it myself. Watching the professor do it is not going to help. I’ve got to do it on my own…. In this course, we teach ourselves and each other.

In labs, for instance, students get their primary feedback not only from the instructor, but from the hands-on experiments and simulation-based problems that they themselves set-up and control. And they’re not only learning physics—they’re liking it, too. Students made this clear when describing their labs to us:

Nick: The computer-based exercises in the class were awesome.
Paul: There was a video camera part that was excellent—seeing the movement step by step, each frame....
Andy: Analyzing it, breaking it down by cut. Cropping them, taking them in.
Nick: We could never do that on our own. We can’t visualize it without the computer. We can’t possibly test it. But to have that was incredible. That was amazing. I loved that lab!
Steve: That was the best lab.
Nick: And that last one we did, we used a spring with a mass on it. Compressing it, and letting it go, and finding out its forward motion, amplitude, and things like that gives you a better understanding, as there is less, probably no, experimental error in that.
Susan (interviewer): So you are visualizing this? What is happening when you set up the parameters?
Paul: You are watching the compression and expansion of the spring on the computer screen.
Nick: That was cool. Yeah, we were talking about the strengths of using simulations. The three of us are working with differential equations now, so we can do them a different way. We can work on them with the simulations. A lot of things popped up in the simulation program that I hadn’t ever thought about with differential equations. Just working the problems in the chapter on differential equations [in our textbook] is not enough to pass the test. The book teaches you how to do things, how to work spring problems out. It’ll work everything out with the spring problem, but it won’t teach you exactly what’s going on with the physics. That’s not going to be enough to pass his tests. For his tests you have to know the physics and how to work out a problem. That simulation lab taught me the concepts of the physics, so from that alone I got the concept.
Curt’s students are also quick to point out the power and meaningfulness of visualizing physics concepts: how the use of technology enables this visualization and how visualization leads to new insight into everyday experiences.

_Alice:_ [As a result of this course,] I try to visualize things more.
_Maggie:_ I think of physics more. I’m doing it.
_Alice:_ Yeah. Driving down the road, I think of physics more. Like when we were doing acceleration, I link it together. I’m going up a hill, so my velocity—my acceleration—is decreasing. You think in terms of math…. Going around the curves—that acceleration thing, that’s why I don’t fly off the road. [laughter]

In short, the technology in the lab has changed the way these students understand and appreciate physics not only inside the classroom, but outside as well.

**Wow! Now, how can I get _my_ students to learn like that?**
Curt’s story may sound simple, but it’s not. The truth of the matter is, change is hard. And in this case, you can’t go about it without a plan. Through the following links, we offer you a more complete and comprehensive story of Curt Hieggelke’s—and his colleagues’—efforts to improve the quality of student learning in the hopes that his experience may serve as a guide to others.
I. The Setting

*Note: For useful tips and information on how this case study is organized, please see the Reader’s Guide.*

This case study features the learning environments (see [Resource A](#)) created by Professor Curtis Hieggelke of the Department of Natural Sciences and Physical Education at Joliet Junior College (see [Resource B](#)) for his introductory physics students. Central to this narrative are the efforts of three of Curt’s colleagues (presented below), all of whom have adapted his methods in various ways to suit the needs of their own students.

**Dr. William (Bill) Hogan** teaches physics courses for students in technical programs, as well as for students planning to transfer to four-year programs in life sciences and engineering. He has adapted many computer teaching methods for use in all of his courses.

**Dr. Marie Wolff** teaches general and organic chemistry. She was one of two faculty members chosen for the JJC Outstanding Teaching Award in 1992. She is also a member the Chicagoland Consortium to Improve Chemistry, a group that received an National Science Foundation grant to link nine two-year colleges with the NSF’s Chemistry Systematic Reform Initiative.

**Dr. Michael Lee** is Chairman of the Natural Science/Physical Education Department and President of the JJC Faculty Union. He teaches microbiology, healthy, human anatomy and physiology, and uses technology extensively in all his courses. He has also taught video telecourses and courses using interactive television for JJC’s Distance Learning Program.
The learning environments that these faculty *bricoleurs* create are informed by two key teaching principles: that faculty should

- shift major responsibility for learning from themselves to the students, and
- enable learning to occur in diverse ways.

These principles guide the JJC instructors’ choices of learning activities, such as the computer-dependent uses of hands-on experimentation, visualization and graphical representation and simulation, and Interactive Lecture Demonstrations as described in the Introduction.

The JJC *bricoleurs* use these activities in conjunction with learning activities that are computer-independent to address common problems that arise in the classroom (namely, weak student performance and student values that contrast with those of the faculty) and to achieve their goals for student learning (to develop in students a conceptual understanding of basic ideas and a lasting interest in physics). As we have seen, the results are impressive: On nationally recognized physics exams, JJC students perform at levels comparable to those achieved by students at elite four-year institutions.

Curt believes that the successful transformation of his physics courses at JJC depends, in large part, on computer-based labs.

His enthusiasm for these labs and the animated responses of his students are contagious: his faculty colleagues have adapted his methods and are even participating to some extent in the vigorous national dissemination efforts that occupy most of Curt’s time outside of teaching.

Curt combines his computer-enhanced strategies with other active-learning strategies, such as carefully guided group work projects and *formative assessment* practices, in order to foster deeper student engagement and learning. As you will find in the other sections of this study, Bill, Marie, and Mike also use these computer-independent activities with much success. All of them are finding that these diverse learning strategies reinforce each other, providing students with challenging, engaging, and effective science learning experiences.

**The introductory science courses mentioned in this study include:**

- **Basic Physics** (*Physics 100, 4 credits*), survey course for non-science majors. Includes lab.
- **Engineering Physics** (*Physics 201-202-203, 5-5-3 credits*), requires calculus and is for students preparing for engineering and science program. *Physics 201-202* are lab courses, while *Physics 203* is not.
- **Technical Physics** (*Physics 103-104, 4-4 credits*), for students in technology programs leading directly to employment.

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1. A French term for a person who is adept at finding, or simply recognizing in their environment, resources that can be used to build something she or he believes is important and then putting resources together in a combination to achieve her or his goals.

2. An activity that simultaneously (1) provides instructors with feedback about how and what students are learning, which the instructors can then immediately use to adjust and improve their teaching efforts; and (2) fosters student learning directly because the students learn in the process of performing such an activity.
College Physics (*Physics 101-102, 5-5 credits*), requires algebra and trigonometry and is for students preparing for life science programs (e.g., pharmacy, physical therapy). Includes lab.

General Chemistry (*Chemistry 101-102, 5-5 credits*), for students planning science-related careers. Includes lab.

Organic Chemistry (*Chemistry 209-210, 5-5 credits*), lab course for students planning life science and chemistry-based careers.

Human Anatomy and Physiology (*Biology 250, 4 credits*), lab course for students planning careers in the health fields.

Syllabi for some of these courses appear in Resource C.
II. Learning Problems and Goals

A. Problems Motivating JJC Faculty to Try Computer-Dependent Learning Strategies

Two key problems motivated the Joliet science faculty members to begin using what Curt calls “the second generation” of computer technology:

- student learning was low (that is, they were not developing a conceptual understanding of course topics and materials); and
- student engagement was weak.

Of foremost concern to Curt and his colleagues was the problem that students were not developing a real understanding of the material being taught; in other words, they just weren’t “getting it.” The JJC bricoleurs suggested different reasons for this.

Curt pointed out, for example, a general dissatisfaction with the lecture method of teaching: “Lecture doesn’t necessarily transmit any information. For a long time I’ve been somewhat aware of students’ difficulty in understanding physics, and I became convinced that no matter how much I told them the right answer, they still didn’t pick it up—that becoming a better lecturer does not have a better impact on them.”

Geoff White, a computer lab technician who works with Curt, observed how students come in with mental habits, perhaps learned in previous courses and other life experiences, that prevent them from understanding what science really is. For example, the students often “don’t want to predict,” Geoff said. “For me, making predictions and coming back to verify them is the crux of science. If they’re not catching that, then they’re missing a lot of what science is.”

Geoff White is the Physical Science Lab Supervisor for the JJC Department of Natural Resources. He is responsible for maintaining the lab equipment for chemistry and physics courses.

Marie Wolff, Curt’s chemistry colleague, noted that before she implemented such teaching techniques as guided inquiry or group work, students had difficulty comprehending basic reading assignments. “The students didn’t read with a purpose,” she commented, and consequently “they would feel swamped by this reading and would complain about the book being hard to read and not understandable.”

Even the students expressed similar concerns about not “getting it.” One explained, “[In typical courses, the lectures] and books tell us how to do physics problems, but they don’t tell us what we’re doing. We don’t have a clue what we’re doing.”

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3 A French term for a person who is adept at finding, or simply recognizing in their environment, resources that can be used to build something she or he believes is important and then putting resources together in a combination to achieve her or his goals.
So what did Curt do about this concern that students were not really understanding physics?
First, he looked around, nationally, and found that his students’ failure to learn in the way that he and his colleagues—and for that matter, his students themselves—want is far from unique to JJC. This insight led Curt to get engaged with a growing national network of physics educators who are experimenting—with significant successes—with new ways of achieving their goals for introductory physics students.

The faculty and the students interviewed at JJC also expressed concern about low-level student engagement. Marie articulated the idea that students these days are different—an idea that we’ve all heard faculty express in conversations recently. She believes that the media really are changing students’ attention span and that this affects the way they respond in their academic courses.

The students we interviewed gave us different reasons why student engagement might be a problem. One of the students in Curt’s Engineering Physics course explained, in so many words, that students are very strategic and will do just what they have to, and only at a pace that works for them, in order to get a degree. “A lot of people need Physics 1… to complete a degree,” this student noted, “[but] aren’t really interested in the class.”

The students in the Basic Physics course further explained that students lose their will to get deeply engaged in courses when they experience an intimidation barrier. “The class is two hours long and we do a lot of labs,” noted one student, “so people were just intimidated by long sessions that meet only twice a week. People get turned off by that.”

Fortunately, Marie and her JJC colleagues are not folks who merely observe these changes in students’ values and behaviors. They thought through their goals and began using active learning strategies—whether enabled by computers or not—to achieve these goals. And like so many other science faculty across the nation who have begun using these methods, they found that these new strategies are energizing not only their students, but themselves as well.

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4 Curt: One of the historical problems in teaching physics is revealed in the Hestenes Force Concept Inventory. The FCI is a well-known test published in the early 90’s. It’s famous for very simple questions that all instructors predict all their students will get perfectly, but which they get wrong. For example, Eric Mazur, a well-known professor at Harvard, was stunned at how poorly his students performed on the FCI. Students get confused about some of the most basic ideas about forces. They don’t understand motion. They think it takes a force to keep something moving.

I think everybody agrees that the FCI covers stuff that everybody should cover and that we all assumed our students did know…. People found that they had students who in a formal classroom could get these questions right. Like on Newton’s Third Law, if you ask the students, “If object A exerts a force on object B, does object B exert a force on object A, and if so with what magnitude and direction?” They can rattle off the correct answer. But confront them with a baseball bat hitting a ball, or people having a tug of war, or something using more natural language, and students immediately abandon their classroom learning. Their perceptions didn’t change—they revert back to their intuitions.

5 Marie: I think it is getting more difficult to hold the students’ interest, because they are so used to a lot of action in the videos that they watch and in the movies that they see. Nowadays things are always happening, and I could be wrong, but I really think that their attention span is not quite as long now as when I first started. So if you don’t get something that grabs their interest during the course of the class, they get bored and lose interest.
B. Learning Goals the JJC Faculty Seek to Achieve
The specific learning strategies employed by the JJC *bricoleurs* were strongly influenced by their goals for student learning. In particular, they wanted students to:

1. develop *real* conceptual understanding of the material presented;
2. develop insight into how scientists “know what they know;”
3. develop analytical and problem-solving skills;
4. develop greater awareness of technical terms.

Bill Hogan, Curt’s physics colleague, stepped back from the particulars and gave us a “big picture” answer to our question about goals for student learning. He wants to develop in students a lasting interest in physics:

> My big goal is to contribute to a person’s education in a way that makes a difference. In other words, if my contribution is a significant one, it goes way beyond this semester. It is going to last, it is going to inspire the students, give them a foundation or basis for being interested and for understanding these topics.

Like educators everywhere, the *bricoleurs* at JJC want to foster deep learning and life-long learning skills in their students. They want to challenge students to think about science analytically, to develop thought processes that enable them to connect the classroom world to the real world, and to build a "foundation" that will endure "far beyond one semester."

For an in-depth discussion of teaching goals, see *Getting Students to Make the Connection: A Discussion of Curt’s Teaching Goals*.
III. Creating the Learning Environment

The JJC bricoleurs are among the growing number of faculty who are designing their courses as learning environments. To meaningfully examine these learning environments, we first consider the relationships between the problems and the goals that motivate the bricoleurs to create alternative learning environments:

The JJC bricoleurs are able to choose from an array of learning activities to achieve these goals. Their specific choices are, in general, guided by two underlying teaching principles:

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6 A learning environment is a place where learners may work together and support each other as they use a variety of tools and information resources in their pursuits of learning goals and problem-solving activities (Wilson 1995).

7 A French term for a person who is adept at finding, or simply recognizing in their environment, resources that can be used to build something she or he believes is important and then putting resources together in a combination to achieve her or his goals.
The JJC faculty give highest priority to the first teaching principle—shift major responsibility for learning from the faculty to the students. This entails actively engaging students in a set of mental processes that allow the students to restructure and add to what they already know. The JJC *bricoleurs* effect such processes using curricula based on “predict-observe-explain” or “elicit-confront-resolve” (a variation of predict-observe-explain) models.

That the JJC faculty are very committed to the second teaching principle—enable learning to occur in diverse ways—is evident in their decision to provide various ways of learning in each course. This principle is important to them because it helps “level the playing field” for students who may have a high capacity to learn, but who are not inclined to learn by listening to and reading largely abstract material. As Bill Hogan puts it, these are the students who are “learning because of the things we do.”

The JJC *bricoleurs* have not only chosen a set of introductory principles that they believe are most important for their students to understand (as exhibited by their course syllabi); they have also chosen a set of learning activities that “weave together”—that is, that work synergistically—to achieve their goals for student learning (see *Learning Goals the JCC Faculty Seek to Achieve*). As with all the case studies appearing in the LT² site, the activities are organized into three categories:

1. **Computer-dependent activities** that faculty believe simply would not be possible, or at least not feasible, without computers.
2. **Computer-improved activities** that faculty believe work incrementally better with technology but can still be implemented without it. (The JJC faculty did not give us examples of this type of activity.)
3. **Computer-independent activities** that can be done without technology.

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_The hope is that [the computer work we are doing now] will feed nicely into how I am interacting with the students and how the students are interacting with each other, even when we are not in lab... that these parallel activities will feed into each other.... Now, I'm not sure if the technology, in and of itself, is essential to start doing this “elicit, confront, resolve” approach. But it might be essential. It’s not the only reason it works, but the technology allows us to do it, and this new way carries over into the rest of our class._

--Curt Hieggelke

Below, we provide information on the synergistic set of learning activities that the JJC *bricoleurs* use to create their effective learning environments.

**A. Computer-Dependent Learning Activities**

The JJC faculty employ three learning activities in ways that would not be possible without what Curt calls the “new generation of computer technologies that demand active engagement of the students.” These activities are:
• **Hands-on experiments** (real-time hands-on acquisition and analysis of data using electronic probes, and computer interfaces to provide connections to real-world events). The instructors require the students to undertake hands-on experiments in which they use electronic probes or other electronic input devices, such as video cameras, to gather data. Students then feed this data into computers, where it is converted into digital format. Students then use graphical visualization software to make sense of the data they are analyzing.

• **Visualization, graphical representation, and simulation.** Once students understand the relationship between the data-gathering and analysis activities, the JJC faculty can provide their students with software-enabled exercises that help them visualize, graphically represent, and simulate the principles at work in physical systems.

• **Interactive Lecture Demonstrations (ILD).** ILD activities depend on both a computer-sensor projection system and the fact that students have begun to develop, through the hands-on experiments, an understanding of the relationship between data-gathering and analysis activities. The computer-sensor projection system allows all the students to observe the graphs being generated while a professor carries out a demonstration. Throughout, the professor engages the class by asking students to predict what’s going to happen to the graphs on screen. Students then watch what actually happens and are asked to explain what happened and why.

(See *We can do things with a computer that years ago took hours to do: Faculty Discuss Computer-Dependent Learning Activities.*)

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*I read it, and then I see it, and then I know it.*  
--Joan, Basic Physics Student

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For Joan, and for other students, these computer-dependent activities provide clear illustrations of concepts that might remain murky if the students were to rely solely on "reading the book and answering questions." The students we talked with explained how even the most mundane activities they took part in outside of class reminded them of concepts they’d learned in their
physics labs. For years, science teachers have been assigning hands-on experiments—with and without the help of computers—in an effort to "convince students that what we talk about in class is true" and to force them to "predict, observe and explain" the data with which they're presented. As science students and faculty from Joliet explain, however, the effectiveness of such experiments has greatly increased since instructors have begun using computers in a “second generation” way.

(See *The labs are incredible, absolutely incredible: Students Discuss Computer-Dependent Learning Activities*.)

B. Computer-Independent Learning Activities

The JJC *bricoleurs* do not rely solely on computer-dependent activities, of course. They also incorporate activities that are computer-independent: primarily, formative assessment and group work/guided discussion. Throughout, we pay attention to how the faculty synergistically integrate all their learning activities.

1. **Formative Assessment**

Curt places great importance on the use of formative assessment tools as learning activities. He believes that these activities are critical in directly fostering learning and in providing faculty the information about student learning that instructors need in order to constantly adjust and improve their teaching strategies. The formative assessment activities Curt uses fall into two general groups: pre-/post-tests that have been developed recently by physics faculty around the nation and a set of activities that he calls “Tasks Inspired by Physics Education Research” (TIPERs).

**Pre-/Post-tests** To be sure, Curt uses these pre-/post-tests for both “formative” and “summative” purposes (Glossary). When he uses them formatively, his purposes are to:

- foster learning by forcing students to “really think” and making them “hungry to know;”
- provide instructors with information about student knowledge that they can use to fine-tune their teaching.

Importantly, Curt and other faculty who use these formative assessment activities include them only sparingly in their course grading scheme: the “hungry to know” state of mind requires a low stakes environment, one in which it is safe to make mistakes.

(For specific examples of assessment activities, see Resource D, Pre- and Post-tests Used by Curt for Formative Assessment.)

By contrast, when Curt uses these pre-/post-tests for summative assessment, his purposes are to:

- foster learning;
- obtain performance data on which to assess individual student grades;
- help students achieve “closure” and a sense of confidence on each of the physics topics they are learning.

---

8 An activity that simultaneously (1) provides instructors with feedback about how and what students are learning, which the instructors can then immediately use to adjust and improve their teaching efforts; and (2) fosters student learning directly because the students learn in the process of performing such an activity.
The first purpose—to foster learning—is shared by formative and summative assessments, but the other two purposes are unique to summative assessments. Summative assessments are “high stakes” for students—they determine grades. They also provide intellectual closure, whereas formative assessments are designed to make students feel uncertain and ready to adjust their view of reality. Curt attempts to achieve his third summative purpose—help students achieve closure and confidence—during the discussion period he holds when he returns students’ graded exams. He uses this time to help the students develop their capacity to correctly assess what they do and do not know, and to develop techniques for addressing the weak spots in their knowledge. He also believes that his exam review process is very important because physics is a very sequential discipline, and students need confidence in their understanding of earlier material in order to proceed successfully to the new topics.

**Tasks Inspired by Physics Education Research (TIPERs)** Curt also places great importance on the use of a second category of formative assessment activities, which he calls “TIPERs” (Tasks Inspired by Physics Education Research). In his opinion, a number of physics education researchers have asked research questions that provide good insight into students’ reasoning processes. Their questions focus on important physical concepts and scientific reasoning skills that students in math-based physics courses need in order to develop a functional understanding of key physics concepts. The intent of this research, Curt explained, is to develop insights that can help faculty more successfully enable students to solve problems with understanding.

These education researchers found that students enter introductory college physics courses with beliefs about the way the physical world behaves that are often only partially consistent, at best, with beliefs substantiated through physics research. The physics education research also has established that it is very difficult to modify some of the typical beliefs that students hold and has ascertained through experimentation that certain methods of teaching are more effective than others in getting students to make the appropriate modifications. In particular, this research provides evidence that instructional approaches that

- compel groups of students to confront inconsistencies between their beliefs about physical phenomena and how physical phenomena actually are, and
- require the students to make predictions, argue with each other, test their ideas, and make coherent explanations

lead to more productive learning.

Having learned of this research, it occurred to Curt that many of the learning tasks or formats that these education researchers had designed in order to pursue their research questions could be used effectively as formative evaluation activities in his course. These tasks could do double duty—as classroom “tasks inspired by physics education research” (TIPERs). He uses these tasks to introduce, teach, clarify and review a wide range of concepts and believes this practice builds robust learning.

The different types of TIPERs Curt uses and the sources from which he developed them are listed and described in Resource E. (Some of these use computer technology.) More details about the TIPERs can also be found at [http://tycphysics.org](http://tycphysics.org).
Curt has found that students adapt quickly to the format of TIPERs. The Ranking Tasks, for example, require students to provide fill-in-the-blank responses, explain the reasoning they used, and rank the level of confidence they have in their answers. Often during class, he asks his students to work on Ranking Tasks or other TIPERs individually on paper and then compare their work with a few others or the class as a whole. Sometimes, instead of asking students to work independently on paper during the first stage, he will present a problem, ask them to think about it, and then poll them or ask for a show-of-hands. He then asks the students to explain why they made these choices, and eventually (with some coaching) they come to the correct consensus. To achieve the “hungry to know” purpose of these activities while also encouraging students to take the TIPERs seriously, Curt sometimes allocates a few points in his grading scheme to these tasks.

Curt calls TIPERs “one of the power tools for learning:” they provide a good means to ask questions in different ways and to ask very similar questions that are interrelated—processes that he considers especially valuable in implementing all his “active” learning activities (whether computer-dependent or independent). He has observed that students like these tasks—they know that they learn a lot from them. Moreover, TIPERs are easy for faculty to use. They do not take a lot of additional time to administer and are easy to analyze because patterns in student responses are easy to spot.

Curt’s rationale for using TIPERs is entirely “formative.” First, TIPERs force students to make their reasoning evident, thereby providing the instructor with useful information about what the students do and do not understand. He uses this information immediately to decide how to interact with the students that day and in subsequent class sessions. Second, the process of completing the tasks encourages students to engage in the predict-observe-explain learning sequence that is so central to Curt’s teaching philosophy.

(See We have to know where students’ problems are and not where we think they will be: Curt Discusses Formative Assessment Activities.)

It appears, based on the student testimony, that TIPERs (all of which the students referred to as “Ranking Tasks”) involve a “pushing” factor that is critical to the learning process. They get students to think hard about a concept that is genuinely puzzling, which pushes them out of their comfort zone and makes them feel unsettled and confused. Thus, as they begin working on a topic in class, they already have their wheels spinning on the subject and are much more likely to get actively involved.

(See Once you do the task, you learn it: Curt’s Students Discuss Formative Assessment Activities.)

2. Group Work/Guided Discussion
Curt, Bill, Marie, and Mike use group work activities both with and without computers. By requiring their students to work together on all their labs, they integrate small group work with their computer-dependent lab activities: hands-on experiments; visualization, graphical representation and simulation; and Interactive Lecture Demonstration. (When we described these activities in the Computer-Dependent Learning Activities section, we did not highlight the group
work elements.) In so doing, they make a virtue out of what might have been viewed as a resource “problem”—that the number of computers in the labs is two to three times smaller than the number of students in the class. Curt has designed the computer-based labs to function synergistically with group work.9

When the class meets in a regular classroom, Curt uses guided discussion activities that are so interactive, it is difficult to distinguish them from “group work.” The activities essentially demand active participation from all the students. (We suspect that it would be very difficult to implement group work and guided discussion at the same time with more than 20 students in the class.) Primarily, the group work/guided discussion activities that Curt uses consist of:

- requiring all the students to provide a response to a pre-test or TIPER question, round-robin fashion;
- asking students to take turns solving and presenting problems at the board in a Socratic mode (an activity that the students dubbed “cooking”);
- using a more free-flowing format in which he forces the full group to grapple with hard questions that he won’t answer for them. In such a format, students are encouraged to speak freely and to spiritedly disagree with each other.

In addition to the group work/guided discussion initiated and sustained by the JJC faculty, there is group work that the students themselves organize. As the students see it, there are two approaches to group learning, both of which entail students teaching students:

Susan (interviewer): You said before that you "teach it to others." What type of student-to-student teaching is going on?
Steve: Basically two different types. A lot of us get together in the mornings before class and crunch to finish the homework, and then afterwards we turn in what we have done. Then in class, he wants us to go up to the board and present it to other classmates and show them the way we did it. That way, you know that there are variations as to ways you can do it, different concepts you can look at.

The JJC faculty recognize that group work is critical to designing an effective constructivist learning environment for two main reasons: it gets students to teach each other, and it helps them to feel safe enough to participate actively in class. One thing essential to the success of their learning environments is that students must not be too apprehensive about contributing the ideas and explanations that instructors are trying to help them develop. If they are too shy or not very confident, they will be inhibited from participating. Group work, according to the students and staff we interviewed, diminishes these inhibitions. It lowers the intimidation factor because it helps students take charge of their own learning.

9 Curt: Generally what you see in the lab when you’re using the computers is that students do really focus on the task in front of them, and it gives them something in common to talk about. The level of what they’re doing is different than when we set up the labs in the past, where their big question was, “What do the instructions tell us to do next?” They’re not trying to follow instructions. As a matter of fact, today the students, who are so used to not following instructions, got in trouble because they tried to skip ahead. But they were able to talk and analyze about what’s going right, what’s going wrong, and so forth. And I think that’s what you see in all the classes. It’s a different type of teaching strategy.
IV. Summative Outcomes Data

When you plot Hieggelke’s students’ post-test results on both the Mechanics Baseline and the Force Concept Inventory along with the results of students taught by other faculty who use the interactive engagement approach to physics, Hieggelke’s students show as much if not more gain.

--Alan Van Heuvelen (The Ohio State University Department of Physics)

The JJC faculty are striving to make learning meaningful by concentrating on teaching concepts rather than focusing on repetition of formulas and laws. This philosophy also shapes their summative assessment practices. Curt explained, for instance, how many flawed assessments test only the students’ ability to regurgitate facts without challenging their true knowledge of the subject. His view, which is widely shared, is that having students who can rattle off Newton's Third Law without really understanding it does not constitute evidence of meaningful learning. Summative assessments should instead say something about a student’s deeper understanding of these basic laws of physics. Moreover, faculty who are trying out new learning activities intended to help students achieve meaningful understanding can use the results of these tests to gauge the success of their new approach.

Accordingly, Curt uses a number of tests, some of which are used nationally, that are designed to assess conceptual learning in physics. Below he briefly describes the various exams he gives and the results of those tests.

*Curt*: Now those tests I mentioned, I give those to all my classes—whether it’s the liberal arts conceptual physics course, the algebra-trig based course, the course for allied health students or the physics course for engineering students—because they all have components of what I expect them to learn. I use a set of tests at the beginning of the semester. During the semester they take tests that other people have developed . . . and then the final exam. I’ve extended my final exam from two hours to four. They schedule exams for two-hour time blocks, so I get two of these blocks and give my students some of those assessment tools in those time slots.

*Susan (interviewer)*: Do you have any data from the various classes that show, in national comparisons, how well your students are learning? Something about the value-added?

*Curt*: Yeah, my data show rather strong gains.... The problem, which [large] universities don’t face, is that I have particularly small classes. So I have to add all those classes together to get a statistically significant picture.

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10 A formal examination or test, the results of which faculty use to demonstrate in a way that is definitive and visible to people outside the course the degree to which students have accomplished the course’s learning goals.
Because class size at JJC is small, it is difficult to obtain statistically significant information from these assessments on a semester basis. However, Professor Alan Van Heuvelen (The Ohio State University Department of Physics), a national expert in this area, informed us that,

When you plot Hieggelke’s students’ post-test results on both the Mechanics Baseline and the Force Concept Inventory along with the results of students taught by other faculty who use the interactive engagement approach to physics, Hieggelke’s students show as much if not more gain. His students’ outcomes compare favorably with those of students taught by Eric Mazur at Harvard University, Paul D’Alessandris at Monroe Community College, and Tom O’Kuma at Lee College.

Below we list the names and acronyms for the summative assessment tests that Curt uses and indicate how, and in which physics courses, he uses them. [Note: These tests are the same as those described in the section on formative assessment, where we presented formative assessment as a learning activity. In Resource D, we provide brief descriptions of these tests and information about how to obtain them. Clearly, Curt uses these tools for both formative and summative assessment purposes.]

1. Maryland Physics Expectations Survey (MPEX); Pre/Post-test in Physics 100, 201, 202
2. Force Concept Inventory (FCI); Pre/Post-test in Physics 100, 201
3. Force and Motion Conceptual Evaluation (FMCE); Pre/Post-test in Physics 100, 201
4. Testing Understanding of Graphs – Kinematics (TUG-K); Post-test in Physics 100, 201
5. Mechanics Baseline Test (MBT); Post-test in Physics 201
6. Vector Evaluation – Tools for Scientific Thinking (TST); Post-test in Physics 201
7. Heat and Temperature Conceptual Assessment (HTCE); Post-test in 201
8. Conceptual Survey of Electricity and Magnetism (CSEM); Pre/Post-test in Phys 202
9. Conceptual Survey of Electricity (CSE); Pre/Post-test in Physics 202
10. Conceptual Survey of Magnetism (CSM); Pre/Post-test in Physics 202
11. Determining and Interpreting Resistive Electric Circuits Test (DIRECT); Post-test in Physics 202
12. Electric Circuit Conceptual Assessment (ECCE); Pre/Post-test in Physics 202

Note that Thornton, Sokoloff, and Laws have developed Items 3, 6, 7, and 12. Much of the data obtained using these tests has been collected to help inform the development of the computer-based MBL lab materials that they have produced. Curt and Bill use these tests because they have adapted many of the Thornton, Sokoloff, and Laws lab materials for their courses.

The Maryland Physics Expectations Survey (MPEX, Item 1) is not a test, but rather a survey that attempts to measure students' attitudes before and after taking a physics class. It asks students to assess the degree to which they agree with statements such as, "Physics is relevant to the real world." Published data for this instrument indicate that students tend to agree with this statement before a standard physics course (usually calculus-based) and tend to disagree with it after having completed the course. This outcome is not what most physics professors seek to achieve. MPEX outcomes for JJC physics students go against this trend.
The Force Concept Inventory (FCI, Item 2), and the Force and Motion Conceptual Evaluation (FMCE, Item 3) tests measure related and somewhat overlapping conceptual areas. The FCI and FMCE deal with kinematics and Newtonian thinking. Questions are multiple-choice and are written in non-technical language, but answers are included among attractive distractors that specifically address common-sense misconceptions about physics. The FCI is widely used, and data on student performance on the FCI are available from scores of courses at various institutions across the nation.

To enable consistent comparison of performance on the FCI of students from diverse institutions (from the most to the least selective), Richard Hake of Indiana University introduced an “average normalized gain” factor (Hake, 1998). As noted in the Introduction, Hake developed this factor, which has come to be known in the physics community as the “Hake factor,” while researching the difference between traditional physics classes and what he calls “interactive engagement” classes in terms of students’ pre-instruction and post-instruction performance on the FCI. The significance of the Hake factor is that it adjusts for the fact that percentage improvement is normally easier for those who start with lower pre-test scores than for those who initially score quite high.

\[
\text{Hake factor (h)} = \frac{\text{actual gain}}{\text{maximum possible gain}}, \text{or} \\
\text{h} = \frac{\text{average post-test score} - \text{average pre-test score}}{(100 - \text{average pre-test score})}
\]

Hake reported that 14 “traditional” courses that “made little or no use of interactive-engagement (IE) methods” achieved an average gain of 0.23±0.04 (std dev), whereas 48 courses that made “substantial use of IE methods” achieved an average gain of 0.48±0.14 (std dev), almost two standard deviations above that of the traditional courses (from 1998 article abstract). These numbers provide a kind of benchmark for other faculty nationally who use the FCI. Curt is using the Hake factor to establish average normalized gains on other tests, as well (as explained below).

At JJC, the FCI results for students in Curt’s Engineering Physics course (Physics 201) vary a great deal from semester to semester, in part due to the very small class size. However, averaged over six semesters (Fall 1997 - Spring 2000), their Hake factor is 0.47 for the FCI (Table 1, below), which is comparable to the average Hake gain nationally for interactive engagement courses. The Hake factor for the same students on the FMCE, to which Curt has added several questions dealing with momentum is 0.62.
Table 1.
FCI and FMCE Test Results for JJC Physics 201, Fall 97 – Spring 2000
(Number of students=68; SD=Standard Deviation)

<table>
<thead>
<tr>
<th></th>
<th>FCI</th>
<th>FMCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Test</td>
<td>Post-Test</td>
</tr>
<tr>
<td>Mean score</td>
<td>49%</td>
<td>73%</td>
</tr>
<tr>
<td>SD</td>
<td>16 pts.</td>
<td>15 pts.</td>
</tr>
<tr>
<td>JJC Hake gain</td>
<td>.47</td>
<td>.62</td>
</tr>
<tr>
<td>Nat’l Hake Gain – Traditional Course</td>
<td>.23</td>
<td>n/a</td>
</tr>
<tr>
<td>Nat’l Hake Gain – Interactive Course</td>
<td>.48</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Table 2 provides data on how Engineering Physics students performed on three post-tests:
- Testing Understanding of Graphs – Kinematics (TUG-K, Item 4), which considers kinematics only.
- Mechanics Baseline Test (MBT, Item 5), which claims to measure problem solving and was developed by the authors of the FCI to measure problem solving in Newtonian mechanics.
- Heat and Temperature Conceptual Assessment (HTCE, Item 7), which measures special aspects of physics courses (not widely used, and little published data are available).

Table 2.
TUG-K, MBT, and HTCE Test Results for JJC Physics 201, Fall 97 – Spring 2000
(Number of students=68; SD=Standard Deviation)

<table>
<thead>
<tr>
<th></th>
<th>Post-TUG-K</th>
<th>Post-MBT</th>
<th>Post-HTCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean score</td>
<td>80%</td>
<td>60%</td>
<td>70%</td>
</tr>
<tr>
<td>SD</td>
<td>16 pts.</td>
<td>14 pts.</td>
<td>17 pts.</td>
</tr>
</tbody>
</table>

Table 3 provides data on how Engineering Physics students performed on three pre/post-tests:
- Conceptual Survey of Electricity and Magnetism (CSEM, Item 8)
- Conceptual Survey of Electricity (CSE, Item 9), and
- Conceptual Survey of Magnetism (CSM, Item 10).
Table 3.
CSEM, CSE, and CSM Test Results for JJC Physics 202, Fall 97 – Spring 2000
(N=Number of Students; SD=Standard Deviation)

<table>
<thead>
<tr>
<th></th>
<th>CSEM</th>
<th>SCE</th>
<th>CSM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Test</td>
<td>Post-Test</td>
<td>Pre-Test</td>
</tr>
<tr>
<td>Mean score</td>
<td>28%</td>
<td>61%</td>
<td>35%</td>
</tr>
<tr>
<td>SD</td>
<td>13 pts.</td>
<td>17 pts.</td>
<td>15 pts.</td>
</tr>
<tr>
<td>N</td>
<td>46</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>JJC Hake Gain</td>
<td>.45</td>
<td>.47</td>
<td>.44</td>
</tr>
<tr>
<td>Nat’l Hake Gain</td>
<td>.25</td>
<td>.20</td>
<td>.29</td>
</tr>
</tbody>
</table>

Finally, data for JJC Engineering Physics students on two more tests are shown in Table 4:
• Electric Circuit Conceptual Assessment (ECCE, Item 11), and
• Determining and Interpreting Resistive Electric Circuits Test (DIRECT, Item 12).
These tests measure student learning in the area of circuits and focus on basic concepts and
difficulties that students typically have.

Table 4.
DIRECT and ECCE Test Results for JJC Physics 202, Fall 97 – Spring 2000
(N=Number of students; SD=Standard Deviation)

<table>
<thead>
<tr>
<th></th>
<th>DIRECT</th>
<th>ECCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Test Post-Test</td>
<td>Pre-Test Post-Test</td>
</tr>
<tr>
<td>Mean score</td>
<td>66%</td>
<td>35%</td>
</tr>
<tr>
<td>SD</td>
<td>14 pts.</td>
<td>20 pts.</td>
</tr>
<tr>
<td>N</td>
<td>57</td>
<td>.43</td>
</tr>
<tr>
<td>JJC Hake Gain</td>
<td>n/a</td>
<td>.59</td>
</tr>
</tbody>
</table>

Bill’s students show gains for algebra/trig-based College Physics course that are comparable to
these presented here for Curt’s Engineering Physics students. These gains provide evidence that
Curt and Bill are achieving their goals for student learning.

(For evidence of positive gains in student attitudes, see *The labs are incredible, absolutely
incredible: Students Discuss Computer-Dependent Learning Activities.*)

(For more in-depth discussions of the assessments tools used by Curt, see *We have know where
students’ problems are and not where we think they are: Curt Discusses Formative Assessment
Activities* and *One you do the task, you learn it: Students Discuss Formative Assessment
Activities.* )
V. Implementation

It’s important to keep in mind that implementing the kinds of changes that Curt and his colleagues made requires hard work, planning, and access to good resources. During our interviews with Curt, Bill, Marie, Mike, and Geoff, we explicitly asked “how” questions, such as:

- “What kinds of new resources did you need?”
- “What were the nitty-gritty tasks and problems you faced when you were just getting started?”
- “How did you deal with the stresses that come with change?”

We also asked them for advice they would give to others who are about to embark on this path—things they would have appreciated knowing before they got started. Drawing on their responses to these questions, we present JJC faculty insights and advice on how to implement the kind of learning environments they have developed. We start with resource issues, which can pose major problems for many faculty. We then consider processes that the JJC bricoleurs believe are crucial for getting going.

We will also consider a set of issues that have more to do with the cultural factors that shape faculty teaching practices. We have chosen to organize these latter issues under the header, “Managing the Dissolution of the ‘Atlas Complex’.” We take this term from a useful article entitled, “Teachers and Learning Groups: Dissolution of the Atlas Complex,” written by Donald Finkel and Stephen Monk (1983). Finkel and Monk use this term to identify a constellation of implementation issues that are experienced by nearly all the faculty we know who are seeking to help students take more responsibility for their own learning.

A. Resources

JJC instructor comments and advice on resources are divided into two sections: personal resources and institutional resources. Personal resources address the “internal” qualities or personality traits needed to implement these innovative learning environments. Institutional resources deal with “external” necessities—money, space, time, software, and support staff.

1. Personal Resources

We were drawn to the faculty bricoleurs at JJC because of the initiative, leadership, and creativity they showed in turning to new combinations of learning activities—some of which are computer-based—to address concerns about their students’ academic performance and values. We wanted to know what it took for them to get started and then keep going down this path. One way JJC people answered us was to describe certain personality traits. In broad brush strokes, they painted a picture of people who enjoy innovation, are willing to take risks, and have vision, tenacity, energy, enthusiasm, and self-confidence. These features are consistent with those identified as characteristic of “innovators” (or “pioneers”) and “early adapters” in research on the diffusion of innovation.61

Enjoy Innovation. We noticed that the words toys and gadgets surfaced occasionally when Curt, Bill, Marie, or Mike described themselves or each other. Mike, for example, describes himself as “a gadget person and a computer sort of person.”
Scott, the campus web-master, waxed eloquent about the obvious delight that Curt takes in trying new things. “Curt really likes the toys and trying new and different things,” he told us. “When he sees new things at a conference, he comes back saying, ‘Can we implement this, can we do this?’” Scott also mentioned how “Curt’s desire to try new things” led him to create alliances with several companies, thereby participating in an emerging information-age practice called “creator/consumer blurring.” This enabled them to work with prototype equipment, equipment that “wasn’t available anyplace else.” As Scott put it, “We ended up essentially beta testing this equipment and adapting it into the curriculum.”

**Willing to Take Risks.** People who take pleasure in trying new equipment are easier to find, however, than people who are willing to take substantial risks in the way they use this equipment. Mike pointed out, for example, that faculty “are so used to being the authority that we tend not to wander into areas that we are not comfortable with.” It’s therefore imperative that, in order to initiate change, people be “willing to make the effort and willing to go through the learning curve that [they] have to go through…to learn to use the technology and learn the applications and learn to supplant what they already do with the improved things that you can do with technology.”

**Have Vision, Drive, Enthusiasm, Tenacity, and Self-confidence.** JJC people had much to say about the importance of being a person of vision; that is, someone who thinks of possibilities and imagines better alternatives. Curt believes that that vision is something easily ignited in early adapters, if only they are exposed to the new possibilities. But vision may not be enough. Drive and enthusiasm are also required, as are good health and a high energy level. As he put it, “[Because] there are some challenges when you implement, you need to have a high energy level. People probably typically don’t say that. You should be in fairly good health because if you’re sick and so forth, it really can be difficult to do all the extra work.”

Vision, drive, enthusiasm and health are still not sufficient, however, especially for the pioneers. As J.D. Ross, the president of JJC, pointed out, implementation also takes “creativity and hard work.” Curt, he explained, “had some wonderful ideas, but frankly, they would have never been

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11 Curt’s description of how he first got started using computers in the classroom illustrates what it means to have this visionary skill: “We had this idea that computers were going to make a big difference. So we bought an Apple II. We had to get it from two hundred miles away because there were no Apple dealers within driving distance. We started using it in our offices and in our classes, but one computer for all those students really didn’t make much sense. So we started doing what we called “demos” with it. We bought a sonic motion detector, and in a course like the Physics 100 class for non-science students, we set up a little motion detector experiment where some students were moving back and forth in front of the detector, and we were seeing and explaining the graphs of their motion. And then I could see that power of it for students in real use. And I could see that power of it in real use: besides crunching data and getting an average or fitting data or something like that, they could actually learn from it.”

12 Curt: You need enthusiasm and drive. The pioneers have more drive, and have a vision that this is something really worthwhile and is doable. The barriers for pioneers and early adapters are different, [so they] need different energy levels to deal with them. A pioneer, for example, may be turned down but won’t take no for an answer, whereas an adapter can have a great idea and get turned down or the equipment or computer isn’t good enough, and that will be it. Less energy is required for the mainstream adapters, because a lot of the bumps and kinks have been worked out. But all adapters are still making changes. They have to realize that change takes time and energy.
implemented if he had relied solely on institutional resources. He needed to go out and seek the grants to make it happen.”

J.D. Ross’s remarks about creativity and hard work point clearly to another very important characteristic: tenacity.13

The JJC people we talked with emphasized one more very interesting personal characteristic that early adapters need: self-confidence. Geoff, who provides technical support to Curt and Bill, astutely observed that adapters must have confidence that their way of moving down a path of innovation, while different than the pioneers’, is also good. “Adapters,” he explained, “can’t take their esteem from a pioneer like Hieggelke.”14 Bill echoed this, commenting on how important it is for adapters to feel comfortable putting together their own version of the innovation and developing their own “innovator’s voice” that is independent of that of the pioneers. “I’ve gone through the workshops that Curt holds, to see what can be done,” he explained. “You start, you get more comfortable, you modify things on your own, you don’t do some of the things, you know. And this makes you feel a lot more comfortable.”

2. Institutional Resources
The JJC faculty advised us, based on their experience, that it would be helpful if we passed along information and advice on institutional resources. “You need support from the administration, support from the department, and support from instructors and the students,” said Mike. Getting that kind of support “is difficult, and the full transition is going to take a lot of time because there are a lot of impediments to it—economic, personality, and administrative impediments.” For the complete discussion of the types and importance of various institutional resources that the JJC bricoleurs found necessary and how they procured them, see Discussion 6.

13 Curt himself holds some pretty strong views on the importance of tenacity. He feels that you have to be the kind of person who is so committed to and dogged about your vision that you are “bulletproof” to set backs and can view challenges as learning experiences: “I use this term ‘bulletproof.’ I don’t know if you’ve heard this term before in what’s called direct marketing, like Amway. To be bulletproof is to expect difficulty. If you go up to someone and say, ‘Do you want to buy some Amway soap?’ they’re not going to want to hear about that stuff. You have to be bulletproof to their reaction. There are going to be ‘disasters,’ in a sense, and you have to realize that tomorrow is another day. I mean, there’s never really a disaster, it’s a new challenge often with a learning experience. That’s what I mean by being bulletproof.”

14 Geoff: As an early adapter, you have to have an outside sense, something else that’s telling you that what you’re doing is right. And you have to look at the way Dr. Hieggelke treats himself. I’m around here enough to know the way he drives himself, and he’s driving you. He’s not expecting anything from you that he’s not expecting from himself. And when I first started working, it was like, “He wants me to do everything and there’s no way I can do all this!” And then I look, and I’m like, “He’s trying to do everything, and there’s no way that he can do all that.” He’s not being unfair in that sense.

Bill is able to hold his own in terms of Curt being so vocal and out there. I mean, Bill is also involved in the Illinois Association of Physics Teachers, and he’s been to the national meetings and so forth. Curt’s been trying to drag him to those things, and Bill has taken on some of them. But he says, “I’m not going to be like you. I’m not going to be gone as much” and so forth. It seems like it’s a heavy price. He spends a lot of time on it, Curt does. I think Bill recognizes that he can’t do that, just in terms of who he is.
B. Processes for Getting Going: How Not to Reinvent the Wheel

No less critical than personal and institutional resources is knowledge about how to actually implement innovative learning activities in your courses. We know that every faculty member develops his or her own style and will only rarely simply “adopt” a new approach—this characteristic of faculty is one of the greatest strengths of higher education. At the same time, we suspect that, with respect to knowledge about how to implement new learning activities, the vast majority of faculty innovators and early adapters end up “reinventing the wheel,” and that, quite frankly, is a poor use of faculty time and effort. With this point in mind, we asked the JJC bricoleurs for their advice on “getting going.”

1. Establishing Faculty Learning Groups: Workshops and Networking

The JJC bricoleurs all knew that, without opportunities to network with faculty peers while implementing new computer-dependent and computer-independent learning activities, they would have struggled more and probably been less successful. All of the faculty strongly advised others to start this networking process by attending workshops, as workshops offer valuable opportunities to get your hands on the hardware and software as well as to network with colleagues.

Marie noted that “the more you can network with people, the better off you are.” She has been working with a group, under an “Adapt and Adopt” NSF grant, to adapt Modular Chemistry materials. “It is sometimes hard to start something brand new on your own,” she pointed out, “where nobody else in the school is really interested. But when you are working as part of the group, like I am right now with some of these other community colleges, you get a lot of support to go ahead and do something. And then, even if there isn’t anybody at your particular school to discuss the issues with, you have somebody else to talk with and that has made a big difference.”

Bill had much to say, as well, on the benefit of networking: He explained that getting involved in a community of folks across the nation who are trying out these new approaches keeps him motivated.15

Curt, too, is very clear on the value of workshops. He recommends that “the first thing faculty interested in these methods need to do is go to a workshop to get some preliminary experience with the technology.” But, he quickly added, it can’t be just any workshop. The workshop should be “something more than a day long—so you can get some hands-on experience. You have to make sure that you’re not just watching someone else demonstrate it. You have to do it yourself.” Curt told us that professional development workshops for faculty “have to be hands-

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15 Bill: The point of the “Two-Year Colleges for the 21st Century” grant [TCY21, an NSF grant to the American Association of Physics Teachers] is to build a network for two-year college physics teachers. In addition, Curt and Tom O’Kuma have this NSF grant program [to Joliet Junior College], “Two-Year College Physics Workshops,” where they go to a place and people come in and spend four days learning how to use MBL [Microcomputer-Based Labs] and some of the MBL microcomputer-based tools. There’s an MBL2 workshop for electromagnetism and rotation labs. They also do a workshop on simulations using Interactive Physics—a Knowledge Revolution product, and other things. We [the TYC21 network] get on a more personal level with folks from Moraine Valley and Prairie State who have all been here. They say, ”I am thinking of getting this,” or they’ll send e-mails to each other—“What kind of machines do you guys have?”
on, not demo,” because “faculty members are just like students” —they need to have the participatory experience.16

For a lengthier discussion of the merits of networking, both nationally and locally, see Discussion 7.

2. “One Thing at a Time”
Geoff, who for years has been observing the way Bill and Marie have adapted methods from Curt, observed that “the adapters tend to pick things up a little bit at a time.” Curt developed on Geoff’s point, explaining that if you are just getting going, it is wise to alternate learning to use new technology with changing your curriculum, rather than to work on both simultaneously. For this alternating strategy to work, however, it is necessary to have good, tested curricular materials that you can rely on while in your “focus on technology” stage. “That allows you to focus more on implementing the technology,” Curt explained. “Then you come back and deal with curriculum materials, after you’ve got the technology under control.”

In other words, trying to do too much, too fast—trying to learn new technologies and processes while concurrently implementing them into a curriculum—can be overwhelming. Curt points out that “today, implementers have a chance to take some other materials and use them and then adapt them.”

Marie told us how she is doing just that. Initially, she focused on how the availability of technology-rich curriculum materials that were tested by colleagues whom she trusts has really helped her get going with these new methods. Using tested materials can work well, once you understand these new methods, even if you don’t have the chance to try them out in workshops. “We have been able to buy a workbook,” Marie explained, “where the lessons are set up and all we have to do is adapt them a little bit to our needs and pick out what we want to do. It works great because a lot of times, in two-year schools, we have pretty big class loads so there is not a lot of time to develop your own handouts and those kinds of things.” Moreover, she continued, using tested materials gives you “an idea of how other people are doing things. This helps if you don’t get a change to go to a lot of meetings to learn how to actually implement these methods.”

Now Marie is focusing on technology, rather than on curriculum. She is able to do this not only because she has access to good curricular materials that work with the technology, but also because she has adjusted to the shift away from the use of lecture. In the past, when she relied heavily on lecture as a teaching method, “I focused on my presentation—what the content was,

16 Curt: I think these workshops are important because they give people the chance to do it themselves. Often times people say, “Well, we’ll get Priscilla Laws to come in or Lillian McDermott, or someone who gives a really nice talk, and we’ll change our physics department.” You’re not going to. Change only comes when someone says, “Look, come into this room, sit down at the computer, and try this.” You are only able to do the change by doing, because unless you’ve done something, you’re not going to necessarily believe that it can be done…. Faculty members are just like students when it comes to change. They have to have the experience.

Faculty members may feel more secure because they understand the science, so the technology is less of an obstacle. But they have to see how the technology can enhance the teaching, and enhance the learning of their students. So try to go to a workshop where there’s no more than two or three people per computer. Two is better than three when you’re learning how to use this stuff because you need the hands-on real experience.
making everything as logical as I could, maybe simplifying some things.” In implementing technology into her teaching, however, her focus has changed:

"Now when I prepare, what I focus on is, “Is this web site going to work for me? Am I going to be able to access the right part of the CD-ROM when I do this demonstration?” So I spend more preparation time making sure that I can effectively use the technology than actually preparing the content. And I think maybe part of that, too, is that I have been doing the content for such a long time now that it is not as much of an issue. More of my preparation time is spent looking for different ways to use the technology and making sure it is going to work if I do use it a particular way.

C. Managing the Dissolution of the “Atlas Complex”

A growing number of science, math, and engineering instructors are acting on the conviction that their courses need to be designed in ways that help students take more responsibility for their own learning. This is the first teaching principle that informs the JJC bricoleurs’ decisions about which learning activities to use in their courses. Having the necessary internal and external resources isn’t all you need to implement these new activities. In addition, you must be willing to forego old patterns and try new ways of interacting with your students. Most faculty and students—including those featured in this case study—bring to their courses complex assumptions about teacher and student roles, plus a whole set of social and psychological habits associated with these roles, that present formidable barriers to implementing this teaching philosophy. Donald Finkel and Stephen Monk summed it nicely with their phrase, the “Atlas complex” (see Resource F).

Encouraging students to take more responsibility for their own learning requires faculty to relinquish some responsibility—in other words to abandon the notion that they must, like Atlas, bear the weight of the entire classroom world on their shoulders. Breaking out of the Atlas complex involves a willingness to step aside from the authority and power of center-stage and a desire to empower students. It requires asking questions instead of providing answers, listening instead of talking, and feeling comfortable with student confusion instead of rushing to fix things. Below, Curt describes the challenges he faces as he makes the transition from “expert provider” to “guide on the side”:

_Curt:_ I’m also applying alternative types of learning strategies in the classroom, like Ranking Tasks and some of the other things we do, when students go to the blackboard and have to explain what they’re doing and so forth in sort of a Socratic dialogue. What I do in the classroom is quite different because I’m not preparing a lecture. It’s very intense, because I have to be listening all the time and also thinking about the next question I want to pose to them that moves them from that point to the next point. That’s the challenging thing—trying to think ahead at the same time I’m trying to listen to what they’re saying. The real difficulty for me is that sometimes I’m trying to get something out ahead and I don’t pay close enough attention to the students, so I have to have them repeat [a comment] or clarify it. And they don’t necessarily repeat it—sometimes you hear them change what they said.

_Susan:_ There’s an accidental learning opportunity, right?

_Curt:_ Right. For a faculty member trying to do this, one of the challenges is to realize that you have to not just give the answer all the time. You’ve got to be willing to give [power]
over to the students. You saw me go around the classroom asking, “What do you think? Does anyone want to explain why, compared to what someone else said?”

**Susan:** I saw a little bit of twisting in the wind there.

**Curt:** Yeah. Because I want people to have the chance to think for themselves and wrestle with ambiguity, because most of the time things aren’t necessarily black or white.

**Susan:** You didn’t give them any clues either. You’d hear one answer and you’d sort of nod and the next would speak and you’d sort of nod and what they said was different.

**Curt:** Right, I was trying to be noncommittal because I want them to be willing to say why they think they’re right, not what they think I want to hear.

Both students and faculty at JJC struggled as the faculty worked to dissolve the bonds of the traditional learning roles. As Finkel and Monk suggest, it is difficult for faculty to step aside from their role as central figure in the classroom and to relinquish full responsibility for all that goes on in a course. It is equally hard for students, for they have spent a lifetime as recipients of the information provided by “experts” who evaluate student mastery of a body of knowledge by assessing how well they give it back on exams. Rarely are students asked to be active, to challenge an instructor, to make connections among disparate ideas and to apply information in creative ways. When they are suddenly required to do so, they often resist. It is no surprise, then, that Curt’s effort to shift the focus of his class away from himself isn’t always appreciated or understood by students. Here, one of the students describes Curt’s efforts to elicit participation from every student in the class and their subsequent confusion, while a second student talks about seeking help from another instructor because of his frustration at Curt’s reluctance to provide answers.

**Nick:** He focuses more on the concepts than the mathematics…. A lot of times he won’t just say the right or wrong answer. Instead, before class he’ll give little experiments that show us about force or other physics concepts. He’ll make a presentation about it, and then he’ll ask us questions about it, and we’ll be confused. If there are discrepancies in the class, he’ll ask everybody about it, and then he’ll prove it by doing something.

**Andy:** Several times I went to him before class and asked him a question, but he never really helped with it. So I’d ask my physics teacher or my differential equations teacher—he helps me more than anything. He’ll show you the dynamics of the problem and stuff whereas Dr. H is just [not as willing to do that]… even during office hours…. That kind of irritates me. It’s different when you come in just one-on-one for help and you don’t get it.

No teaching approach is going to work for every student all the time. At the beginning of the following passage, some students express similar complaints they have about Curt, who is reluctant to spoon feed answers to them, even when one-on-one. The students feel that the one-on-one venue should be the place where instructors provide quicker relief for their frustration than they do in the classroom. However, by the end of the passage, Nick and Steve reveal their awareness of Curt’s teaching philosophy and express how that philosophy guides his one-on-one interactions with them. It is clear from Steve’s final comment that even shy students, for whom speaking up doesn’t come easily, ultimately discover that they need to commit themselves to taking intellectual risks, because doing so provides a more fruitful learning experience and is “a good way to think.”
Paul: Doctor H. is very reluctant to give one-on-one assistance. His approach is that if you’re going to learn it and it’s going to stick, you’ve got to figure it out by yourself.

Nick: I made an appointment with him once. He worked out some problems with me but only as long as I did the problems. He would go through and say, “Now here’s what you did wrong.” But he wouldn’t just sit down and work problems out with me.

Andy: We waste a lot of time going around the classroom, to be honest with you, because we have no pull on the question. He’s like, “What do you think?” And we’ll just go around, “Yeah, I agree. No, I don’t agree.” None of us knows the answer. We’re just guessing. It’s better for the professor to just come out and say it and we write it down and learn it.

Nick: I think he just wants us to form an opinion and think about something, analyze what we’re doing, form an opinion right or wrong, just say it. And then we’ll find out the right answer.

Steve: If you go further in engineering, it’s not up to the teacher, it’s up to the student. If you can’t sit down and check on your own, you’re going to need to make some changes. If you’re somebody who has a more passive personality, you’re just going to sit back, wait and see. But you can’t do that. I have a more passive personality, and it made me commit. It made me see thought processes. Even if you get the wrong answer sometimes, it still may be a good way to think. You have to be an independent learner.
VI. Summing Up – You have to be an independent learner.

It is clear from this comment, made by a student who described himself as someone who used to just “sit back, wait and see,” that the Joliet Junior College bricoleurs have begun to transform their own roles as teachers—and consequently, their students’ roles as learners. In designing new environments for introductory college physics, chemistry, and biology, they have stayed true to the first teaching principle that informed their efforts: teachers should shift major responsibility for learning from the faculty to the students. It is evident from the summative outcomes data that the computer-dependent lab work and the computer-independent formative assessment and group work/guided discussion activities used in these leaning environments have enhanced student performance in JJC science courses. These activities have, more importantly, transformed the way JJC students learn.

JJC bricoleurs rely relatively little on lectures as a learning activity. Instead, they encourage active participation, design hands-on experiments, ask challenging questions, and give students time to wrestle with ambiguity. The students responded clearly to these activities. The JJC students we interviewed talked explicitly and animatedly about the fun they had in labs, the way they were able to apply concepts learned in class to experiences they had outside it, and the value of student-to-student teaching. They clearly conveyed excitement about their learning. It seems to us is that these students experienced a transformation both in the way they learn and in themselves—their physics course clearly left them more curious, self-confident, and resilient learners.

Likewise, the JJC bricoleurs who teach these students reaped benefits. Seeing student performances improve, they felt that their efforts to teach were rewarded. Instead of spending hours preparing a lecture only to realize that the students “don’t have a clue” what’s going on, they saw in student engagement and heard from student comments that they “get it.” In addition, when these faculty networked with colleagues on campus or across the nation, they found energy to continue trying new strategies, in addition to finding information and support. Finally, the faculty gained intellectual stimulation when they adapted technology to meet the learning goals they have for their students. We must point out, however, that these benefits were earned through hard work, commitment, and willingness to take risks.

In sum, the transformation of science courses at JJC has provided meaningful and exciting learning experiences for students and faculty alike, as well as impressive student outcomes. This transformation depends on the JJC faculty’s synergistic use of second-generation software tools that foster a predict-observe-explain learning process, and computer-independent formative assessment and group work/guided discussion activities that encourage students to struggle with new concepts and to participate and teach one another.
Discussions

1. Getting Students to Make the Connections: A Discussion of Curt's Teaching Goals

2. We can do things with a computer that years ago took hours to do: Faculty Discuss Computer-Dependent Learning Activities

3. The labs are incredible, absolutely incredible: Students Discuss Computer-Dependent Learning Activities

4. We have to know where students’ problems are and not where we think they will be: Curt Discusses Formative Assessment Activities

5. Once you do the task, you learn it: Curt’s Students Discuss Formative Assessment Activities

6. The JJC Faculty Discuss External Resources

7. This networking thing can be critical: More Reflections on Networking
1. Getting Students to Make the Connections: A Discussion of Curt’s Teaching Goals

Curt is someone who has given careful thought to his goals for student learning. When we asked about his goals, he began with his “physicist” goal: help students understand relationships, connect concepts with the real world, and develop true conceptual understanding. He emphasized how this last goal does not include skill with computation, but does include “ah-ha!” experiences about what is actually happening in specific situations.

**Curt:** One goal is to make them aware of some of the basic laws of physics, and how those laws connect their world to the physics world.

**Susan (interviewer):** Okay. This is the context thing you were talking about before.

**Curt:** Right—that they can see that physics is relevant to their world. I’m not expecting them to compute things. By and large it’s, “Can you explain what’s happening? Are you aware of what’s happening?” The lab is a great place then for them to build their understanding, because it doesn’t take a lot of mathematics to explain what’s happening. They can say, “Oh, this is happening here, or that’s happening there.” So they get a really good understanding of the physics underlying the world they live in. I’m not talking about the computational stuff, not the mathematical equations. It’s about the relationships. It’s what I call basic conceptual understanding. Now that’s my goal as a physicist.

Interestingly, one of Curt’s students captured this first goal precisely when we asked, “What do you think the professor’s goals are for what you should be learning in this class?”

**Nick:** I believe he wants us to learn how to apply our knowledge in situations, not necessarily the mathematics part of being able to do it, but rather the interpretation of raw data from the environment. He wants us to know what to look for and how to apply it.

**Susan (interviewer):** So it is mostly about applying rather than about the abstract concepts?

**Nick:** Correct. You’re given variables, and you want to understand what these variables are and what you are going to do with them. It’s not so much “A plus B equals C” type mathematics, but rather the everyday, “How do you apply this? And if you do this to one thing, what is going to happen to the other?”

When asked to characterize Curt’s goals for students, Scott Olson, a top-level information technology administrator at JJC, also focused on Curt’s first goal—and was quick to note how technology can help to achieve it.

**As I can understand it, he is trying to create a conceptual type of environment where you have reality and then you can conceptualize how that reality exists and build from there. Computers can actually create that conceptual environment for you—it is kind of a unique way of presenting the information. What Curt is doing is really taking the traditional material and actually giving a whole new dimension to it.**

Curt’s second goal is one that could easily be shared by all science faculty and pertains to how scientists “know what we know”:
The second goal is to give them some insight or some feeling for how we as scientists know what we know. Oftentimes the public is confused when they hear two scientists coming in on opposing sides, because they think science has one answer. There are limits to what we know and how we define what we know. So there’s this matter of how do we know what we know.

Curt’s third goal—develop students’ capacity to “think about things” by developing their ability to analyze data—could be embraced by academics in all disciplines, ranging from theater to theoretical physics. As Curt explains it, this analytical and problem-solving skills goal involves helping students acquire that "unique skill of separating the irrelevant from the relevant," and developing problem-solving strategies that can be used in all walks of life.

*Curt*: The third goal is to have students gain some skills for analyzing data—that is, the general process of how you deal with data and how you analyze it.

*Susan (interviewer)*: Whether they’re looking at economic data in the newspaper or physics data or whatever?

*Curt*: Yes. For example, I’ve got this little chip thing from Micron Technology where they give the area in number of millimeters, and they tell you how much memory there is in this chip. The students can actually calculate the memory density for that. It’s a little more of a technology project, but it’s the idea of, “Can you apply what you’ve learned to other places, besides just to science questions?”

We’re serving these students by teaching them physics, but more than that, we’re teaching them how to think about things, and developing their ability to analyze complex sets of data and developing the unique skill of separating the irrelevant from the relevant. We’re teaching in context—in a context where they try to do physics. So in the future they may not measure a magnetic field, but they will understand and be able to use the concept of how you make measurements. They will have strategies for how to do this. They’ll transfer learning from the physics class to other areas.

Last on Curt’s list of goals is the matter of developing greater awareness of technical terms, which he quickly acknowledged is a goal that ties back to developing conceptual understanding (his first goal).

*There is also a language goal. In their everyday terminology, people use words like “energy” and “power” and words like “momentum” and “force” as interchangeable terms. I want to try to refine their understanding of how key terms really should be utilized. And part of that deals with conceptual difficulties, too. Because when you communicate, the conceptual difficulties are inherent in the language and their understanding. “What does that mean? What does ‘uniform electric field’ mean? Does that mean it’s constant?” So there is this language difficulty.*
2. We can do things with a computer that years ago took hours to do: Faculty Discuss Computer-Dependent Learning Activities

In discussing the benefits of computer-dependent activities, the Joliet instructors explained that computers enable students to:

- engage in the predict-observe-explain process that is essential to good science;
- repeat experiments;
- get an immediate response to their experimental conclusions; and
- focus more on learning concepts than on doing calculations.

They observed that without the capacities provided by computers, students tend to get sidetracked by technical detail. As a result, the meaning—the heart of what is exciting about science—gets lost. These instructors believe that when labs are properly tailored to address students' conceptual difficulties, aren’t too automated and keep student interest, students learn physics in a meaningful way.

Bill believes that he can achieve his goals for student learning by using hands-on experiments that employ technology in a “second generation” way. These hands-on experiments clarify the material students are learning because they force students to use the "predict, observe, explain" approach, as opposed to the "read, write, figure it out" tactic. By using technology to help conduct these experiments, students learn much more efficiently because the technology allows instructors and students to address "idea after idea" rather than dwell on one problem for an extended period of time. Bill explains:

＞We use a lot of Tools for Scientific Thinking and Real Time Physics from the Laws group. I would call it “guided inquiry.” It’s not “here’s some stuff; figure it out.” Are you familiar with what we call the “predict, observe, explain” approach? You ask students to write down what they think will happen. You make them do it so it does happen. And then you have them explain why it happened. The hope is that we’re changing their whole intuition in a way that reading about physics never could, and the technology allows us to do that on idea after idea, instead of doing it on only one idea a week.

Helping to change student intuition, Curt believes, is the main function of computers in today's classrooms. He said that the first round of efforts to use computers involved merely taking over the busy work, whereas now the purpose of computers is to encourage small groups of students to "gather, interpret, and analyze" data, helping them learn to distinguish which data are relevant. As he put it:

＞Computer-based methods help them gather, interpret, and analyze what they’ve got. It helps them discriminate good data from bad. We [instructors] forget that we’re experienced. We can look at graphs and say, “Well, the relevant part does this,” and throw away the irrelevant. Students quite often, in the past, couldn’t tell the difference.

＞The first generation of computer technology was “do the old lab experiment and hook a computer to it, and the computer would do graphing or fitting.” The second generation demands an active engagement of students. It’s predict and observe and explain. That’s
what an MBL--microcomputer-based laboratory\textsuperscript{17}--does: two or three students, by themselves working at a computer, interacting with what they see the sensors reading. Students are really engaged with the experiments. After they set them up, they can interact with them and see exactly how things changed.

Curt moved without a pause from this description of how “second generation” computer-based, hands-on experiments work to a description of how another computer-dependent activity works. While different, both activities are designed to foster new “predict, observe, explain” habits of thinking in his students. He continued:

We also use Interactive Lecture Demonstrations, a term Ron Thornton uses. It’s the idea of using a computer projection system to carry out a demonstration so that you can ask, “What do you think?” You can ask students to predict what’s going to happen, and then do it, and have them explain what happened. The idea is to have them engaged in what they’re seeing. In contrast to the MBL, the Interactive Lecture Demos involve the whole class, where you poll the students on the question.

Linking formulas to theories, mathematics to ideas, and information to meaningful concepts are the key outcomes that these faculty seek by using computers to get students to predict-observe-explain (that is, think for themselves). This is not to say that such outcomes can be achieved only with the use of computers. Curt explains:

I also still do low- or no-tech labs. There are some things that you can do just as well without any technology. In fact, it’s nice to do things without technology. We do a thing balancing and weighing a meter stick. They’re given one weight and by using torques, they can measure the mass of the meter stick. I require them to come within two grams or so, and the students find out that they have to be very careful in taking their measurements. Often, in the MBL technology, the difficulty of having a good careful number is not established. Now that’s fine, but I think it’s also nice for them to see how well they can get a result without using [computer] technology. So I like to blend non-tech activities with the technical ones. In fact, one reason I got these desks is because I wanted them to be able to do desktop activities. And see all those boxes we have back there – batteries and bulbs and so forth? They do labs right in here. They just bring a box over and start hooking up circuits and so forth.

However, technology has the advantage of providing immediate results to experiments that, in the past, required time for setting up materials, making graphs, and taking care of other technical details.

Because MBL technology allows learning to take place immediately, it provides freedom from the "tyranny of tedious calculations" and lets you "strike while the iron is hot," according to Bill.

\textsuperscript{17} A lab that involves the use of (1) electronic probes or other electronic input devices, such as video cameras, to gather data that students then feed into computers, which convert the data to digital format and which students analyze using graphical visualization software; and (2) a learning cycle process, which includes written prediction of the results of an experiment, small group discussions, observation of the physical event in real time with the MBL tools, and comparison of observations with predictions.
His force experiment based on crashing carts used to involve cumbersome materials, the set up of which distracted students from the point of the experiment. Since he started using the technology, technical details no longer come between classroom learning and its connection to real world data. He explains that the technology “brings learning home” for his students because they are able to see results of their experiments right away.

The technology brings learning home for them because how else could you measure these forces in a meaningful way? What you can do is use probes and measure force as a function of time. We can have two carts, one loaded up with mass, one with nothing on it. Based on some work we do beforehand, they are well convinced by this point that the probe on each one measures the force on that cart. Then they slam them into each other, and they can see the graphs. They can line them up in time and they can see, despite the fact that the forces are non-constant, they are equal and opposite. They have an odd shape with two cars hitting each other, a really odd shape—nothing to something along an odd curve—and it’s not even very predictable. They can see these curves are exactly equal and opposite, and they also do the experiment very quickly.

You strike while the iron is hot, while they are doing a lot. The old way of doing this, you could do it with students pulling spring scales; but, by nature, they can’t be doing something with real change. It can’t change quickly or else you can’t read it, so it’s not realistic. The other problem is, to do anything more realistic with some older methods takes so long that students have forgotten the point.... The whole point is to free yourself up from the tyranny of the tedious calculations, to talk about ideas and to get quick feedback in the lab.

Mike, the department chair and a biologist, agrees that complex mathematical calculations and excessive time between experiment and analysis inhibit students from "making the connection."

As for the computer technology and application, I don’t buy into computer applications for their own sake.... It should be appropriate technology. For instance, the lab that I wrote a while ago allows me to do EKGs on a student—resting EKG, exercising EKG—and then to analyze the tracings. We can do things with a computer that years ago took hours to do. And if you were teaching an undergraduate class, you probably didn’t do it, because it just took so long, and frankly it took math skills that were probably beyond most of the students.... So what do you do? Do you take time to teach them trigonometry, or do you throw up your hands and give them the answer?

Using the computer-based applications attaches consequences to behavior and attaches those consequences quickly. I think that is another thing in education that matters—the immediate feedback of getting readings quickly, the immediate result of this EKG, rather than taking it home for hours and laboring over it and maybe not making the connection.

Geoff, the lab technician, also addressed the importance of students’ getting an "immediate response" to the predictions they make. He explained that, without the computers, this valuable immediate response would not be possible.

I see a lot of learning that wouldn’t happen without the technology, in particular with the motion detectors and so forth, where the labs are set up so that the students make a
prediction and then try it out to see if it works. They get an immediate response, and they
can determine whether they have made a correct conclusion. Those sorts of things weren’t
possible when I was a student. I would do a lab and come up with a value, but I wouldn’t
know if it had any significance or not. I didn’t have any way of knowing if I had an
understanding that was going to be useful. So I see that as one of the big things with the
technology – being able to ask students to predict what’s going to happen, and they get to
try it out and see if they’re right, and if they aren’t, they can go back and say, “This isn’t
right. I need to rethink what’s going on here.”

Curt’s style of instruction relies heavily on students' ability to get quick results from the
experiments they do. He emphasizes the need for students to learn from their mistakes and often
intentionally allows them to travel down the wrong path to make them realize those mistakes.
Technology is indispensable to the success of this teaching approach.

Curt: This is part of what we can do with a computer that we couldn’t do before—the
computer can visualize the data for them, put it in a graphical form so they can see it. In
the past, they would take data and then graph it two or three days later. The problem was
that they couldn’t go back and repeat it very easily if there was a problem with it. As you
saw today, they could repeat an experiment really quickly if there was a problem.

Susan (interviewer): And also, I actually heard a number of students say, “Oh that’s
what went wrong,” or “That’s what we did wrong.” So they were learning from their
mistakes.

Curt: Right, in the past, we couldn’t afford to have them make mistakes, because they
wouldn’t see that they’d made them until two or three days later.

The JJC faculty emphasized that computers “work” for their students, not only because they
provide freedom from tedious calculations and enable quick results from experiments, but also
because they enable them to see things graphically. For example, Marie explained that the
technology gives her students a more intuitive feel for the experiments they are doing than
traditional equipment ever could. Her calorimetry experiment, a favorite among students,
involves determining the number of calories in peanuts and other foods. She says the experiment
meant more to students when they could see temperature increases graphed on a computer
screen, even though a thermometer could show those same increases.

I think their lab experience [analyzing real data on the computer] has made a difference.
I think the favorite experiment of Chem 100 and 101 students is the calorimetry
experiment, that we get from Vernier Software, where they determine the number of
calories in a peanut or some piece of food. We tried to do the same thing in a lab bench
with thermometers or calorimeters, but when we started using the temperature probes
connected by the interface to the computers, they could see the temperature increase on
the screen. When they could see it graphically, it actually meant something to them. Now
you would think that they would have had the same basic lab experience while watching
the temperature go up in a thermometer—that they would understand that temperature of
the water goes up when the food in the water absorbs heat—but that didn’t seem to
happen as much. So that one computer experiment is the absolute favorite. Even people
in my second year classes talk about that experiment fondly—how they thought it was so
wonderful. We try to increase the number of those kinds of computer-type experiments as they go through general chemistry, because I really think that their lab experience is enhanced by the experiments where they can use interfaces.

Bill also emphasizes the value of connections to the everyday world and feels that one of the biggest instructional hurdles is "convincing [students] that what we talk about in class is true" and not simply a series of laws and equations to be memorized and repeated. Like Marie, he stresses "the ability to think graphically" as an integral part of this process.

One problem I face is convincing them in lab that what we talk about in class is true. So there are the two fronts we’re fighting on: there’s tying this to the real world—making it more real, so they can actually see it, have a good picture—and there’s trying to get them to think graphically. For example, although I talk with the students about the laws of motion in class, I mainly focus on these concepts in the lab. Now, I could use the air track labs, circa 1980 technology: the point of these labs is to clarify and to make the laws of motion more real to students, and they do tie the book work to the real world. But I use the motion sensors and software packages instead, because these also help my students develop the ability to think graphically, which is a skill that can be carried beyond my class.

Mike recognizes technology’s ability to make science meaningful, as well. In one experiment, he gets smokers from his class to volunteer to do a resting EKG, pulse rate, and breathing test before and after smoking a cigarette. The computer then graphs the results, visually demonstrating how nicotine affects the heart and lungs.

Mike: Students get muddled in the math and miss the whole point. With the computer hardware and software we have, we can do those tracings and do multiple tests at the same time. We can, for instance, do pulse rate, EKG, and breathing tests all at the same time, and put the data together in one graph on the computer.

Susan (interviewer): So instead of understanding the workings in terms of the mathematical details, they are able to get an understanding of the relationships?

Mike: And the concepts. For instance, we still have students who smoke, so one of the things you do in a physiology class is call in a volunteer and, I’ll be darned, you always get a couple of the smokers to do a resting EKG. You get their data on a graph with the breathing apparatus, send them outside, let them smoke a cigarette, and then have them come back and do the same thing over again. So now you’ve got the increased pulse rate, the increased blood pressure, the increased EKG, and you can see them all in one nice table.
3. The labs are incredible, absolutely incredible: Students Discuss Computer-Dependent Learning Activities

The two groups of students whom we interviewed spent considerable time discussing the power of visualizing physics concepts: how the use of technology enables this visualization, and how visualization leads to new insight into everyday experiences. In our view, the positive outcomes these students described attest to the degree to which the JJC faculty are achieving their goals for learning.

Students in Curt’s Basic Physics course explained that the technology in the lab has changed the way they relate to things outside of class.

Alice: [Because of this course,] I try to visualize stuff more.
Maggie: I think of physics more. I’m doing it.
Alice: Yeah, driving down the road, I think of physics more. Like when we were doing acceleration, I link it together. I’m going up a hill, so my velocity, my acceleration, is decreasing. You think in terms of math…. Going around the curves, that acceleration thing, that’s why I don’t fly off the road!
Maggie: When you turn to the right, it actually lifts the left; when you turn to the left, it draws the front end down and makes it easier to turn, so if you want to turn at high speed, turn from the left. [laughter] That’s something that’s not necessarily in the book – how it works like that. That’s what I like about lab; it gives you that concept. How do you find exactly what that is? You’ve got to figure that out on your own. To me, I think that’s the whole class in a nutshell. I love the labs. The labs are incredible, absolutely incredible!

In response to our question about whether the technology used in the course affects their learning, this same group of students commented on the hands-on experiments they have done. Most of these experiments entailed the use of data-gathering probes that feed into a computer, which is programmed to help students analyze the data rapidly.

Maggie: I think the physics class makes you understand what happens when you turn your car and why you go against the outside. It makes you understand what you take for granted and why that’s what happens. You understand why, and I think the technology shows us more, hands-on, why things happen.
Joan: I think the same thing. You just take some things for granted. Before I thought, “It’s just some spins, and you get slammed to the outside.” Now we understand why that happens. To me it’s just visualizing. It’s right there in front of you instead of looking at a picture in a book. You can see exactly how it happens.

Below, four students from Curt’s Engineering Physics course bring out a number of factors about the use of “second generation” technology that help them understand the scientific concepts that are central to their course. These factors are (1) visualization, (2) freedom from tedious calculations, (3) getting quick results from experiments, (4) making graphic the relationship between data and concepts, and (5) simulation. That the students experience these factors as all intertwined is evident in this insightful segment of conversation.
Nick: The computer-based exercises in the class were awesome.
Paul: There was a video camera part that was excellent—seeing the movement step by step, each frame....

Andy: Analyzing it, breaking it down by cut. Cropping them, taking them in.
Nick: We could never do that on our own. We can’t visualize it without the computer. We can’t possibly test it. But to have that was incredible. That was amazing. I loved that lab.
Steve: That was the best lab!
Nick: And that last one we did, we used a spring with a mass on it. Compressing it, and letting it go, and finding out its forward motion, amplitude, and things like that gives you a better understanding, as there is less, probably no experimental error in that.

Susan (interviewer): So you are visualizing this? What is happening when you set up the parameters?
Paul: You are watching the compression and expansion of the spring on the computer screen.
Nick: That was cool. Yeah, we were talking about the strengths of using simulations. The three of us are working with differential equations now, so we can do them a different way.
We can work on them with the simulations. A lot of things popped up in the simulation program that I hadn’t ever thought about with differential equations. Just working the problems in the chapter on differential equations [in our textbook] is not enough to pass the test. The book teaches you how to do things, how to work spring problems out. It’ll work everything out with the spring problem, but it won’t teach you exactly what’s going on with the physics. That’s not going to be enough to pass his tests. For his tests you have to know the physics and how to work out a problem. That simulation lab taught me the concepts of the physics, so from that alone I got the concept.

Interestingly, these same students expressed the idea that simulation makes concepts real, sometimes more effectively than hands-on experience, because computer visualization isn’t prone to “experimental error.”

**Steve:** There was a simulation for oscillatory motion with a mass on a spring being compressed and stretched—and that was all computer-generated simulation.

**Nick:** We told the computer certain facts to make it generate what was supposed to happen...

**Susan (interviewer):** How do you know the simulation was accurate?

**Nick:** It has to be, just given the data. You take the data, and you have to interpret what happens; you have to do certain calculations. Instead of spending time setting up the spring lab and doing stuff and recording the data, we spent all that time thinking about what was going on. That was a great lab!

**Andy:** Yeah, the simulation lab cut out a lot of that setting up time and—

**Nick:** If we could have a simulation lab with every single thing, just through the Internet or a computer, I’d live off it.

**Susan (interviewer):** But wait a minute, you were just saying you liked being able to see the ball thrown.

**Nick:** Yeah, but once again we were using a camera to video record, then we put it on the computer.

**Susan:** Oh, then it became like a simulation?

**Nick:** Exactly. Then we went point by point—

**Andy:** And you can line fit it and do whatever you need to do.

**Nick:** Basically we were finding the pull of gravity coming down off its vertical velocity—as if it’s dropping down—or we could find its horizontal velocity at any point. It was incredible. To be honest, I would rather have that data automatically in the computer and run it like a simulation.
The students explained that “plug and chug” number crunching activities bog down the learning process. They recognize that graphical representations and simulations enable learning to occur in diverse ways and provide much more thought-provoking ways of understanding complex concepts.

**Steve:** I think graphical representations enhance our understanding of what is truly going on in a physical system, and there is a lot of data that you can retrieve from [the video we took].

**Paul:** He bought cameras, one for every lab station. Using them really helped me understand how to graph velocity and acceleration, which didn’t look right to me in the textbook…. I believe that I see more. I learn by visual input, not by just reading. Or I learn by audio and then the examples instead of just reading and being able to understand.

**Susan (interviewer):** You’ve mentioned that you’re not crunching numbers.

**Andy:** Correct. It’s more thought-provoking. Anyone can pretty much, knowing a formula, take the numbers and plug and chug. But what does that answer really mean? I believe that in this class we actually know what the answer means.

[Authors’ Note: The students were using VideoPoint software, a video analysis software package that allows students to collect position and time data from digital video in the form of “Video Points.”]

The students articulated yet another reason why the technology-dependent activities Curt uses help them learn: it’s fun. These activities do more than just entertain, according to one student, who said "the little simple fun things you do help you learn about how things work."

**Maggie:** There was one lab where we played a game, rotation and inertia gain, without friction. We had to travel [like a] spaceship. It got more complicated, where we had to maybe go around the circle—

**Sarah:** We could only change it in 45-degree increments.

**Maggie:** That was interesting.

**Susan (interviewer):** How were you monitoring this?

**Brenda:** It was like a computer game.

**Alice:** Yeah, it’s a lot of fun, because the little simple fun things you do help you learn about how things work. It’s like when you drive a car, you can’t always stop and start, it forces you to just keep going, so it forces you to change directions.

**Susan:** So in this game you were adding or subtracting different forces?

**Alice:** Right, and it was directional force, too. Like the circle thing: you draw a circle and you had to keep inside the circle.

**Sarah:** [If] you hit the wall, you crashed.

**Alice:** It was just fun learning, as opposed to doing boring stuff. One of us would hold onto a force sensor and another person would pull us by a string, and we would record the force.

**Joan:** Yeah, we were sitting on rolling chairs, and one person would hold one of the force sensors, and the other person would pull us along.

**Maggie:** And it would show how the force would increase in the beginning, but then it would decrease as you started moving along.

**Sarah:** It’s a lot of fun.
**Brenda:** It makes it a lot more interesting when you have more than just paper.

Finally, the students made it clear that their interest in the course is significantly greater due to the way computers are used. Listen to them explain how computers, used the right way, can “add that interest factor.”

**Alice:** If we didn’t have the technology, I’m sure I wouldn’t be getting such good grades in that class. I’m sure I wouldn’t have been interested in that class, and I might have already dropped it by now. That totally spices up the class and makes me want to go. I enjoy going to this class—except for doing the problems—but generally I enjoy going.

**Susan (interviewer):** So the technology adds that spice?

**Alice:** Oh, yeah.

**Sarah:** It makes the class fun. It just adds that interest factor.

**Maggie:** Just a little more. That little push to make you come to class every time.

**Brenda:** I think it’s neat. It makes it interesting. One time we had the videotapes all set up, and I wanted to see what would happen when I jumped, so I recorded myself jumping, and, well, it didn’t turn out so well, because my shirt went up where I had my focus points, but it makes it interesting. It makes you think on your own of all the things you can stick in there to make the technology useful.

**Alice:** We’re given a lot of free time when we get out of our labs, so if we want to mess around and figure out how stuff works a little more, then we have the ability to do that ourselves.

In sum, the students gave essentially the same reasons the faculty did for why these technology-dependent learning activities work: they provide freedom from tedious calculations, enable quick results from experiments, and allow them to see things graphically.
4. We have to know where students’ problems are and not where we think they will be: Curt Discusses Formative Assessment Activities

Curt explained why the formative assessment activities he uses—pre-/post-tests and Tasks Inspired by Physics Education Research (TIPERs)—work: they provide the information he needs so the students move to new levels of understanding, and they “force students to think.” In the long quote below, he explains how pre-post-tests and TIPERs get students to think.

In the Basic Physics course, I give the Hestenes Force Concept Inventory\textsuperscript{viii} and the Force and Motion Conceptual Evaluation\textsuperscript{ix}[pre-test] tasks. The students follow the pre-test up in the lab and measure and decide what is happening. This is all part of being able to discriminate. These are non-science students, and they need to have that skill in order to understand what a science person does to make a decision…. So they’re learning how to look at something and make decisions on what to do based on what they see. So it’s like just-in-time thinking. They’re able to add to what they’re seeing, and that determines the process they’re going to use.

The Ranking Tasks are essential for students to learn. It forces them to think…. Now I get a lot of ideas by using these Ranking Tasks, because students will present ideas that you never would have thought they had, even after instruction. That’s why teaching is such a daunting task: you say, “I’m going to introduce them to something that they’ve never heard about before. They have a clean slate.” And you give them a nice exposition on it, it’s in the textbook, and then you ask them to explain something and they’ve picked up some other aspect you never would have dreamed of since they put things together in remarkable ways.

And there’s a lot of other things we use: multiple representation problem-solving—getting them to be able to represent problems or information in different ways. There’s a general category called conceptual exercises, where we focus on a particular student difficulty we’re aware of and develop an exercise that’s designed to have them focus on that difficulty and then remove it. These are all part of a general classification I’ve called TIPERs—Tasks Inspired by Physics Education Research. I did not invent most of the tasks, only this name for them.

Curt continues, explaining how he uses the information from pre-tests and TIPERs to inform his own teaching efforts.

...We have to know where students’ problems are and not where we think they will be... so I do a lot of pre- and post-testing to find out where the problems are and to see how much the students’ conceptions changed as a result of the course. I use multiple-choice tests, by and large, because they’re relatively easy to give and grade. They don’t demand a great deal of additional time. I use the Ranking Tasks as a diagnostic reasoning tool because it gives me insight into what students are thinking about and can shape what I can talk about or what types of exercises I may develop within the class period or in the next class period.... For today’s Ranking Task, eight out of ten got it right. They knew what they were doing, and that was just a reinforcement that they had read the chapter and understood and could explain it....
Curt continues his explanation by relating his use of assessment activities to his philosophy of teaching and to a critique of prevailing faculty attitudes toward assessment. In so doing, he compares assessment in teaching to the kind of information gathering that is standard practice in the medical profession.

Now, I have a certain philosophy about assessment. I really think the teaching culture should start regarding testing and assessment as extremely important tools. These techniques are not just “something we have to do,” but something we should do. We should not sacrifice assessment activities because we want to lecture more. That’s typically what people say: “I can’t afford to give anymore time than an hour to give an assessment.”

I’m very strong on assessment, sometimes for diagnostic needs, but primarily for an evaluation of how well we’ve been doing [as teachers]. I compare it to doctors. When you go to a doctor, do they lecture you? No, you spend more time when you go to physicians these days having tests done and answering questions. Most of the time they’re trying to get information, so they know what to do. So I try to focus on where students have problems—not what they already know, but what they don’t know. So I look at assessment tools as useful to me and useful to students.

As Curt pointed out, not everyone agrees with the emphasis he places on assessment. Bill is one of these people who thinks that giving students so many tests is unnecessarily time consuming. Despite their differences, the computer technician, Geoff, explains that Curt and Bill both share the goal of accurately measuring what students have learned.

Curt and Bill have spent a lot of time on these assessments. I don’t know if Curt’s mentioned anything to you about the Force Concept Inventory? Bill doesn’t like to take as much class time as Curt does to assess, but they both do the Force Concept Inventory pre-test and a post-test for the force concepts. There is also one for heat and temperature. They’re trying to determine whether or not the students really understand these concepts. They’re always trying something else to see if it can more accurately measure, or how they correlate with each other and so forth. I think [Bill] is sold on the idea, but he just feels like it takes a lot of time at the beginning of the semester that he would rather put into other things. Likewise at the end.
5. Once you do the task, you learn it: Curt’s Students Discuss Formative Assessment Activities

Student testimony provides insight into how well formative assessment activities help Curt to achieve his goals for student learning. Here, students from his Engineering Physics course explain how Curt’s Ranking Task “teaching tool” is one of the regular classroom activities that “makes them think.”

Nick: Ranking Tasks are generally used for concepts we don’t have a clue about and are just starting to get going with. They don’t count for a whole lot, but they make us think and put on paper what we think and how we came up with the idea. We’ve probably had fifty of those. There’s a ton of them, and they range from the simplest concepts to some that are really tough. Yeah, we’ve had “Ranking Tasks” on concepts we hadn’t even learned yet. They hadn’t been assigned for homework.

Paul: He gives out eight quizzes that really don’t count for much, but we haven’t learned all the material yet.

Nick: So afterward he’ll go over it and say, “OK, here’s what you do, here’s why you do it, here you go.” That’s one of the big teaching tools that he uses. When we’re in the classroom, that’s how we learn from him.

As mentioned above, Curt also puts some Ranking Task questions onto his graded exams. Although some of the students don’t understand these questions while taking the exam, they said that afterward, the concepts are clarified. It appears, from the student testimony below, that even when these tasks were graded, the class environment was sufficiently “low stakes” that the goal of using TIPERs to make students “hungry to know” was achieved.

Nick: He threw a Ranking Task right on the test. {Laughter among all the students} …In class he gave us [back] the graded tasks and said, “This is just awful.” Then he took them and threw them in the grade book and said, “Alright, have a nice day.”

Andy: Your grades don’t really reflect what you’re getting out of the class, but you are learning…. But once you do the task, you learn it. That’s the way I feel. I learn it usually after [completing it].

Nick: He lectures on it after the task. He goes slower and says, “This is the answer, and this is why.”

Students in Curt’s Basic Physics course describe his use of pre- and post-lab surveys and Ranking Tasks. They explain how they felt “stupid” for not being able to correctly answer questions that challenged their intuition about Newton’s third law, for example. It seems likely, however, judging from the following discussion, that these students won’t soon forget that opposite forces are equal.

Alice: Well, at the beginning of class he’ll talk to us about what we are learning, and he does a lot of surveys to make us think about our answers. For instance, he’ll give out a question sheet on forces. Before the lab [where we used force probes and analyzed our data on the computer], we were all confused, so he gave us some stuff about forces—that they’re always supposed to be the same, because one force is the same as another. Some people
didn’t understand it right then, and we answered that different forces would be greater or less. Then after the lab, he did a post-lab survey. Before the lab we all had different answers, and afterward we all had the same answer—it’s because of Newton’s Third Law. So we have a lot of fun, and then after class we’re all like, “Oh, man, we were stupid,” because it’s so easy after the lab to realize that the forces are the same.

**Sarah:** We also have Ranking Tasks that we do. Like when we were doing force, “If a ten-gram cart is pulling on a five-gram cart, which would have the greater force?” And we would rank the most force to the least force, and it took us about three or four Ranking Tasks to realize that all the forces were equal.

These same students also discuss the confusion they feel responding to Curt’s show-of-hands surveys.

**Alice:** I feel more comfortable in this class.

**Brenda:** Sometimes he confuses the class, though. He makes you think, and you give him one answer, but he doesn’t really say much, and then he says, “No, the other one.”

**Sarah:** Or he’ll make us answer a survey—“Is it a, b, or c?”—and we all feel kind of stupid.

**Alice:** He makes you think about the stuff you do in class.

**Sarah:** He doesn’t just give you the answer. You have to think about it for awhile, and then he tells you the answer, and then you move on instead of just being told the answer and moving on.

Curt also works with the summative assessments—the exams—afterward in ways that foster the same discomfort-based learning process that he evokes with the formative assessment activities. According to the students, his exams are challenging, “designed to trick you and make you think a lot.”

**Sarah:** The tests are relatively difficult.

**Maggie:** They’re pretty challenging. What he did was take a lot of tasks and look at the questions that were most frequently missed on them and put them on one test. His tests are designed to trick you and make you think a lot.

**Alice:** It’s hard to study for them. [You have to examine] every nook and cranny that you would normally miss, because none of the bold words are going to be on the test; it’s going to be everything in between the bold words.

**Susan (interviewer):** Well, in the end do you think the tests are fair?

**Alice:** I think they’re fair, but they’re hard. Learning is hard, so tests are going to be hard.

The students then explain that it is only after missing concepts on the exam and listening to the explanations in class afterwards that they really got it—because you need this whole process to get “committed” to an answer. That is, they must engage themselves in that predict-observe-explain process in order to get beyond the “blank screen in the back of my head.” Below, they contrast the process of learning through exams in Curt’s course with the process in more traditional courses, where “if you just read the book, you don’t really focus on the actual physics of it.”
**Susan (interviewer):** What worked for you in the class—for your learning needs?

**Alice:** After we took the test, he explained it, and I realized, “Yeah, this is what I did, I should have known that, but how could I know that without you teaching us before we took the test?”

**Maggie:** So we’re back to the original discussion of how once we committed [ourselves] and put down our answer and tried to rationalize it, then regardless of how it comes out, I’m not looking at a blank screen in the back of my head. Would I have liked it if he lectured to us on it before the test? Yeah, probably. But we’re not getting it before the test because we don’t have the time. If there were more time in the class, I think we would know just about everything about physics up until this point, because he could teach a lot.

**Alice:** Yeah, ’cause he pulls the concepts out of you. If you just read the book, you don’t really focus on the actual physics of it. You’re just worried about doing the formulas—you know, “Where do I put this? Where do I put that?” [But when he teaches], you’re actually understanding the physics behind it and what’s going on.

**Maggie:** And I do a ton of formulas. I have a whole workbook full of them. When I hit test time, if he asks me a question, I’ve done it. I’ve done the work, so I can do the problems. That goes back to the independent learning issue.
6. The JJC Faculty Discuss External Resources

In the following, the JJC *bricoleurs* discuss the types and importance of various institutional resources they find necessary and explain how they went about procuring them.

*a. Money*
With regard to money, the JJC *bricoleurs* relied heavily on grants from the National Science Foundation, as well as matching grants from their institution, when creating a budget for their technological undertaking. Along with planning, Scott Olson, a campus-level technology administrator, told us that budgeting was one of the "big things" in the first few years of the project. But despite the "very expensive bleed" that the technology placed on the department's economy, going ahead with implementation was nevertheless necessary "to be competitive." Here, Scott comments on Curt's initiative in obtaining the NSF grants and later the institutional matching grants.

*Curt had NSF grants for programs, so that was one problem we could solve.... We were all diverse and trying to do things, and Curt needed to have the institution back him on his matching grants. So essentially, with the help of the Technology Planning Committee, he got the matching funds.... The planning and the budgeting were the big things in the first few years, just trying to figure out where we were going to go with computers and how best to utilize funds that we had.... I was working with the Vice President of Academic Services and the Director of the Information Technology Center. We were the three people who started it and incorporated faculty and students, particularly in those departments that were trying to coordinate the use of equipment, standardization of equipment, and policies.... We realized this technology was going to be a very expensive bleed in terms of money and budgets, but it was money that had to be spent to be competitive, track students, and so forth.*

Department Chair Mike Lee also commented on the economics of staying competitive by pointing out that the value of instituting a new program like that of Joliet will not be realized "for a long time to come," because students may not get every penny's worth spent in the short term. However, to not spend the money would be to deny students a "foundation of familiarity to instrumentation" which will be essential in the long run. In other words, they will not get the experience with computers that they will need in the future.

**Mike:** We spend $400,000 a year at this institution on technology, and the question is, "do the students get $400,000 a year more in learning?" My guess on that is no, but I don't think we can know the answer to that for a long time to come.

**Susan (interviewer):** Is that because you can’t just look at one data point in time?

**Mike:** Right. I think that for our $400,000 we may get, I don’t know, $200,000 worth of value. But if we didn’t have that, we would be going into reverse, because the students walk out of here to go to an upper-level institution or to go to work.

**Susan:** So you’d be getting shunned by the recipients of your students for not getting them up to speed.

**Mike:** Yes. And with respect to the instrumentation part of chemistry and biology, we can’t expect to keep students exposed to the very most up-to-date technology or the very most current instruments. I mean, only a few places in the whole state have certain analytical
instruments. However, building that foundation of familiarity with instrumentation will allow them to go from a Macintosh to a PC and back again.

b. Space
To build such a “foundation of familiarity,” students would ideally be able to use a computer whenever they needed to. However, as President J.D. Ross explains, such accommodation is difficult when there is a lack of space. In this all-too-common situation, the institution has to get creative to provide adequate, if not ideal, facilities.

Unfortunately, unlike some of our community college sisters and brothers, we don’t have any space here where we could create one big mega-lab. Those are obviously easier to staff.... We’ve got a lab here and a lab there, because those are the spaces we had available. In an ideal world, if I had the opportunity to construct a new technology center, what I would have is a great big open lab where students have the opportunity to just go to a room and have access to the technology in an unfettered way any time they need it, versus the lab being just part of the class. The lab would have 150 to 200 computers in the center and then individual teaching labs around the perimeter.

c. Time
Along with needing space, the JJC faculty also talked about the importance of having time to construct their effective learning environments. Here, Marie, the chemistry faculty member, discusses how the time it takes to implement the tech-enhanced learning environment is largely dependent upon the technological savvy of the people involved in the project.

Will (interviewer): Tell me about the time you need to invest to make this work.
Marie: I think the time factor depends on what your computer experience is. Mine was limited. I had an old IBM PC at home that I could type tests on, but the Physics Department used the Macintosh and seemed to be real happy with that. Then I saw how great that worked, so we started to incorporate the Macintosh, which meant that we had to learn about the Macintosh, so the learning curve was pretty steep at the beginning. But I think now we’re pretty good with it. But the time factor was also a problem, because we had to do these experiments for ourselves rather than saying, "Well, this should work on paper." You don’t know how it is going to work out until you actually do it for yourself, and normally what takes you a while is going to take students a really long time. So I’d say there was a steep curve, learning how to use the technology, both with the computer interfaces and, for me, even using Power Point or sometimes even getting on the Internet.

Marie also talked about the need for release time for professional development.

Marie: It might be helpful at some point to have release time in the summer to work on those kinds of things. A person that I know from the College of Du Page was starting up a computerized lab. They realized that by trying to do it incrementally over time, everything would be obsolete by the time they got everything to work. So they gave him a whole quarter’s worth of release time just to get the lab experiments where they would work for the general chemistry students. It is a good idea.
Will (interviewer): Which means that the administration has an understanding and is on board, or it just wouldn’t happen?
Marie: That’s right.

d. Hardware and Software
The JJC bricoleurs made it clear that their success depended, in part, on having department-, college-, and institution-level administrators who understood their need for—and who took action to obtain—adequate hardware and software resources.

Susan (interviewer): What are the important technical things that people who maybe aren’t as far along as you are here need to be aware of that you experienced?
Mike: Well, as a department chair, I’ve tried to make the hardware and the software available to the instructors, because they surely can’t use it if they don’t have it. So that’s got to be the first step. It is a risky step and an expensive step, but it is one that you have to decide either you are going to take or not.

As department chairs, we don’t want to be an impediment. I think it’s our responsibility to provide the technology, knowing full well that there are risks there and that some people may use it, while some may not. And also knowing that the investment we make now may turn out to be invalid in a few years. There was a huge investment many years ago at this college in audio tutorial classes. That was the way to do it at the time, and people of the day were certainly innovators. You need to go down those roads even though you don’t know where they go. The application of technology in a classroom is one of those roads. We don’t know where it is going, but we had better go that way, with our eyes open, and try to keep the good and evaluate as we go along.

Once faculty members take the time to become familiar with the new hardware they will be using, they must then find software for use in their classrooms. Here, Curt tells about a few places where such software is available.

Curt: Unfortunately there are not enough good simulations, but in the physics community there’s a place called Physics Academic Software that usually will market the most effective physics computer simulations. It’s a commercial enterprise that has been supported in part by the American Institute of Physics and other groups. They’re peer reviewed in a sense. It’s not just someone selling you something—they have a certain standard that they use. And some members of the physics education research community have developed software based on their research, and these faculty typically will market that. We use a program called Graphs and Tracks that was developed by a University of Washington group, another program that deals with identifying forces, and an excellent one called Electric Field Hockey.

Curt suggested that faculty can benefit by working with the hardware and software vendors.

Curt: By accident, when I was president of the Illinois Macintosh Users Group, I happened to call Apple to set up a speaker for a meeting, and the guy asked, “Did you hear about this opportunity that Apple has?” They were offering matching grants at one-third and did not have a candidate for this region, so I used the roughly $50,000 or $60,000 I had from JJC
and NSF and matched it again. So I got more and better equipment. That’s how we got started.

And the other place I look for external support is software vendors, like Pasco Scientific Company and Vernier Software. Vendor support is a key issue, so when you are implementing new hardware and software, you have to interact with the vendor as well as the faculty developers. Someone who is implementing new technology has to be aware of the important role of contacting and talking with the vendors and developers.

e. Support Staff

The JJC faculty explained that, even when the necessary money, space, time, software and hardware are available, innovators and early adapters are likely to find that a "tyranny of details" inhibits their efforts to achieve more ambitious student learning goals. The strategy for resolving this last implementation problem is technical support staff, people who have the time and ability to get all the other resources to work together harmoniously. Having a qualified technical support person, the JJC bricoleurs indicated, “really helps a lot” when trying to foster deep learning and avoid getting bogged down in the technical details to which a tech-enhanced learning environment is susceptible. Here, Marie talks about how crucial a technical support person is.

Marie:  We relied on Curt quite a bit through those early days to get things going, and what was good, too, is that within this time we got a part-time paraprofessional…. He works part time for us and part time for Curt. Having him here has really helped a lot, because he knows all these computers and the interfaces and probes from both sides. So when everything goes really badly, you scream for Geoff and he comes over and fixes everything.

Will (interviewer):  So, it’s mandatory that you have this type of support?

Marie:  I’d say so. Either that or someone that you can call who doesn’t mind answering questions, initially on a daily basis, or answering a lot of email from you. I really needed to have somebody whom I could ask, who could explain things to me, or just have a place to go and see how things are working. Every time Curt gets a new piece of equipment, we can go over and say, “Oh, yeah, how can I use that?”

Geoff is the "paraprofessional" Marie turns to for answers to such questions. Geoff understands the importance of his role as a facilitator of deep learning. This learning could suffer if instructors had to abandon their focus on how well students are learning in order to concentrate on technical problems. Talking with us, Geoff acknowledged his value as a technical support person who can fix things that go wrong and thereby liberate the classroom from the tyranny of details.

Susan (interviewer):  Could this program fly if the instructors had to do the work that you do in addition to what they’re doing?

Geoff:  I think it would be hard. They’ve used student workers in the past to do things, but I don’t think students would be as effective, because the faculty would have to make decisions on what they were willing to leave behind.

Susan:  So the faculty couldn’t do the whole thing? They would have to give up some things?

Geoff:  Right. Curt will bring and implement new things and say, "Let’s try this out.” I’ll usually go back to him with something, saying, “Here, this is what I’ve got so far. What do
you think?” And then he’ll work on fine-tuning it, so I’m not left all on my own. But I don’t think they would be able to do as much if I weren’t here…. The students as well definitely see me as helping them get over the obstacles of computer equipment having trouble. They recognize that I’ve spent a lot of time with it, so I know if something little is going wrong or if it really is doing what it should be.

Significantly, Geoff also recognized that “the needs of instructors are different.” Because he works in the classroom while instruction is taking place, students often ask him questions about both technical problems and conceptual issues related to the subject matter. The way in which he answers such questions depends upon which instructor is teaching the class he happens to be in.

With Bill, I feel a little freer. If there is some misconception the students have, I will try to address it. With Curt, I have to be a little more careful, because he might want to let them go in that wrong direction. He may not want me to give them an answer. So I try to be helpful without giving too much. In other words, I mirror the methods of the instructor, which can be very tricky at times. It’s important to recognize that the needs of the instructors are different. When I first began, I tried to do the same things for Bill and Curt and Marie, but as time went on, I realized that the ways I could be most helpful to them and to their students were really quite different.

These students from Curt’s Engineering Physics class concur that getting technical details taken care of and having their lab equipment “set and ready to go” are essential in a challenging class where their “heads are already filled with so much information.”

Andy: If we have a [problem], Geoff comes over and gets us into a program that we maybe can’t get into.
Paul: Geoff has been through all the labs, so he understands.
Susan (interviewer): Do you feel that that type of support is necessary for what you do in this class?
Andy: Yeah, absolutely. We don’t have time to deal with the lab set-ups at the end of the week. We’re already complaining that we don’t have enough time.
Nick: When we walk in, it’s set and ready to go; it’s all right there.
Andy: And if you get stuck, [Geoff] is right there ready to fix it.
7. **This networking thing can be critical**: More Reflections on Networking

Like his other JJC colleagues, Curt emphasized networking as a critical reason for attending workshops. He got pretty specific about how to use these networks: find folks who are at the same stage of experience with these new methods, and who are using the same equipment you are.

You ought to have a chance at the workshop to make contact with other people who will be going through that same stage. You need to have others who are doing it because you’re facing similar problems. If someone who was just getting started were to ask a veteran like me something like, “What kind of computers should I buy?” I couldn’t answer because my computers are three years old and the technology has changed. They need to get someone who has the same interests and needs as they do [and ask that person], “Well, what did you find out, what’s the best digital camera to buy?” and so forth.

And you need to get a network of people who are using kind of the same equipment. For example, if you use a PASCO System, and everyone else is using the Vernier Software system, it’s harder to relate to the same type of difficulties. But when you network with someone who’s got the same type of equipment, you can share experiences [and ask], “How did you get this to work?” or “Why that didn’t work?” An email network is just as good as anything. And it doesn’t have to be a national network. It could just be one or two or three people working together on common problems.

This networking thing can be critical; I’ve called many people around the country many times to ask them a question. “How did you get this to work? Why can’t you get the software to do what you think it should do?” This helps you learn that sometimes the issue is that the software doesn’t do what you need and not even the developer or vendor can tell you how to make it work.

Curt also emphasized that an important effect of getting one’s hands on the technology is that it gets people intellectually engaged, so they begin thinking about how to modify someone else’s materials.

Another thing when faculty members are working on these hands-on things [in workshops] is that they need to be able to develop materials as part of the exercise. It doesn’t work to just say, “Use my materials.” They need a chance to test out how they might adapt it themselves, because that’s what provides the intellectual stimulation that is so important for them. To me, that’s a critical point for making a systemic change.

Curt’s conviction that workshops are important is based on his own experience. This is how he tells his own story:

I went to national meetings of the American Association of Physics Teachers. And I became aware that other people were recognizing some of these difficulties that I was seeing and were trying different things out. I was also very dissatisfied with what lab work represented. Lab work for me should be the type of experience we saw today, with students enjoying it,
when you hear students say, “We loved it.” This is the type of lab I want, not the kind that we used to do. So I was looking for better labs.

I knew that these computers were coming along…and was looking at a way of using them in my classroom because they seemed to be so easy to use. At the time, I went to a talk by Priscilla Laws and Ron Thornton at one of these American Association of Physics Teachers meetings. They are at separate institutions but were both working on the same project, trying to use a design and interface so that the Macintosh can collect data. And I said, “This is right up my alley!” So did everybody else there, because the room was packed from one end to the other with people trying to get in….

[Later] I went to one of their workshops and said, “This is exactly what we need to do.” It’s got force and motion and wasn’t like what most people had been doing up to that point—taking old labs and just hooking the computers to them and repeating the same thing we used to do. What Laws and Thornton had actually done was develop a new way of teaching or curriculum using the power of the computer.

Before leaving the topic of workshops, Curt returned to his point about the value of hands-on activities and offered a host of practical “getting started” suggestions: “Borrow equipment, get a network, be prepared to troubleshoot.” In listening to this advice, we heard intimations of “seize the day!” and “the squeaky wheel gets the grease.”

When you come back from a workshop, borrow some equipment right away—from the workshop people or the manufacturers. Quite often the companies will send you a loaner piece so you can see how it’s going to work before you forget what you learned at the workshop. One of the real problems is the technology. You go to a workshop this year, and it’s probably going to be a year before you can implement it in your classroom if you don’t have the equipment already. [So you’ve got to take steps to figure out] whether what you learned at the workshop can be done in your classroom next year. You need to get a network so you can have somebody to troubleshoot some problems with you. And you need to practice with the technology before you forget most of what you’ve learned. The technology takes longer than you think to get in place, so you have to do this unless you’ve already got the stuff in your lab and someone there to show you how to use it.

Despite the fact that Marie values networking with “Adapt and Adopt” colleagues outsider her institution, she still prefers “next-door” support from within her own institution, which yields faster results than attending meetings and other forms of networking:

We were already willing to start the implementation process, and Curt helped a lot; he got us into that. Then with all the software that he used for his applications, I felt really comfortable about going over to the physics lab and looking at the interfaces and probes and asking questions about how he uses those kinds of things. I would get ideas about how I could use them on the chemistry side, so I think that made our transition to the technology easier because it was in the room next door. I could look at it whenever I wanted; I didn’t have to wait until I went to some meeting to get the five-minute explanation on how these things go together.
Networking in the “room next door” also allows departmental colleagues to stay “on the same page,” according to Marie. She talked about several projects at JJC that she and her colleagues have collaborated on.

In terms of guided inquiry and cooperative learning, we all attended a PKAL\textsuperscript{1} workshop, so we were able to get on board at the same time, which was good, because before that there was a little struggle going on with these things. But we are all pretty much together on the use of the guided inquiry and cooperative learning. I would say also, for the general chemistry experiments that involve computers, we are all on board with that. Where we diverge a little is on this project that I am working on with some of the area and community colleges. As for the Modular Chemistry material, I am not sure whether I presented it in the best possible light to my two colleagues in the beginning. They are not too sure about what I do with that in general chemistry. But, lab-wise and group work-wise, I think we are all pretty much on the same page.

Geoff White, the technical support behind the JJC initiative, also plays an important role in the internal networking process by acting as a liaison among faculty members who might not always be sure how to implement one another's ideas. Here, Geoff comments on his role as a link among colleagues who are attempting to adapt new learning activities from one another:

\textbf{Susan (interviewer)}: What sorts of technical learning, support, development and so on, would Marie and Bill in particular need in order to get started and to be successful in adapting these methods?

\textbf{Geoff}: Part of it is finding out what’s there to begin with and then being able to have some of the equipment available to try. I’ve brought them different things at different times. Particularly Marie. Bill and Curt have talked more about what they’re doing, so there’s some interaction there…. Bill might come to me and say, “Curt’s doing such and such, and I think I know what he’s talking about, but can you explain it to me?”…. I’ll also bring up to Marie things that we’re doing in physics, because I might see a connection between the two, something that she might be able to implement in the chemistry lab, particularly thermal things with the temperature probes.

\textbf{Susan}: So you’re really a connector, in some sense, among the faculty.

\textbf{Geoff}: Yeah, I view it that way. I don’t know if they do or not, but that’s one of the ways I can be helpful to them. Curt tends to say things that will spark their interest, but not give them information, so that they’ll come back for more. I don’t know to what degree the other teachers are comfortable going back and asking him about it, because it’s easier to ask me. Part of it is that I have a lot of experience in implementation, so they’ll bring stuff back to me and say, “Can we do this?”

Colleagues aren’t the only people to bounce ideas off. Curt also uses his students as a way of finding out whether his implementation process is working.

\textbf{Curt}: I think you ought to tell your students up front that they’re part of the process. This is really a joint venture between you and the students. You’re designing new materials, and they will recognize that there are difficulties and flaws. In my syllabus I say something like that, that a lot of materials are under development… that students are part of the process. We’re not just turning something over and they have to do exactly what I say.
Susan (interviewer): What does that do for the students?

Curt: I think it allows them to complain when things don’t work right and alert you to difficulties. It gives them a chance to respond to what they’re going through. I think it’s important in the implementation to recognize and engage students as part of the process. They’re part of our group, they’re part of our community.

Mike, the biologist who now chairs the Department of Natural Sciences, amplified on this point by explaining that he was motivated to make changes by the expectations of his “technology savvy students.”

Now the students are pushing us. I have a website for my microbiology course. Some of the students actually go onto that website and do practice quizzes and all that. At the beginning of the semester, when I didn’t have this thing completely done, they were coming to me [and asking], “When are you going to finish this?” The students that we get now are so technologically savvy, so computer savvy that they expect this. They push us. They help to drive it.
Resources

A. WHAT IS A “LEARNING ENVIRONMENT”?  

B. BRIEF DESCRIPTION OF JOLIET JUNIOR COLLEGE  

C. SYLLABI FOR SELECTED COURSES FEATURED IN THIS CASE STUDY  

D. PRE- AND POST-TESTS USED BY CURT FOR FORMATIVE ASSESSMENT  

E. CURT’S TASKS INSPIRED BY PHYSICS EDUCATION RESEARCH (TIPERS)  

F. FINKEL AND MONK’S “ATLAS COMPLEX”  

G. METHODS USED TO PRODUCE THE CASE STUDY
A. What is a “Learning Environment”? 

A learning environment is a place where learners may work together and support each other as they use a variety of tools and information resources in their pursuit of learning goals and problem-solving activities (Wilson, 1995). Based on this definition, all courses are “learning environments,” but not all courses are intentionally designed to achieve goals for student learning. The *bricoleurs* featured in the LT² Web site are among the growing number of faculty who are designing their courses to achieve their goals for student learning. This is explained in the “learning environment” model below.

**Model of a Learning Environment**

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Problems - Goals

First, consider more closely the relationships between typical problems that the featured *bricoleurs* experience and their goals for student learning. This relationship may be presented as follows, using the Joliet Junior College case study as an example:

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18 A French term for a person who is adept at finding, or simply recognizing in their environment, resources that can be used to build something she or he believes is important and then putting resources together in a combination to achieve her or his goals.
Teaching Principles
Now, it is a big jump to go from a set of abstractly-stated goals, like those above, to the kind of complex, on-the-ground learning activities that we saw during our case study visits and that the *bricoleurs* and their students described. As the above Learning Environment model shows, the main steps linking faculty goals to effective *learning activities* are their *teaching principles*.

Typical of the teaching principles that guide the decisions of the faculty featured in the LT² Web site are the following, which are drawn from the Joliet Junior College case study.

Of note, the teaching principles held by the LT² *bricoleurs* are strongly consistent with the “*Seven Principles for Good Practice in Undergraduate Education*” that Zelda Gamson and Arthur Chickering synthesized from research on undergraduate education (1991). The teaching principles of the *bricoleurs* featured on the LT² site also are consistent with a *constructivist* Philosophy.

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19 According to Swandt, constructivism is a “philosophical perspective interested in the ways in which human beings individually and collectively interpret or construct the social and psychological world in specific linguistic,
Synergistic Set of Learning Activities
To implement their teaching principles, the faculty featured in our case studies have chosen a set of activities that they attempt to synergistically “weave together” to achieve their goals for student learning. We have organized these activities into the following three categories:

1.) **Computer-dependent activities** that faculty believe simply would not be possible, or at least not feasible, without computers. Examples include:
   - hands-on experiments (real-time hands-on acquisition and analysis of data, using electronic probes, that provide connections to real-world events)
   - visualization, graphical representation, and simulation

2.) **Computer-improved activities** that faculty believe work incrementally better with technology but can still be implemented without it. Examples include:
   - the use of electronic response systems in large lectures, that enable individual students to vote on their answer to a multiple-choice question by pressing a button rather than raising a hand.
   - the use of a course website rather than/in addition to paper to post the syllabus, handouts, and so forth.

3.) **Computer-independent activities** that can be done without technology. Examples include:
   - group work/guided discussion, and
   - formative assessment tasks.

To summarize, each learning environment created by the *bricoleurs* featured in the LT² case studies consists of an integrated set of *learning activities*, some of which are computer-dependent and all of which implement the *teaching principles* that the instructors believe will achieve their goals for student learning.

Outcomes
Throughout the LT² case studies, our picture of the learning environments developed by diverse *bricoleurs* is completed by “outcomes,” a term that refers to four types of information that faculty use to determine how well their learning environment is achieving their goals:

- **Student testimony** – provides key insights into how students experience different activities.
- **Instructor testimony** – conveys instructor views about how, why and how well different activities implement his or her teaching principles and goals.
- **Formative assessments** – activities that simultaneously (1) provide instructors with feedback about how and what students are learning, which the instructors can then immediately use to adjust and improve their teaching efforts; and (2) foster student learning directly because the students in the process of performing such activities.
  (For more information, see the [FLAG website](http://www.flag.northwestern.edu), which features classroom assessment techniques that have been shown to improve learning.)

social, and historical contexts” (1997, p.19). During the last 20 or so years, cognitive psychologists (James Wertsch, Barbara Rogoff, and Jean Lave, among many others) have found that constructivist theories of how people construct meaning are closely aligned with their observations of how people learn: knowledge is mediated by social interactions and many other features of cultural environments.

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- **Summative assessments** – formal examinations or tests, the results of which are used by faculty to demonstrate, in a way that is definitive and visible to people outside the course, the degree to which students have accomplished the learning goals for a course.
B. Brief Description of Joliet Junior College

Joliet Junior College (JJC), located just southwest of Chicago, Illinois, is a comprehensive community college that offers pre-baccalaureate programs for students planning to transfer to a four-year university, occupational education leading directly to employment, adult education and literacy programs, work force and workplace development services, and support services to help students succeed. JJC is America's oldest public community college. The "brain child" of J. Stanley Brown, Superintendent of Joliet Township High School, and William Rainey Harper, President of the University of Chicago, it began in 1901 as an experimental postgraduate high school program. Today, it is one of 40 community college districts governed by the Illinois Community College Board under the Illinois Board of Higher Education, and is directly governed by a seven-member elected Board of Trustees.

An entirely commuter institution, JJC serves more than 10,000 students in credit classes and 21,000 students in noncredit courses. Of the students enrolled in credit classes, about one-third attend full-time, and two-thirds attend part-time. Of the students enrolled for credit, women comprise about 56%; the distribution by ethnic background is 7.5% African-American, 7.5% Hispanic, 1.5% Asian, 82.3% white non-Hispanic, and 1.2% other. The average age is 28.5 years.

Like most two-year colleges, JJC serves students from a wide spectrum of backgrounds, from the occasional National Merit scholar to students who are seriously under-prepared for college. Students attend for various reasons, ranging from an inability to afford a four-year institution, to getting turned down elsewhere and trying to get a start in a postsecondary institution. Due to the mathematics prerequisites, the most poorly prepared JJC students rarely enroll in the science courses featured in this case study. Even so, one of the physics faculty, Bill Hogan, described the range of students as follows:

"We see a lot of students who are not "instructor immune." We see some who will learn no matter what you do. We see some who are so weak that they can't learn no matter what you do. And we see a lot of students in the middle, who we feel are learning because of the things we do—maybe with a different instructor, they wouldn't be learning. That makes me feel a little more involved as an instructor.... At JJC, doing a good job can make a difference. A lot of these students just need someone to pay attention to them."

The JJC instructional staff includes 165 full-time faculty and 380 part-time faculty. The faculty is unionized, and their salary structure is tied exclusively to years of service. The course load is 15 equated credits per semester. Class size is generally small, with most course capacities ranging from 10 to 35 students.

The faculty are organized into 12 departments. The four bricoleurs featured in this case study are members of the Department of Natural Sciences and Physical Education. This department has 19 full-time faculty and 43 part-time faculty. Adjunct professors teach about 40% of its courses.

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20 A French term for a person who is adept at finding, or simply recognizing in their environment, resources that can be used to build something she or he believes is important and then putting resources together in a combination to achieve her or his goals.
C. Syllabi for Selected Courses Featured in This Case Study

PHYSICS 100  Basic Physics
PHYSICS 201  Engineering Physics I
PHYSICS 202  Engineering Physics II
PHYSICS 100  Basic Physics
Course Information

Description
This course provides an introduction to the basic principles and concepts of physics. These are discussed and applied to explain common experiences. It provides an overview in the areas of mechanics, heat, sound, properties of matter, electromagnetism, optics, and atomic/nuclear physics. This course is designed to satisfy part of the general education requirements for a transfer lab science course. It generally will not serve as a required course in physics for various majors such as engineering or bio-science.


Instructor  Dr Curtis Hieggelke (hay-gull-key)
Office Hours: 9 am MWF and 1 pm TR
(815) 280 - 2371 or email: curth@jjc.cc.il.us

Grade - based on the following factors:
1) major unit exams
2) lab work
3) class discussion of assignments (homework)
4) other class participation (attendance)

The class discussion score will be based on the percentage of assigned discussion questions and exercises completed and ready to be presented in class on the due date. These must be written out in a notebook before the start of the class session but need not be entirely correct to receive credit. In addition, students in attendance will receive 5 points for participation. Students in attendance must turn in the daily assignment sheet even if they do not have it done to receive credit for participation and not be counted absent. There will be an online web component for this course. In connection with this activity, you will be given an email account and will be able to do access the course web site and email on computers at the college or at home. This part will be included as part of the class discussion score.

Lab work will be evaluated on factors such as completeness, neatness, and correctness. In order to pass the lab, a student must do at least 80% of the experiments. All students must pass the lab in order to receive any passing grade.

The final grade will be the average of the tests, class discussion, and lab work. The lowest test score will be deleted from this average. The following system will be used to assign grades:

<table>
<thead>
<tr>
<th>Score</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>90-100</td>
<td>A</td>
</tr>
<tr>
<td>80-89</td>
<td>B</td>
</tr>
<tr>
<td>70-79</td>
<td>C</td>
</tr>
<tr>
<td>60-69</td>
<td>D</td>
</tr>
</tbody>
</table>

In addition, your instructor reserves the option of adjusting the grades up or down of students who are close to the border (± 2) based on the class participation of the student in the class. This is a judgment decision of your instructor.

EXTRA CREDIT will be given for special activities and efforts that should be approved in advance by your instructor. These may include items such as book reports, planetarium shows, field trips, and other undertakings. The amount of extra credit will be determined by the instructor based on the event and the written report submitted for the credit. All materials must be submitted by 1 pm on December 4.

ATTENDANCE/WITHDRAWAL

This course information is subject to adjustment. Notification of any changes will be announced in class.
Students are expected to attend all class sessions. Students may be recommended for withdrawal at midterm if they have missed an excessive number of classes (more than 2). Students dropping the class are expected to follow normal college procedures.

**COURSE LEARNING MODE/STRATEGY -**
This class will utilize an active cooperative learning mode as opposed to the lecture mode found in many other classes. Much of the course materials are under development by your instructor and others, thus there may be mistakes or omissions — be patient and please ask questions if you need clarification. The materials are based on the latest developments in physics education research.

In this course, some use of computer technology will also be employed — particularly in the lab, to collect, display, and analyze data. Students will also gain experience with spreadsheets, graphing, and simulation/visualization software.

It is important to note that each student is responsible for preparing him/herself for each session. This means reading the background material (textbook) and doing the specific questions before each class. Because of the nature and demands of the schedule of this course, there will be no make-up for sessions missed or lack of preparation.

**WEB Online Course ACCESS**
To connect to the web section of this course, launch some type of browser software such as Netscape Navigator or Internet Explorer and connect to http://online.jjc.cc.il.us. You can also enter this via the college homepage http://www.jjc.cc.il.us and look for the link to Blackboard. You can do this from any college computer or from home using your internet provider such as America Online. Then log in and select this course from "My Blackboard." Your Blackboard login user name is your full JJC E-mail address. For example, if your user name was: rwennerd and you are a student, it is now: rwennerd@student.jjc.cc.il.us. Your password are the first 5 digits of your social security number with no space or -. For help with the Blackboards system, please contact R Scott Wennerdahl at 280-2275 or email rwennerd@jjc.cc.il.us.

**MAKE-UP POLICY -**
Late assignments generally are not accepted. Written class work prepared for discussion must either be turned in advance or other prior arrangements made to receive credit for it if a student is going to miss the class discussion. However no credit for the discussion participation will be received. If a student is sick on this date, it will be accepted if it (the assignment sheet and hard copy of the work) is mailed with a postmark on or before the date the assignment is due. However, no credit will be received for class participation.

Tests can be made up at the discretion of the instructor providing prior or timely notice is provided. Phone messages are date and time stamped and may be received anytime. This must be completed before tests are returned to the class.

**INAPPROPRIATE ACADEMIC BEHAVIOR -**
Students are expected to be responsible and to take credit for their own individual work. There are times when collaborative efforts between two or three students are OK (discussion questions and exercises) — but this should be work sharing NOT copying and there are times when collaborative work is expected — laboratory. Of course, there are times when collaboration is forbidden (tests) — if this occurs appropriate course/college action will be taken depending on the nature and seriousness of this action.

**FOOD and DRINK**
No food or drink (except for water) is allowed in the physics classroom.
No food or drink is allowed in the physics lab at any time.

**SEXUAL HARASSMENT -**
The college has a strong and firm policy against sexual harassment. Such conduct will not be tolerated in this class, and any victims are encouraged to report any incidents. Learning is best achieved in an environment of mutual respect and trust.

Physics 100 Course Outline

I. INTRODUCTION (1 week)
   A. Science
      1. Method/Attitude
      2. Science and Technology
      3. Goals of Physics
   B. Experiments
      1. Measurements
      2. Metric System
   C. Computers
      1. Operating
      2. Spreadsheet
      3. Graphing
      4. Data collection
      5. Video capture

II. MECHANICS (3-4 weeks)
   A. Description of Motion
      1. Position
      2. Speed
      3. Velocity
      4. Acceleration
      5. Free Falling Bodies
      6. Projectile Motion
   B. Newton’s Laws of Motion
      1. Newton’s First Law of Motion
      2. Newton’s Second Law of Motion
      3. Mass and Inertia and Weight
      4. Newton’s Third Law of Motion
      5. Friction
   C. Momentum
      1. Impulse and Momentum
      2. Conservation of Momentum
      3. Collision
   D. Energy
      1. Work
      2. Power
      3. Mechanical Energy
      4. Potential Energy
      5. Kinetic Energy
      6. Conservation of Energy
      7. Machines and Efficiency
   E. Rotational Motion
1. Uniform Circular Motion
2. Centripetal Force
3. Rotational Inertia
4. Torque
5. Center of Mass and Center of Gravity
6. Conservation of Angular Momentum

III. PROPERTIES OF MATTER (2 weeks)
A. The Atomic Nature of Matter
   1. Atoms
   2. Molecules
   3. Molecular and Atomic Masses
   4. Elements and Compounds and Mixtures
   5. Atomic Structure
   6. States of Matter
B. Solids
   1. Density
   2. Elasticity
C. Liquids
   1. Pressure in a Liquid
   2. Archimedes’ Principal
   3. Buoyancy
   4. Pascal’s Principle
   5. Surface Tension
D. Gases
   1. Pressure
   2. Ideal Gas Law
   3. Bernoulli’s Principle

IV. Heat (class selection and as time permits - 2 weeks)
A. TEMPERATURE AND HEAT
   1. Temperature
   2. Thermometers
   3. Quantity of Heat
   4. Specific Heat
   5. Thermal Expansion
B. Heat Transfer
   1. Conduction
   2. Convection
   3. Radiation
C. Change of State
   1. Evaporation and Condensation and Boiling
   2. Melting and Freezing
D. Thermodynamics
   1. Absolute Zero
   2. Internal Energy
3. First Law of Thermodynamics
4. Second Law of Thermodynamics
5. Entropy

V. Sound (class selection and as time permits -1 week )
A. Vibrations and Waves
   1. Pendulum
   2. Mass on Spring
   3. Wave Motion and Velocity
   4. Transverse and Longitudinal Waves
   5. Interference
   6. Standing Waves
   7. Resonance
B. Sound
   1. Origin of Sound
   2. Transmission of Sound Waves
   3. Speed of Sound
   4. Decibel Levels
   5. Doppler Effect
   6. Beats

VI. ELECTRICITY AND MAGNETISM ( 2-3 weeks )
A. Electrostatics
   1. Electrical Forces
   2. Coulomb’s Law
   3. Electric Field
   4. Electric Potential
B. Electric Current
   1. Flow of Charge
   2. Electromotive Force and Current
   3. Electrical Resistance and Ohm’s Law
   4. Direct Current and Alternating
   5. Electric Power
   6. Simple Electrical Circuits
C. Magnetism
   1. Magnetic Force
   2. Magnetic Field
   3. Magnetic Forces on Moving Charged Particles
D. Electromagnetic Interactions
   1. Magnetic Force on a Current-Carrying Wire
   2. Electromagnetic Induction
   3. Electric Motors
   4. Transformers

VII. LIGHT (class selection and as time permits-1 week)
A. Reflection and Refraction
1. Law of Reflection
2. Plane Mirrors
3. Law of Refraction
4. Lenses

B. Light Waves
1. Wave Interference
2. Diffraction
3. Thin Films and Diffraction Gratings
4. Polarization

VIII. ATOMIC AND NUCLEAR PHYSICS (class selection and as time permits-2 weeks)

A. Light Quanta
1. Photoelectric Effect
2. Wave-Particle Duality
3. Uncertainty Principle

B. The Atom
1. Atomic Spectra
2. Wave-Particle Duality
3. Uncertainty Principle

C. Atomic Nucleus
1. Nucleus
2. Radioactivity
3. Isotopes
4. Half-life
5. Transmutation of Elements

D. Nuclear Fission and Fusion
1. Mass-Energy Equivalence
2. Nuclear Fission
3. Nuclear Fusion
PHYSICS 201 - Engineering Physics I

Course Information

PREREQUISITE
Completion of Math 170 (Calculus 1)

INSTRUCTOR
Dr. Curtis Hieggelke (hay-gull-key)
Office: E2012

PHONE: 815 - 280 - 2371
OFFICE HOURS: 9 AM MWF AND 1 PM TR
email: curth@jjc.cc.il.us

REQUIRED MATERIALS

*Physics: For Scientists and Engineers with Modern Physics,* 5th Ed, Serway & Beichner
*Tutorials in Introductory Physics* and *Tutorials in Introductory Physics: Homework*, preliminary edition, McDermott

Homework notebook
Scientific calculator
Blank 3.5” Mac Disk

OPTIONAL MATERIALS
Student Study Guide

COURSE GOALS
The goals of this course are to (1) build a strong and robust understanding of the fundamental concepts in the areas of mechanics and thermodynamics and to (2) develop the skill to explicitly express and use models (mathematical descriptions) to describe the physical world in these areas.

COURSE LEARNING MODE/STRATEGY
This class will utilize active and cooperative learning modes as opposed to the lecture mode found in many other classes. Much of the course materials are under development by your instructor and others, thus there may be mistakes or omissions — please be patient and ask questions if you need clarification. The materials are based on the latest developments in physics education research. There will be many standard pre/post tests to measure your learning gains and gaps in your understanding.

In this course, extensive use of computer technology will also be employed — particularly in the lab, to collect, display, and analyze data. Students will also gain experience with graphing, spreadsheets (MS Excel) and simulation/visualization software (Interactive Physics).

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22 This course information is subject to adjustment. Notification of any changes will be announced in class.
There will be an online web component for this course. In connection with this activity, you will be given an email account and will be able to do access the course web site and email on computers at the college or at home.

It is important to note that each student is responsible for preparing him/herself for each session. This means reading the background material (textbook, lab material) and doing any specific work such as problems or online work before each class. Because of the nature and demands of the schedule of this course, there will be no makeup opportunities for sessions missed or because of the lack of preparation for the class sessions.

LAB WORK

All students must pass the lab in order to receive any passing grade. In order to pass the lab, a student must do (and turn in) at least 80% of the experiments/activities and pass all lab tests. Lab work affecting the final grade because of borderline scores will be evaluated on factors such as completeness, neatness, correctness and performance on the lab test.

Do NOT share your work (data) with lab partners who are not present. Check with your instructor when the deadline is for the completion of the lab work— it may be at the end of the class session, at the beginning of the next class session, or one week after the lab session. You MAY need to schedule time outside of class for lab work if you are not able to complete it within the session(s) scheduled. This includes homework associated with the labs.

HOMEWORK

The in-class homework problem assignments for each chapter will be listed on the problem sheets and are due according to the tentative schedule (subject to modifications during the semester). Students should indicate (circle and total) on the problem sheet those problems they have solved and have a written solution.

These problem sheets are to be turned in at the beginning of the class on the due date. Students may be penalized for not submitting them to the instructor at that time (e.g., late for class). Students will be selected to present solutions (or attempts at such) on the blackboard. This is one of the major activities of this course.

Homework Notebook

Should contain correct(ed) solutions to all assigned problems-rewritten after class discussion.
Problems should be in order in the notebook. If not, the location should be indicated in the correct place.
Label each problem by number and chapter.
Clearly state or paraphrase problem. A sketch or diagram with labels should be included also.
Define symbols with values if known and list known and unknown quantities.
Indicate approach and source of equations— e.g., starting with Newton's 2nd law.
Use words/sentences/phrases between steps indicating process— e.g., solving for t.
Use units in equations/steps or indicate why omitted— e.g., clarity.
Underline or circle answer to each part.
Do not fall behind in keeping this notebook up-to-date.

**FINAL GRADE** based on four factors:
1) 5 major unit exams
2) comprehensive final exam (multiple components)
3) homework
4) lab work

The final grade will be determined from the average of the major unit exams, homework score, and the final exam weighted equivalent to two hour exams. The lowest major unit exam or homework score will not be included in the average. This average score will then be converted to a grade on the following scale:

- A 85 - 100
- B 65 - 85
- C 50 - 65
- D 40 - 50

Scores between 84-87 (A or B), 64-67 (B or C), 49-52 (C or D), and 39-42 (D or F) are considered borderline and lab work will affect the final grade. Pretests will not count toward the final grade.

The homework score will be the product of the percentage of assigned homework worked on or before the due date and the evaluation of the homework notebook. The homework must be completely written up on the due date and must indicate any collaborative efforts (list of names). The evaluation of the homework notebook will be on the basis of completeness and neatness. For example, 80% of the problems worked by the due date and a grade of 90% on the notebook yields a score of 72% (\(0.8 \times 0.9 = 0.72\)).

**OUTSIDE CLASS SCHEDULE ACTIVITIES**

This course is considered a demanding course in terms of effort by an average good (A-/B+) student. You should plan to schedule **at least 14 hours per week** for this course. Check with the Academic Skills Center (2nd floor of J) for extra help and tutoring. In addition, you will also need to plan to spend some time in the Physics Lab or the Academic Computer Center in E1001. This Center is open during the days, evenings, and Saturday mornings. Check the schedule on the door.

**PLEASE LIMIT OR REDUCE YOUR OUTSIDE WORK SCHEDULE.**

**ATTENDANCE/WITHDRAWAL**

Students are expected to attend all class sessions.

Students MAY be recommended for withdrawal if they have missed an excessive number of classes (more than 3). Students deciding to drop the class are expected to follow normal college procedures. Failure to attend is NOT proper procedure for dropping the class.

**MAKE-UP POLICY**
1) Homework (problems sheet AND work) must either be submitted in advance or other prior arrangements made to receive full/partial credit for it. If a student is sick or out-of-town, it will be accepted if it is mailed with a postmark on or before the date the assignment is due. All such homework must be submitted at the level of homework notebook in order to receive credit. Homework is not accepted late.

2) Tests sometimes may be made up at the discretion of the instructor providing prior or timely notice is provided. Phone messages are date and time stamped and may be received anytime. All such tests must be completed before tests are returned to the class.

3) Lab work is very difficult to make-up because of scheduling problems. Sometimes it can be arranged to be done in the afternoons depending on the nature of the lab and/or the schedule of the instructor or staff.

INAPPROPRIATE BEHAVIOR

Students are expected to be responsible and to take credit for their own individual work. There are times when collaborative efforts in class are expected (lab) and there are times when it is OK (homework) — but this should be work sharing not copying. Of course, there are times when collaboration is forbidden (tests or lab data when not present) — if this occurs appropriate action will be taken depending on the nature and seriousness of this action. You are not allowed to copy software, only to save data files on disk.

No food or drink (except for water) is allowed in the classroom. No food or drink is allowed in the lab.

The college has a strong and firm policy against racial or sexual harassment. Such conduct will not be tolerated in this class, and any victims are encouraged to report any incidents. Learning is best achieved in an environment of mutual respect and trust.

WEB Online Course ACCESS

To connect to the web section of this course, launch some type of browser software such as Netscape Navigator or Internet Explorer and connect to http://online.jjc.cc.il.us. You can also enter this via the college homepage http://www.jjc.cc.il.us and look for the link to Blackboard. You can do this from any college computer or from home using your internet provider such as America Online. Then log in and select this course from "My Blackboard." Your Blackboard login user name is your full JJC E-mail address. For example, if your user name was: rwennerd and you are a student, it is now: rwennerd@student.jjc.cc.il.us. Your password are the first 5 digits of your social security number with no space or -. For help with the Blackboards system, please contact R Scott Wennerdahl at 280-2275 or email rwennerd@jjc.cc.il.us.

SAFETY

Safety should be practiced by students in all aspects of this course. There are some rules (such as no eating or drinking in class/lab) but in general, common sense should be used as a guide. MSDS (Material Safety Data Sheets) for all chemicals are available in the campus police office for students. In physics, it is unusual to use any chemicals that are hazardous. Special instructions will be given in the lab if needed. If in doubt, ask your instructor. Safety violations
are taken seriously and everyone should be aware that appropriate action will be taken if necessary.

CAVEAT
The course schedule and the above information is subject to adjustment. Adequate notification of any changes will be announced and posted in class.

Study Hints to work smarter
1. Set Priorities
2. No intrusions on study. Study is or should be your main focus.
3. Study anywhere — or everywhere
4. Stick with consistent time slot for study — schedule and maintain it
5. Get organized.
6. Do more than you are asked — more problems for example.
7. Schedule your time — break up major projects.
8. Take good notes and use them.
9. Don’t fall behind on your homework notebook or lab work and remember neatness counts!
10. Speak up — ask questions when you don’t understand or when you think you do.
11. Study together — discuss, don’t copy.
12. Test yourself — make up possible test questions and answer them.

OUTLINE

I. PHYSICS AND MEASUREMENT
   A. Standards of Length, mass, and time
   B. Uncertainty and Significant Figures
   C. Dimensional Analysis
   D. Measurements and Units

II. VECTORS
   A. Coordinate Systems and Reference Frames
      1. origin
      2. set of axes
      3. point labeling rules
      4. rectangular
      5. polar
   B. Vectors and Scalars
      1. scalar definition
      2. vector definition
   C. Some Properties of Vectors
      1. equality of two vectors
      2. addition
      3. resultant vector
      4. commutative law of addition
      5. associative law of addition
      6. negative of a vector
7. subtraction of vectors
8. vector components
9. unit vector notation

D. Vector Addition Methods
1. geometric and graphical methods
2. adding three or more vectors
3. algebraic/component method

E. Multiplication
1. scalar-vector
2. vector-vector
   i) dot product
   ii) cross product

III. MOTION IN ONE DIMENSION
A. Position/Displacement
   1. Motion diagrams
   2. Motion graphs
B. Velocity
   1. average velocity
   2. instantaneous velocity
   3. derivative
C. Acceleration
   1. average acceleration
   2. instantaneous acceleration
D. One-dimensional Motion with Constant Acceleration
   1. velocity graphs/equations as a function of time
   2. displacement graphs/equations as a function of time
   3. velocity as a function of displacement
E. Freely Falling Bodies
   1. acceleration due to gravity
   2. free fall motion
   3. kinematic equations

IV. MOTION IN TWO DIMENSIONS
A. Kinematic Vectors in Two Dimensions
   1. displacement vector
   2. average velocity
   3. instantaneous velocity
   4. average acceleration
   5. instantaneous acceleration
B. Motion in Two Dimensions with Constant Acceleration
   1. velocity vector as a function of time
   2. position vector as a function of time
C. Projectile Motion
   1. definition
   2. trajectory of a projectile
3. equations of motion
4. height of projectile
5. range of projectile
6. time of flight

D. Tangential and Radial Acceleration in Curvilinear Motion
   1. tangential acceleration
   2. centripetal acceleration
   3. total acceleration

E. Relative Motion
   1. relative position
   2. relative velocity
   3. relative acceleration

V. THE LAWS OF MOTION
   A. The Concept of Force
      1. definition
      2. types
      3. fundamental forces in nature
   B. Newton's First Law
   C. Inertial Mass
      1. inertia
      2. mass
      3. weight
   D. Newton's Second Law
      1. restricted form
      2. momentum
      3. unrestricted form
   E. Units of Force and Mass
      1. Newton
      2. dyne
      3. pound/slug
   F. Weight
   G. Newton's Third Law
   H. Applications of Newton's Laws
      1. normal force
      2. tension
      3. free-body diagrams
   I. Resistive Forces of Friction
      1. sliding
         i) static
         ii) kinetic
      2. rolling
      3. fluid
         i) terminal velocity
         ii) drag force proportional to the velocity
         iii) drag force proportional to the velocity squared
J. Newton's Universal Law of Gravity
K. Circular Motion
  1. uniform circular motion
     i) magnitude
     ii) direction
  2. non-uniform circular motion

VI. WORK
A. Work Done by a Constant Force
   1. work done by a sliding force
   2. work done when $F$ is along $s$
   3. work is a scalar quantity
B. Work Done by a Varying one-dimensional Force
   1. area under the curve
   2. integral of single variable
C. Work Done by a Varying Force-General Line Integral
D. Work Done by a Spring
   1. spring force
   2. work done by a spring force
E. Work and Kinetic Energy
   1. kinetic energy
   2. work-energy theorem
   3. work-energy theorem bar graphs
F. Power
   1. average power
   2. instantaneous power
   3. units

VII. ENERGY
A. Conservative Forces
   1. definition
   2. examples
B. Non-conservative Forces
   1. definition
   2. examples
C. Potential Energy
   1. definition
      i) one dimensional case
      ii) general case-line integral
   2. change in potential energy
   3. zero point
   4. relationship with conservative forces
      i) one dimensional case
      ii) general case-gradient
   5. examples
      i) gravitational potential energy
ii) elastic spring potential energy

D. Mechanical Energy
   1. definition
   2. conservation of mechanical energy
   3. examples

E. Work Done by Non Conservative Forces

F. Relationship between Conservative Forces and Potential Energy

G. Potential Energy Diagrams
   1. stable equilibrium
   2. unstable equilibrium
   3. neutral equilibrium

H. General Conservation of Energy and energy bar graphs

VIII. LINEAR MOMENTUM AND COLLISIONS

A. Linear Momentum and Impulse
   1. linear momentum of a particle
   2. impulse of a force
   3. impulse-momentum theorem
   4. impulse approximation

B. Conservation of Linear Momentum
   1. condition
   2. examples

C. Collisions
   1. types
      i) inelastic collision
      ii) elastic collision
   2. properties

D. One-Dimensional Collisions
   1. coefficient of restitution
   2. equations relating initial and final velocities

E. Two-Dimensional Collisions

F. Motion of a System of Particles
   1. definition of the center of mass
   2. center of mass for a discrete system of particles
   3. center of mass for a continuous mass system
   4. velocity of the center of mass of a system of particles
   5. total linear momentum of a system of particles
   6. acceleration of the center of mass of a system of particles
   7. Newton's second law for a system of particles

IX. ROTATION OF A RIGID BODY ABOUT A FIXED AXIS

A. Rotational Kinematics
   1. angular position
   2. radian
   3. average angular velocity
   4. instantaneous angular velocity
5. average angular acceleration
6. instantaneous angular acceleration

B. Rotational Kinematical Equations

C. Relationships between Angular and Linear Quantities
   1. linear and angular speed
   2. linear and angular acceleration
   3. radial acceleration
   4. magnitude of total acceleration

D. Rotational Kinetic Energy
   1. moment of inertia
   2. kinetic energy of a rotating rigid body

E. Calculation of Moments of Inertia for Rigid Bodies
   1. moment of inertia for a rigid body
   2. parallel axis theorem
   3. plane figure theorem
   4. combination

F. Torque
   1. definition
   2. moment/lever arm
   3. torque and angular acceleration

G. Work and Energy in Rotational Motion
   1. power delivered to a rigid body
   2. work-energy theorem for rotational motion

X. ANGULAR MOMENTUM
   A. The Vector Product and Torque
      1. definition of torque
      2. properties of the vector product
      3. cross products of unit vectors
   B. Angular Momentum
      1. definition of a particle
      2. definition of a system of particles
   C. Angular Momentum and Torque
   D. Conservation of Angular Momentum
   E. The Motion of Gyroscopes and Tops
   F. Rolling Motion of a Rigid Body
      1. rotational kinetic energy of a rolling body
      2. translational kinetic energy of a rolling body
      3. total kinetic energy of a rolling body
   G. Angular Momentum as a Fundamental Quantity

XI. STATIC EQUILIBRIUM OF A RIGID BODY
   A. The Conditions of Equilibrium of a Rigid Body
      1. equivalent forces
      2. coupling
      3. conditions for equilibrium
B. The Center of Gravity
C. Example of Rigid Bodies in Static Equilibrium
   1. procedure of analyzing a body in equilibrium
   2. examples

XII. OSCILLATORY MOTION
A. Simple Harmonic Motion
   1. displacement versus time
   2. period
   3. frequency
   4. angular frequency
   5. velocity in simple harmonic motion
   6. maximum values of acceleration and velocity
   7. phase angle and amplitude
   8. properties of simple harmonic motion
B. Mass Attached to a Spring
   1. Linear restoring force
   2. proportionality of acceleration to displacement
   3. equation of motion for a mass spring system
   4. period and frequency for a mass spring system
C. Energy of the Simple Harmonic Oscillator
   1. kinetic energy
   2. potential energy
   3. total energy
   4. velocity as a function of position
D. The Pendulum
   1. equation of motion for simple pendulum
   2. angular frequency of motion
   3. period of motion
E. Damped Oscillations
F. Forced Oscillations

XIII. FLUID MECHANICS (time permitting)
A. Pressure
B. Variation of Pressure with Depth
C. Pressure Measurements
D. Buoyant Forces and Archimedes’ Principle
E. Fluid Dynamics
F. Streamlines and the Equation of Continuity
G. Bernoulli’s Equation

XIV. TEMPERATURE AND THERMAL EXPANSION
A. Temperature
   1. thermal Contact
   2. thermal equilibrium
   3. Zeroeth Law of Thermodynamics
B. Thermometers and Thermometric Properties
C. The Constant Volume Gas Thermometer
   1. Temperature Scales
   2. Celsius scale
   3. Kelvin scale
   4. Fahrenheit scale
   5. Rankin scale
   6. triple point of water
D. Thermal Expansion of Solids and Liquids
   1. Linear Expansion
   2. Volume Expansion
   3. Differential Rate of Expansion
F. Ideal Gas Law

XV. HEAT AND THE FIRST LAW OF THERMODYNAMICS
A. Heat and Thermal Energy
   1. heat flow
   2. units
   3. mechanical equivalent of heat
B. Heat Capacity and Specific Heat
   1. Specific heat
   2. heat capacity
   3. molar heat capacity
C. Latent Heat and Phase Change
   1. fusion
   2. vaporization
D. Heat Transfer
   1. conduction
   2. convection
   3. radiation
E. Work and Heat in Thermodynamic Processes
   1. state of a system
   2. work done by gas
   3. work and path between final and initial states
   4. heat and path between final and initial states
F. First Law of Thermodynamics
   1. internal energy
   2. isolated system
   3. cyclic process
G. Applications of the First Law of Thermodynamics
   1. adiabatic process
   2. isobaric process
   3. constant process
   4. isothermal process

XVI. THE KINETIC THEORY OF GASES
A. Molecular Model for the Pressure of an Ideal Gas
   1. assumptions of molecular model
   2. pressure and molecular speed
   3. pressure and molecular kinetic energy
   4. molecular interpretation of temperature
B. Heat Capacity of an Ideal Gas
   1. total internal energy of a monatomic gas
   2. constant volume/pressure heat capacity
   3. heat capacity ratio
C. Adiabatic Process for an Ideal Gas
   1. definition
   2. process relationship
D. The Equipartition of Energy
E. Distribution of Molecular Speeds
   1. RMS speed
   2. average speed
   3. most probable speed

XVII. THE SECOND LAW OF THERMODYNAMICS
A. Heat engines and Heat Pumps - Refrigeration
   1. heat engine
   2. thermal efficiency
   3. coefficient of performance
   4. Second Law of Thermodynamics
B. Processes
   1. irreversible process
   2. reversible process
C. The Carnot Engine
   1. Carnot cycle
   2. Carnot cycle efficiency
   3. ratio of heats
D. The absolute temperature Scale
E. Entropy
   1. definition
   2. change entropy for a finite process
   3. change entropy for a Carnot cycle
F. Entropy Changes in Irreversible Processes
   1. heat conduction
   2. change of state
   3. entropy of mixing
PHYSICS 202 - ENGINEERING PHYSICS II
Course Information

PREREQUISITE Completion of Physics 201

INSTRUCTOR Dr. Curtis Hieggelke (hay-gull-key)

OFFICE: E2012
PHONE: 815-280-2371
OFFICE HOURS: 9 AM MWF AND 1 PM TR
EMAIL: CURTH@JJC.CC.IL.US

REQUIRED MATERIALS

Physics: For Scientists and Engineers with Modern Physics,
4th Ed, Serway

Tutorials in Introductory Physics and Tutorials in Introductory Physics:
Homework, preliminary edition, McDermott

Bound cross-hatch paper Lab book

HOMEWORK NOTEBOOK

Scientific calculator
3.5” Mac Disk

OPTIONAL MATERIALS Student Study Guide

COURSE GOALS
The goals of this course are to (1) build an excellent understanding of the fundamental concepts in the areas of electricity, magnetism, waves, and optics and to (2) develop the skill to explicitly express and use models (mathematical descriptions) to describe the physical world in these areas.

COURSE LEARNING MODE/STRATEGY
This class will utilize an active learning mode as was used in Physics 201 as opposed to the lecture mode found in many other classes. In addition, there will be more cooperative collaborative activities involving teams. Much of the course materials are under development by your instructor and others, thus there may be mistakes or omissions — be patient and ask questions if you need clarification.

There will be pre/post tests to measure your learning gains and gaps in your understanding. There may also be videotaped interviews for research in physics education.

This course information is subject to adjustment. Notification of any changes will be announced in class.
There will be an online web component for this course. In connection with this activity, you will be given an email account and will be able to do access the course web site and email on computers at the college or at home.

It is important to note that each student is responsible for preparing him/herself for each session. This means reading the background material (textbook, ALPS, CASTLE material) and doing any specific work such as problems or ALPS or TIPERs before each class. Because of the nature and demands of the schedule of this course, there will be no makeup for sessions missed or because of the lack of preparation for the class sessions.

LAB WORK

All students **must pass** the lab in order to receive any passing grade. In order to pass the lab, a student must do at least 80% of the experiments and pass all lab tests. Lab work affecting the final grade because of borderline scores will be evaluated on factors such as completeness, neatness, and correctness. Check with your instructor when the deadline is for completion of the lab work—it may be at the end of the class session, at the beginning of the next class session, or one week after the lab session. You MAY need to schedule time outside of class for lab work if you are not able to complete it within the session(s) scheduled. This includes homework associated with the labs.

SAFETY

Students in all aspects of this course should practice safety. There are some rules (such as no eating or drinking in class/lab) but in general, common sense should be used as a guide. If in doubt, ask your instructor. Safety violations are taken seriously and everyone should be aware that appropriate action would be taken if necessary.

HOMEWORK NOTEBOOK

Should contain correct (ed) solutions to all assigned problems—rewritten after class discussion.

Problems should be in order in the notebook. If not, the location should be indicated in the correct place.

Label each problem by number and chapter.

Clearly state or paraphrase problem. A sketch or diagram with labels should be included also.

Define symbols with values if known and list known and unknown quantities.

Indicate approach and source of equations—e.g., starting with Newton's 2nd law.

Use words/sentences/phrases between steps indicating process—e.g., solving for t.

Use units in equations/steps or indicate why omitted—e.g., clarity.

Underline or circle answer to each part.

Do not fall behind in keeping this notebook up-to-date.

FINAL GRADE based on four factors:

1) 5 major unit exams
2) Comprehensive final exam (multiple components)
3) Homework
4) Lab work

The final grade will be determined from the average of the unit exams, homework score, and the final exam weighted equivalent to two unit exams. Either the lowest unit exam or the homework will not be included in the average. This average score will then be converted to a grade on the following scale:

- A 85 - 100
- B 65 - 85
- C 50 - 65
- D 40 - 50

Scores between 84-87 (A or B), 64-67 (B or C), 49-52 (C or D), and 39-42 (D or F) are considered borderline and lab work will affect the final grade. Pretests will not count toward the final grade.

The homework score will be the product of the percentage of assigned homework worked on or before the due date and the evaluation of the homework notebook. The evaluation of the homework notebook will be on the basis of completeness and neatness. For example, 80% of the problems worked by the due date and a grade of 90% on the notebook yields a score of 72% (.8 x .9 = .72).

The homework must be written up and the corresponding problem sheet turned in on the due date at the START of the class. If you are late to class, you probably will be penalized if it is accepted at all. You must indicate any collaborative efforts (list of names) on your homework.

MAKE-UP POLICY

1) Homework problems and problem sheets must either be submitted in advance or other prior arrangements made to receive full/partial credit for it. If a student is sick or out-of-town, it will be accepted if it is mailed along with the problem sheet with a postmark on or before the date the assignment is due. All homework submitted must be done at the same level of the homework notebook in order to receive credit.

2) Tests can be made up at the discretion of the instructor providing prior or timely notice is provided. Phone messages are date and time stamped and may be received anytime. All makeup tests must be completed before tests are returned to the class.

3) Lab work is very difficult to make-up because of scheduling problems. Sometimes it can be arranged in the mornings or afternoons depending on the schedule of the instructor and the lab.

ATTENDANCE/WITHDRAWAL

Students are expected to attend all class sessions.

Students MAY be recommended for withdrawal if they have missed an excessive number of classes (more than 2), poor performance, or improper conduct. Students dropping the class are expected to follow normal college procedures.
INAPPROPRIATE BEHAVIOR

Students are expected to be responsible and to take credit for their own individual work. There are times when collaborative efforts are expected (lab) and there are times when it is OK (homework) — but this should be work sharing not copying. Of course, there are times when collaboration is forbidden (tests) — if this occurs appropriate action will be taken depending on the nature and seriousness of this action. It should be noted that software may NOT be copied; only data files may be saved to your own disk.

No food or drink (except for water) is allowed in the classroom. No food or drink is allowed in the lab.

The college has a strong and firm policy against racial or sexual harassment. Such conduct will not be tolerated in this class, and any victims are encouraged to report any incidents. Learning is best achieved in an environment of mutual respect and trust.

OUTSIDE CLASS SCHEDULE ACTIVITIES-

An average good (A-/B+) student considers this course a demanding one in terms of effort. You should plan to need at least 14 hours per week. Check with the Academic Skills Center (2nd floor of J) for extra help and tutoring. PLEASE LIMIT OR REDUCE OUTSIDE WORK SCHEDULE.

You will also need to spend some time in the Physics Lab or the Math-Science Academic Computer Center in E1001. This Center is open during the days, evenings, and Saturday mornings. Check the schedule on the door.

WEB Online Course ACCESS

To connect to the web section of this course, launch some type of browser software such as Netscape Navigator or Internet Explorer and connect to http://online.jjc.cc.il.us. You can also enter this via the college homepage http://www.jjc.cc.il.us and look for the link to Blackboard. You can do this from any college computer or from home using your internet provider such as America Online. Then log in and select this course from "My Blackboard." Your Blackboard login user name is your full JJC E-mail address. For example, if your user name was: rwennerd and you are a student, it is now: rwennerd@student.jjc.cc.il.us. Your password are the first 5 digits of your social security number with no space or -. For help with the Blackboards system, please contact R Scott Wennerdahl at 280-2275 or email rwennerd@jjc.cc.il.us.

CAVEAT

The course schedule and this information is subject to adjustment. Adequate notification of any changes will be announced and posted.

Course Outline

I. ELECTRIC FIELDS
A. Introduction

B. Properties
   1. Electric Charges
   2. Insulators
   3. Conductors

C. Electric Force
   1. charge units
   2. force direction
   3. Coulomb's Law
   4. three point charges systems

D. Electric Field
   1. definition and units
   2. discrete charge distribution
      a. single point charge
      b. group of point charges
      c. electric dipole
   3. continuous charge distribution-vector integral
      a. volume, surface and linear charge density
      b. charged rod
      c. uniform ring of charge
      d. uniformly charged disk

E. Electric Field Lines

F. Uniform Electric Field

G. Electric Dipole in a Uniform Electric Field
   1. electric dipole moment
   2. torque on an electric dipole in a uniform electric field
   3. potential energy of an electric dipole in a uniform electric field

II. GAUSS' LAW

A. Electric Flux
   1. flux of vector field
   2. definition of electric flux
   3. net flux through a closed surface
   4. flux through a cube

B. Gauss' Law
   1. flux through a closed surface
   2. net charge with a closed surface

C. Application of Gauss' Law
   1. point charge
   2. spherically symmetrical charge distribution
   3. cylindrically symmetrical charge distribution
   4. infinite sheet of charge

D. Charged Conductors
   1. electric field just outside
   2. electric field inside
III. ELECTRIC POTENTIAL

A. Electric Potential
   1. electric potential energy
   2. definition of electric potential-line integral
   3. volt and electron volt
   4. equipotential surface
   5. electric potential difference

B. Uniform Electric Field
   1. potential difference
   2. electric field and potential difference
   3. change in electric potential energy

C. Electric Potential of a Discrete Charge Distribution
   1. a single point charges
   2. collection of a several point charges
   3. electric potential energy of a collection of charges
   4. electric potential of a dipole

D. Electric Potential of a Continuous Charge Distribution
   1. electric potential of an infinitesimal charge
   2. uniformly charged ring
   3. uniformly charged disk
   4. finite charged line
   5. uniformly charged sphere

E. Electric Field and the Electric Potential
   1. gradient operator
   2. gradient of the potential
   3. electric field from the gradient of the potential

F. Charged Conductor-inside and outside
   1. hollow conducting sphere
   2. solid conducting sphere

IV. CAPACITANCE

A. General Capacitance
   1. definition
   2. units

B. Calculation of Capacitance
   1. parallel plate capacitor
   2. cylindrical plate capacitor
   3. spherical capacitor

C. Combinations of Capacitors
   1. equivalent capacitance
   2. parallel combination of capacitors
   3. series combination of capacitors

D. Energy Stored
   1. energy stored in a single charged capacitor
2. energy stored in a group of capacitors
3. energy density in an electric field

E. Capacitors with Dielectrics
   1. dielectric constant
   2. effects of dielectric materials
   3. dielectric electric field strength
   4. energy changes with dielectric materials

V. DC CURRENT
   A. Electric Current
      1. definition and units
      2. direction
      3. current in a conductor
      4. drift velocity
      5. current density
   B. Resistance
      1. definition and units
      2. Ohm's law
      3. resistivity and conductivity
      4. resistance of a uniform conductor
   C. Resistivity
      1. variation with temperature
      2. superconductors
   D. Electric Energy and Power
      1. power
      2. energy
      3. joule heat
   E. Electric Conduction Model

VI. DIRECT CURRENT CIRCUITS
   A. Electromotive Force
      1. terminal voltage
      2. power output
      3. in series and parallel
   B. Resistors in Series and Parallel
      1. equivalent resistance
      2. resistors in series
      3. resistors in parallel
      4. current, voltage, and power
   C. Kirchoff's Law
      1. basis
      2. rule for applying
      3. applications
   D. RC Circuits
      1. opening and closing
      2. maximum current
3. maximum charge
4. current versus time
5. charge versus time

E. Special Circuits
1. wheatstone bridge
2. potentiometer
3. voltmeter
4. ammeter

VII. MAGNETIC FIELDS
A. Introduction
B. Properties of the Magnetic Field
1. force on a charged particle in magnetic field
2. definition of the magnetic field
   a. magnitude
   b. direction
   c. units-tests, gauss, weber/meter²
3. differences between magnetic and electric fields
C. Magnetic Force on a Current-Carrying Conductor
1. force on a straight wire carrying a current
2. force on a current element
3. total force on a wire in magnetic field
4. force on wire in uniform magnetic field
D. Current Loop in a Uniform Magnetic Field
1. torque on closed current loop of wire
2. magnetic moment of a current loop
E. Motion of a Charged Particle in a Magnetic Field
1. radius of circular orbit
2. frequency
F. Charged Particles in Electric and Magnetic Fields
1. Lorentz force
2. velocity selector
3. mass spectrometer
G. The Hall Effect

VIII. SOURCES OF THE MAGNETIC FIELD
A. The Biot-Savart Law
1. magnetic field due to current element
2. permeability of free space
3. applications
   a. around a finite thin, straight line
   b. around an infinite thin, straight line
   c. near the center of a circular arc
   d. on the axis of a circular current loop
B. The Magnetic Force Between Two Parallel Conductors
C. Ampere's Law
   1. statement
   2. applications
      a. around an infinite straight line
      b. center of a toroidal coil
      c. outside of an infinite current sheet
      d. inside a solenoid

C. Magnetic Flux

D. Gauss' Law in Magnetism

E. Magnetic Field Along the Axis of a Solenoid

F. Generalized Ampere's Law
   1. displacement current
   2. Ampere-Maxwell law

IX. FARADAY'S LAW
A. Faraday's Law of Induction
   1. changing magnetic flux
   2. induced emf
   3. induced current
   4. Lenz's law
B. Applications
   1. motional emf
   2. power delivered by applied force
   3. rotating conductor
   4. sliding bar conductor

C. Induced Electric Fields

D. Generators and Motors

E. Eddy Currents

F. Maxwell's Equations
   1. Gauss' law
   2. Gauss' law in magnetism
   3. Faraday's law
   4. Ampere-Maxwell law

X. INDUCTANCE
A. Self-Inductance
   1. induced emf
   2. inductance
   3. units
   4. inductance of a coil
   5. inductance of a solenoid
   6. inductance of a coaxial cable

B. RL Circuits
   1. current as a function of time
   2. time constant

C. Energy in a Magnetic Field
1. energy stored in an inductor
2. magnetic energy density

D. Mutual Inductance
1. definition
2. induced emf
3. application

E. Oscillations in an LC Circuit
1. total energy stored
2. charge versus time
3. frequency of oscillation
4. current versus time

F. RLC Circuit
1. charge as a function of time
2. frequency of oscillation

XI. MAGNETISM IN MATTER
A. Magnetization of a Substance
1. description
2. magnetic intensity
3. magnetic intensity

B. Magnetic Moment of Atoms
1. orbital magnetic moment
2. magnetic moment of electron
3. Bohr magneton
4. saturation magnetization

C. Paramagnetism
1. Curie's Law
2. induced magnetization

D. Diamagnetism

E. Ferromagnetism
1. Curie temperature
2. hysteresis

XII. ALTERNATING CURRENT CIRCUITS (time permitting)
A. AC Circuit
1. sinusoidal voltage input
2. angular frequency
3. instantaneous voltage drop
4. sinusoidal current
5. resistor
   a. maximum current
   b. voltage drop across
   c. phase angle

B. Inductors in an AC Circuit
1. inductive reactance
2. instantaneous current
3. instantaneous voltage drop across inductor
4. phase angle

C. Capacitors in an AC Circuit
1. capacitive reactance
2. instantaneous charge and current
3. current and the voltage across a capacitor
4. phase angle

D. RLC Series Circuit
1. instantaneous voltage drop across
   a. resistor
   b. inductor
   c. capacitor
2. maximum voltage across
   a. resistor
   b. inductor
   c. capacitor
3. impedance
4. phase angle

E. Power in an AC Circuit
1. instantaneous power
2. rms voltage
3. rms current
4. average power

F. Resonance In a Series RLC Circuit
1. instantaneous current
2. resonance frequency
3. power in an RLC circuit
4. quality factor

G. Transformer and Power Transmission
1. step-up voltage
2. power
3. equivalent resistance
4. power loss in transformer

XIII. WAVE MOTION
A. Types of Waves
B. One-dimensional Traveling Waves
C. Superposition and Interference of Waves
D. The Velocity of Waves on Strings
E. Reflection and transmission of Waves
F. Harmonic Waves
   1. wave number
   2. angular frequency
   3. wave function for a harmonic wave
   4. velocity of a harmonic wave
   5. general relation for a harmonic wave
G. Energy/Power Transmitted by Waves
H. Linear Wave Equation

XIV. SOUND WAVES
A. Velocity of Sound Waves
   1. speed of sound in solids
   2. sound waves in gas
   3. temperature dependence
B. Harmonic Sound Waves
   1. harmonic displacement
   2. pressure variation/amplitude
C. Energy and Intensity of Harmonic Sound Waves
   1. intensity in watts/m³
   2. intensity in decibels
D. Spherical and Planar Waves
   1. intensity of spherical wave
   2. wave function for a spherical wave
E. Doppler Effect
   1. observer in motion
   2. source in motion
   3. observer and source in motion

XV. SUPERPOSITION AND STANDING WAVES
A. Superposition and Interference of Harmonic Waves
   1. resultant of two traveling harmonic waves
   2. constructive and destructive interference
B. Standing Waves
   1. wave function for a standing wave
   2. position of antinodes
   3. position of nodes
C. Standing waves in a string fixed at both ends
   1. wavelength
   2. frequencies
   3. normal modes of a stretched string
D. Resonance
E. Standing Waves in Air Columns
   1. natural frequencies of a pipe open at both ends
   2. natural frequencies of a pipe closed at both ends
F. Standing Waves in Rods and Plates
G. Beats: Interference in Time
   1. definition of beats
   2. beat frequency
H. Complex Waves

XVI. ELECTROMAGNETIC WAVES (time permitting)
A. Introduction
1. Maxwell's equations
2. Hertz's Discoveries

B. Plane Electromagnetic Waves
   1. wave equations for electromagnetic waves in free space
   2. speed of light
   3. sinusoidal electric and magnetic fields
   4. electric field and magnetic field relationship
      a. phase
      b. ratio of magnitudes

C. Energy and Momentum of Electromagnetic Waves
   1. Pointing vector
   2. Pointing vector for a planar wave
   3. wave intensity
   4. energy density
   5. power
   6. wave intensity
   7. momentum
      a. an absorbing surface
      b. a perfectly reflecting surface
   8. radiation pressure exerted on
      a. a perfect absorbing surface
      b. a perfectly reflecting surface
      c. a partial reflecting surface
   9. average energy density

D. Production of Electromagnetic Waves by an Antenna

E. Spectrum of Electromagnetic Waves
   1. radio waves
   2. microwaves
   3. infrared waves
   4. visible waves
   5. ultraviolet waves
   6. x-rays
   7. gamma rays

XVII. THE NATURE OF LIGHT AND THE LAWS OF GEOMETRIC OPTICS

A. The Nature of Light
   1. photon energy
   2. measurements of the speed of light
      a. Roemer method
      b. Fizeau's technique
      c. Speed of Light

B. The Ray Approximation in Geometric Optics

C. The Laws of Reflection and Refraction at Planar Surfaces
   1. law of reflection
   2. law of refraction
   3. the index of refraction
4. the index of refraction and wavelength
5. Snell's law of refraction
D. Huygen's Principle
E. Prisms
F. Total Internal Reflection
   1. critical angle
   2. light pipes
G. Light Intensity
   1. reflection
   2. transmission
   3. absorption

XVIII. GEOMETRIC OPTICS
A. Images Formed by Planar Mirrors
   1. lateral magnification
   2. images made by mirrors
B. Images Formed by Spherical Mirrors
   1. focal length
   2. mirror equation
   3. magnification of a mirror
   4. sign convention for mirrors
   5. concave mirror
   6. convex mirror
C. Ray Diagrams for Mirrors
D. Images Formed by Refraction
E. Thin Lenses
   1. thin lens formula
   2. lens makers formula
   3. focal length of two lenses in contact
   4. diverging lens
   5. converging lens
   6. combination of thin lenses
F. Lens Aberrations
G. The Camera
   1. f-number
   2. light intensity
   3. exposure time and f-number
H. The Eye
   1. operation
   2. nearsightedness
   3. farsightedness
   4. astigmatism
I. Enlarging Systems
   1. simple magnifier
   2. microscopic
   3. telescope
XIX. WAVE OPTICS

A. Interference
   1. conditions
   2. coherent sources
   3. source phase
   4. path difference
   5. reflection phase change

B. Double-Slit Interference Pattern
   1. bright fringes
   2. dark fringes
   3. intensity distribution

C. Thin Film Interference
   1. reflection
   2. transmission
   3. air wedge

D. Michelson Interferometer

E. Diffraction Grating
   1. interference conditions
   2. resolving power

F. Diffraction

G. Single-slit Diffraction Pattern
   1. Fraunhofer
   2. Fresnel
   3. Rayleigh's resolution criteria

H. Holography

I. Polarization
   1. types of polarization
   2. types of production processes
   3. transmission intensity
D. Pre- and Post-tests Used by Curt for Formative Assessment

Curt’s students begin their semester with him by spending two to four hours on diagnostic pre-tests. He draws on tests from the following list, selecting those appropriate for the particular course he is teaching.


- **Conceptual Survey of Electricity and Magnetism (CSEM):** See Hieggelke et al. (1996). During four years of testing and refinement, the CSEM has been given in one form or another and data collected from more than 8,000 introductory physics students at more than 30 different institutions in a pre/post test mode. It contains 32 questions that comprise a subset of the questions on the CSE and CSM.

- **Conceptual Survey of Electricity (CSE):** See Hieggelke et al. (1996). The CSE was developed to assess students' knowledge of topics in electricity. It combines the electricity questions from the CSEM with a few multiple-choice items, for a total of 32 questions.

- **Conceptual Survey of Magnetism (CSM):** See Hieggelke et al. (1996). The CSM was developed to assess students' knowledge about topics in magnetism. This test (21 multiple-choice questions) is used as both a pre-test and post-test for second semester introductory physics courses. It contains the magnetism questions in the CSEM as well as a few more multiple choice questions.


**Post-tests**

Note that the following tests have been developed by physics faculty across the country and are used across the nation to provide comparative, summative data on student learning:

• **Determining Interpreting Resistive Electric Circuits Concepts Test (DIRECT):** See [http://www2.ncsu.edu/ncsu/pams/physics/Physicsex_Ed/](http://www2.ncsu.edu/ncsu/pams/physics/Physicsex_Ed/) Contact Paula Engelhardt (pgve@hino.email.ne.jp) or Robert Beichner (beichner@ncsu.edu).

• **Mechanics Baseline Test (MBT):** See Hestenes & Wells (1992). This is a companion to the FCI, used as a post-test in order to measure problem-solving skills in physics. Normative scores for this test are published. It is available with password at [http://modeling.la.asu.edu/](http://modeling.la.asu.edu/).


E. Curt’s Tasks Inspired by Physics Education Research (TIPERs)

Ranking Tasks
A Ranking Task (O’Kuma, Maloney, & Hieggelke, 2000) is an exercise that presents students with a set of variations, sometimes three or four but usually six to eight, on a basic physical situation. The variations differ in the values (numeric or symbolic) for the variables involved but also frequently include variables that are not important to the task. Students are to rank the variations on the basis of a specified physical quantity. Students must also explain the reasoning for their ranking schemes and rate their confidence in their rankings. These tasks require students to engage in a comparison reasoning process that they seldom do otherwise.

Working Backwards Tasks
The Working Backwards Task, which could also be referred to as a “Physics Jeopardy” task (Van Heuvelen & D’Alessandris, 1999), essentially reverses the order of the problem steps. For example, the given information could be an equation with specific values for all, or all but one, of the variables. The students then have to construct a physical situation for which the given equation would apply. Such working backwards tasks require students to take numerical values, including units, and translate them into physical variables. Working backwards problems also require students to reason about these situations in an unusual way, and they often allow for more than one solution.

What, If Anything, Is Wrong Tasks
What, If Anything, Is Wrong Task (Peters, 1982) requires students to analyze a statement or diagrammed situation to determine if it is correct or not. If everything is correct the student is asked to explain what is going on and why it works as described. If something is incorrect the student has to identify the error and explain how to correct it. These are open-ended exercises so they provide insights into students ideas (since students will often have interesting reasons for accepting incorrect situations while rejecting legitimate situations), and often students’ responses provide ideas for other items.

Troubleshooting Tasks
Troubleshooting Tasks are variations on the What, If Anything, Is Wrong Tasks. In these items, the students are explicitly told that there is an error in the given situation. Their job is to determine what the error is and explain how to correct it. These tasks can often produce interesting insights into students’ thinking because they will, at times, identify some correct aspect of the situation as erroneous. Once again, this helps develop additional items.

Bar Chart Tasks
Bar Chart Tasks have histograms for one or more quantities. Frequently histograms are given for before and after some physical process with one bar left off. Students are asked to complete the bar chart by supplying the value for the missing quantity. These are a new, or less frequently used, representation. Requiring the students to translate between whatever other representation they are using and this one is usually quite productive in developing a better understanding. These items can be especially useful since most students seem to adapt to bar chart representations relatively easily.
Conflicting Contentions Tasks
Conflicting Contentions Tasks present students with two or three statements that disagree in some way. The students have to decide which contention they agree with and explain why. These tasks are very useful for contrasting statements of students’ alternate conceptions with physically accepted statements. This process is facilitated in these tasks because they can be phrased as “which statement do you agree with and why” rather than asking which statement is correct or true. These tasks compliment the What, If Anything, Is Wrong Tasks.

Linked Multiple Choice Tasks
Linked Multiple Choice Tasks have one set of answer possibilities that applies to questions about a related set of cases. In these tasks, different variations of the situation are described and the students choose from a limited set of possible outcomes. These items allow for the comparison of how students think about various aspects and/or variations of a situation. These tasks have the nice feature that one gets both the students’ answer to a particular question and their pattern of responses for the variations presented.

Predict and Explain Tasks
Predict and Explain Tasks describe a physical situation which is set up at a point where some event is about to occur. Students have to predict what will happen in the situation and explain why they think that will occur. These tasks require situations with which the students are familiar or with which they have sufficient background information to enable them to understand the situation, because if students are not familiar with the situation, they usually do not feel comfortable enough to attempt to answer.

Changing Representations Tasks
These tasks require students to translate from one representation (e.g., an electric field diagram) to another (e.g., an equipotential curves or surfaces diagram). Students often learn how to cope with one representation without really learning the role and value of representations and their relationship to problem solving. Getting them to go back and forth between/among different representations for a concept forces them to develop a more robust understanding of each representation. Among the representations that will be employed at times are mathematical relationships, so this task can serve at times as a bridge between conceptual understanding and traditional problem solving.

Concept Oriented Demonstrations Tasks
These tasks involve an actual demonstration, but with the students doing as much of the description, prediction and explanation as possible. These demonstrations are similar to Interactive Lecture Demonstrations but are narrower in scope and typically use very simple equipment. These demonstrations should be ones where students feel comfortable making predictions about what will happen and which will produce results they do not expect. The task sheets used during these demonstrations will focus the students’ attention on important aspects of the situation.

Meaningful, Meaningless Calculations Tasks
These tasks present the students with an unreduced expression for a calculation for a physical quantity for a physical situation. They have to decide whether the calculation is meaningful (i.e., it gives a value which tells us something legitimate about the physical situation) or is meaningless (i.e., the expression is a totally inappropriate use of a relation). These calculations should not be what we might call trivially meaningless such as substituting a wrong numerical value into the expression. These items are best when the quantity calculated fits with students’ alternative conceptions.

**Qualitative Reasoning Tasks**

These tasks can take a variety of forms, but what they have in common is that the analysis is qualitative. Frequently students are presented with an initial and final situation and asked how some quantity or aspect will change. Qualitative comparisons (e.g., the quantity increases, decreases, or stays the same) are often the appropriate answer. Qualitative reasoning tasks can frequently contain elements found in some of the other task formats (e.g., different qualitative representations and a prediction or explanation).

**Desktop Experiments Tasks (DET)**

These tasks involve students performing a demonstration at their desks (either in class or at home) using a predict and explain format but adding the step of doing it. This “doing it” step is then followed by the reformulating step where students reconsider their previous explanations in light of what happened. These DETs are narrow in scope, usually qualitative in nature, and typically use simple equipment. The task sheets used for the DET guide and focus the students’ attention on important aspects of the situation.

**Concept Oriented Simulations Tasks (COSTs)**

These tasks do not involve an actual live demonstration but rather a computer simulation of one. They are very similar to the DETs, in that they use prediction and explanation before running the simulation and are followed by a reformulating step. COSTs can be done either in class using a computer projection system, like the Concept Oriented Demonstrations tasks, or at individual computer stations similar to the DETs. These are focused, but require software and computer systems. COSTs should involve situations where it would be difficult or impossible to actually do or see the results. The task sheets used for COSTs will guide and focus the students on important aspects of the domain.

Curt draws on a number of active learning curricula that are based on physics education research and that use some of the TIPER formats. For example, he uses pre-tests and other materials from *Tutorials in Introductory Physics*, resources developed by the Physics Education Group of the University of Washington (McDermott & Shaffer, 1998). These materials are intended for introductory calculus-based physics courses and are designed to address specific conceptual and reasoning difficulties that students have in learning physics. He finds that the focused pre-tests included in these *Tutorials* are especially good at helping students understand important conceptual areas. He uses these, as well as some of the other material from the *Tutorials*, in classroom discussion and also uses one or two of the questions from these materials on his exams.
Curt draws TIPERs not only from the Tutorials materials, but from a variety of other resources as well, including:

- *Electric and Magnetic Interactions* (Chabay & Sherwood, 1995)
- *Matter & Interactions* (Chabay & Sherwood, 1999)
- *Physics: A Contemporary Perspective* (Knight, 1997)
- *RealTime Physics* (Sokoloff, Thornton, & Laws, 1999)
- *Workshop Physics* (Laws, 1997)
- *Peer Instruction* (Mazur, 1997)
- *Physics by Inquiry* (McDermott, Shaffer & Rosenquist, 1996)
- *Understanding Basic Mechanics* (Rief, 1995)
- *ActivPhysics 1* (Van Heuvelen, 1997)
- *ActivPhysics 2* (Van Heuvelen & D'Alessandris, 1999)
- *Overview/Case Study* (Van Heuvelen, 1992).
F. Finkel and Monk’s “Atlas Complex”

The Atlas complex, as conceived by Donald Finkel and Stephen Monk (1983), refers to a set of assumptions—which most of us developed through years of formal education—that a teacher should be the central figure in the classroom, assuming full responsibility for what goes on, while a student should be the receiving figure whose success is measured by meeting largely pre-specified expectations for demonstrating mastery of what the teacher provides. In Finkel and Monk’s words, teachers who participate in the Atlas complex “supply motivation, insight, clear explanations, even intellectual curiosity. In exchange, their students supply almost nothing but a faint imitation of the academic performance that they witness” (p. 85). Teachers “exercise their authority through control of the subject matter,” but they “lack the power to make things happen for their students” (p. 85). The ideal relationship is understood to be that of the teacher (expert provider) and the student (novice receiver)—what Finkel and Monk call the “two-person model” (p. 85). Classes are a modification of this ideal wherein, due to economic factors, the teacher fulfils the expert provider role for many students and also adds the group leader role. The Atlas complex comes full circle with the belief, held by both student and teacher, that the students should rely on the expert leader for answers and not view themselves or other students as learning resources.

Finkel and Monk explain that most faculty, when they consider this “ideal” paradigm, are quick to realize that it assumes an approach to teaching that is at odds with their own experience of effective learning.

A teacher who takes responsibility for all that goes on in the class gives students no room to experiment with ideas, to deepen their understanding of concepts, or to integrate concepts into a coherent system. Most teachers agree that these processes, together with many others, are necessary if students are to understand a subject matter. Any teacher will say that the best way of learning a subject is to teach it—to try to explain it to others. Scientists agree that intellectual exchange, discourse, and debate are important elements in their own professional development. . . .

...Almost anyone who has learned something well has experienced the particular potency that a collaborative group can have through its ability to promote and make manifest such intellectual processes as assimilating experience or data to conceptual frameworks, wrestling with inadequacies in current conceptions, drawing new distinctions, and integrating separate ideas. The evidence that collective work is a key ingredient to intellectual growth surrounds us. (p. 88)

Nonetheless, Finkel and Monk conclude that most faculty remain trapped in a kind of monolithic Atlas complex state of mind. Those who attempt to break out of it often find both themselves and their students resisting the change. It feels odd—and risky—to insist that students focus on projects and their interactions with each other, rather than on the teacher. They feel that standards of clarity and accuracy, to say nothing of intellectual rigor, will surely be lowered by trusting novices to figure things out.

Finkel and Monk observe that a successful way to release oneself from the Atlas complex and to cope with student resistance is to distinguish teaching and learning roles from functions. Roles
are interlocking sets of behavioral norms that apply to categories of persons within the context of a particular institution. The Atlas complex entails particular teacher and student roles. Functions, in contrast, are the particular duties or performances required of a person or thing in order to achieve a goal or complete an activity. Examples of teaching functions include having students examine particular phenomena from a new perspective, getting students to organize facts and events into a general scheme, or developing in students new skills. Each of these functions involves particular ways of operating in the classroom—and does not, ipso facto, need to be performed by the teacher. Separating roles from functions allows a teacher to decide what functions would be performed most effectively by whom—whether the teacher, lab assistants, undergraduate or graduate teaching assistants, an individual student, pairs or groups of students, or even electronic tutors. It also opens up options regarding the best settings for performing these functions. The beautiful thing about making this role/function distinction, as Finkel and Monk present it, is that it releases both teachers and students from the dilemmas created by being locked into roles. They explain:

*Teachers ask, Is my role of teacher one of expert or helper? As if they must choose between these two roles. The conflict disappears if the teacher performs functions that require expertise at one time and place and functions that require helping at others. To say that students must be independent (bold, skeptical, imaginative) and dependent (relying on the accumulated knowledge of past generations) sounds like a contradiction because it is couched in the language of roles. The adjectives prescribe contradictory norms for a category of persons. But if we say instead that some of the activities in which a student must engage require independence and that others require dependence, then the contradiction disappears.* (pp. 91-92)

Explaining the role/function distinction opens up options for distributing teaching functions across different individuals, options that are right on the mark for faculty whose teaching principle is help students take more responsibility for their own learning.
G. Methods used to Produce the Case Study

Susan Millar and William Clifton, researchers for the Institute on Learning Technology, conducted interviews and observed labs and classrooms during early December 1999 at Joliet Junior College. We interviewed five members of the Department of Natural Sciences: Professors Curtis Hieggelke and William (Bill) Hogan, who teach physics; Marie Wolff, who teaches chemistry; Michael Lee, who teaches biology and is department chair; and Geoff White, who is the lab technician for Curt, Bill, and Marie. At that time, Curt was teaching the Basic Physics and the Engineering Physics courses, Bill was teaching the College Physics and Technical Physics courses, and Marie was teaching General Chemistry. Approximately 15 students were enrolled in each of these courses. Each of these courses met three times a week in a regular classroom and twice a week in a lab. Geoff White was supporting Curt, Bill, and Marie as a lab technician.

We interviewed a group of four students from Curt’s Engineering Physics course and a group of five from his Basic Physics course. These groups comprise relatively large samples from the two courses. The students who participated were those who happened to be available for lunch on the two days we were present. We also interviewed Scott Olson, a campus-level information technology administrator, one other campus level technology administrator, and the college president, Professor J.D. Ross. To obtain an external appraisal of the performance outcomes for Professor Hieggelke’s students, we conducted a phone interview with Professor Alan Van Heuvelen. Alan, a member of The Ohio State University Physics Department, is highly regarded for his knowledge of performance outcomes associated with physics reform efforts.

The interviews were guided by the protocols used in all the Learning Through Technology case studies and were taped and transcribed. With substantial help from Andrew Beversdorf, Susan analyzed the interview material to produce this case study. Dr. Charlotte Frascona and Sharon Schlegel also assisted with interview analysis and provided valuable editing.

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Glossary: Special Terms Used in the LT² Website

**Assessment** – What do faculty who are experimenting with interactive learning strategies (see *constructivism*) mean by “assessment”? In the simplest terms, assessment is a process for gathering and using data about student learning and performance. The LT² web site distinguishes the following two types of assessment:

- *Formative assessments* – activities that simultaneously (1) provide instructors with feedback about how and what students are learning, which the instructors can then immediately use to adjust and improve their teaching efforts; and (2) foster student learning directly because the students in the process of performing such activities. (For more information, see the [FLAG website](#), which features classroom assessment techniques that have been show to improve learning.)

- *Summative assessments* – formal examinations or tests, the results of which faculty use to demonstrate in a way that is definitive and visible to people outside the course the degree to which students have accomplished the course’s learning goals.

Tom Angelo (1995) defines assessment as an ongoing *process* aimed at understanding and improving student learning. It involves:

- making our expectations explicit and public;
- setting appropriate criteria and high standards for learning quality;
- systematically gathering, analyzing, and interpreting evidence to determine how well performance matches these expectations and standards; and
- using the resulting information to document, explain, and improve performance.

When it is embedded effectively within larger institutional systems, assessment can help us focus our collective attention, examine our assumptions, and create a shared academic culture dedicated to assuring and improving the quality of higher education.

**Bricoleur** – a French term for a person who is adept at finding, or simply recognizing in their environment, resources that can be used to build something she or he believes is important and then putting resources together in a combination to achieve her or his goals.

**Constructivism** – According to Schwandt, constructivism is a “philosophical perspective interested in the ways in which human beings individually and collectively interpret or construct the social and psychological world in specific linguistic, social, and historical contexts” (1997, p.19). During the last 20 or so years, cognitive psychologists (James Wertsch, Barbara Rogoff, and Jean Lave, among many others) have found that constructivist theories of how people construct meaning are closely aligned with their observations of how people learn: knowledge is mediated by social interactions and many other features of cultural environments.

**Learning activity** – As used in the LT² case studies, learning activity refers to specific pursuits that faculty expect students to undertake in order to learn. Thus, “Computer-enabled hands-on experimentation is a useful way to get students to take responsibility for their own learning” is a statement of belief that a particular learning *activity* (experimentation) helps realize a particular teaching principle.
**Learning environment** – According to Wilson, a learning environment is a place where learners may work together and support each other as they use a variety of tools and information resources in their pursuit of learning goals and problem-solving activities (1995). This definition of learning environments is informed by constructivist theories of learning.

**Microcomputer-Based Laboratories (MBL)** – A set of laboratories that involve the use of (1) electronic probes or other electronic input devices, such as video cameras, to gather data that students then feed into computers, which convert the data to digital format and which students analyze using graphical visualization software; and (2) a learning cycle process, which includes written prediction of the results of an experiment, small group discussions, observation of the physical event in real time with the MBL tools, and comparison of observations with predictions.

**Seven Principles for Good Practice in Undergraduate Education** – These principles, published in “Seven Principles for Good Practice in Undergraduate Education” by Zelda Gamson and Arthur Chickering, were synthesized from their research on undergraduate education (1991). According to their findings, good practice entails:

1. Encouraging student-faculty contact.
2. Encouraging cooperation among students.
3. Encouraging active learning.
5. Emphasizing time on task.
6. Communicating high expectations.
7. Respecting diverse talents and ways of learning.

**Teaching principles** – Teaching principles refer to a faculty member’s more general beliefs about, or philosophy of, learning. For example, the idea that “students should take responsibility for their own learning” is a teaching principle. It is general and informed by a theory of learning. It does not refer to something specific that one might actually do in a course.
References


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Endnotes

1 Of note in this regard, J. L. Frand (2000) highlights a number of characteristics of “information age” students, including a tendency that he calls “Nintendo over logic”: a Nintendo player is more likely to win by constantly losing, using trial and error to discover the hidden doors, than by using analysis that involves thinking through consequences ahead of time.

2 Frand (2000) focuses on the characteristics of students who grow up taking computers for granted,

3 Research conducted by Elaine Seymour on why students leave SMET undergraduate majors indicates that becoming “turned off” to these disciplines is one of the primary problems SMET faculty face in retaining students. See Seymour and Hewitt (1997), and Seymour (1995).

4 The concept of “deep learning,” developed by Swedish (Marton & Säljö, 1976) and English (Entwhistle & Ramsden, 1983) researchers, entails higher-level cognitive skills and deeper and more meaningful engagement with a discipline.

5 For more on the MBL Interactive Lecture Demonstrations, see http://vernier.com/cmat/ild.html.

6 Innovator and early adopter are terms used in the classic work by Everett M. Rogers, Diffusion of Innovation (1995). However, we instead use the terms innovators and early adapters, which are consistent with current research on diffusion of innovation among faculty (Foertsch, Millar, Squire, & Gunter, 1997; Hutchinson & Huberman, 1993; Light, 1998; Kozma, 1985; Millar, 1995). Other terms that have been suggested recently are “pioneers” and “second wave” faculty (Hagner 2000).

7 Frand (2000) has dubbed this practice “consumer/creator blurring.” In the commercial world, this practice is used by software vendors when they “release a product that is known to be ‘buggy’ and have the users ‘de-bug’ it (by calling it a beta-test version).”


9 See Thornton and Sokoloff (1998); also Sokoloff, Laws, and Thornton (1999).

x Author’s note: Based on our observations, Curt does not lecture but rather uses activities such as Ranking Tasks, guided discussion, and other inquiry-based methods to introduce students to new content. Maggie’s remark about “lecture” reminds us of comments we’ve heard students make in many other courses that make heavy use of inquiry-based methods: students tend not to “recognize” new material when it is introduced in these other ways because they are so accustomed to having it introduced only through lecture.

xi PKAL (Project Kaleidoscope) is “an informal alliance working to strengthen undergraduate learning in mathematics, engineering, and the various fields of science.” See www.pkal.org.

xii See Maloney, O’Kuma, Hieggelke, and Van Heuvelen (2000); Hieggelke and O’Kuma (1997); Maloney, O’Kuma, Van Heuvelen, and Hieggelke (1997); O’Kuma, Maloney, Van Heuvelen, and Hieggelke (1998).