Teaching Contemporary Physics Topics Using Real-Time Data Obtained via the World Wide Web

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Abstract

As a teaching tool, the World Wide Web (WWW) is unprecedented in its ability to transmit information and enhance communication between scientist and student. Just beginning to be developed are sites that actively engage the user in the learning process and provide hands-on methods of teaching contemporary topics. These topics are often not found in the classroom due to the complexity and expense of the laboratory equipment and the WWW is an ideal tool for overcoming this difficulty. This paper presents a model for using the Internet to teach high school students about plasma physics and fusion energy. Students are given access to real-time data, virtual experiments, and communication with professional scientists via email. Preliminary data indicate that student collaboration and student-led learning is encouraged when using the site in the classroom.

Keywords: Real-time data, World Wide Web, teaching, high school, fusion energy, plasma physics

I. INTRODUCTION

"On the Internet you can do them [experiments] yourself so that you can experience exactly what would happen if you were the actual scientist." A high school student after using the WWW site discussed in this paper.

The recent explosion in popularity of the World Wide Web (WWW) is based upon the fact that it is readily accessible and its ability to transmit information at an unprecedented speed without regard for the distance between the person transmitting and receiving the information. As an educational tool, the WWW provides not only the capability to transmit information via text, pictures, sounds, or movies, but also allows students access to scientific data, scientists (via email), and remote computing power.

Coincident with the use and development of the WWW, a movement to reform science teaching at all levels, especially in grades K-12, has gained momentum nation-wide. Based upon research on how students learn, the profession is moving from a "teacher centered" approach to a "student centered" one. The reform emphasizes learning science by doing. Rather than memorize and regurgitate facts and perform "labs" where the outcome is well determined, this new methodology encourages open-ended, student-led investigations and peer learning. Here, the student has an active part in choosing the question to be investigated, designing the experiment, and analyzing the data. Through its highly non-linear dissemination of information (as opposed to a standard textbook), the WWW can provide a unique experience which encourages this type of learning.

Like any other innovative teaching tool, developers of WWW-based curricula must understand not only how students learn, but how the use of a computer and the WWW fits into our current understanding of learning. Recent studies show that “active engagement” computer-based learning can provide a measurable improvement in student comprehension[Redish et al., 1997]. Students explore and construct their own understanding while receiving immediate feedback from a medium that encourages collaboration.

The WWW is particularly well suited to introduce students to modern or “contemporary” physics topics. A typical introductory course almost exclusively contains “classical” physics; contemporary physics topics are rarely covered. Whether it is the origin of the universe or the fundamental building blocks of matter, topics like these are often what spark a student’s interest and imagination. However, it is difficult, if not impossible to have students perform laboratory investigations of most contemporary physics topics due to the complexity and expense of most modern scientific equipment.

In this paper, we present a WWW-based model for teaching high school students a contemporary physics topic using an approach that is investigative and student-centered. Our model, which focuses on, but is not specific to, fusion energy and plasma physics, makes use of the interactive capabilities of the WWW, allows students to learn science by using real data, and provides a link between the student and scientists actively engaged in the research topic.

II. The Model

The model has four main components each designed to be as open-ended and student-centered as possible. Together, these four components effectively mimic several of the primary processes used by professional scientists in their research: background content, computer modeling, data analysis, and communication with colleagues. A schematic of the model is shown in Figure 1.

IIa. Interactive background material

A scientist conducts a literature search before beginning a new investigation to ensure sufficient knowledge of the topic studied. Similarly, before a student can analyze virtual or actual data, a familiarity with the relevant terms and concepts must be established. Since these topics are not typically covered in the classroom, the model provides the required background material, utilizing the dynamic environment of the WWW.

IIb. Virtual experiments

Along with experimentation and data analysis, computer modeling is an essential component of the modern scientific approach. An interactive virtual experiment provides a method for students to test their understanding of the topic both before and after the data analysis. Rather than an idealistic simplification, the virtual experiment is based upon experimental evidence, as is a scientific computer model. Thus, the student can compare the virtual and actual data sets and explore the differences in the same way that a scientist compares predictions from a computer code with experimental data.

IIc. Provide students access to data

When the ability to perform actual experiments on a contemporary physics topic is not available, the next best option is to provide students with data from actual experiments. Of course simply giving access to the data is not sufficient by itself and it is necessary to create a coherent curriculum that focuses upon the data. The analysis of this data, however, gives the student insight into the primary variables and their relationship to each other of the phenomena under study. This method inherently promotes active learning by the student and is naturally open-ended. Further, students are able to access all the data from a particular experiment so that they have the capability to continue their analysis beyond the scope of the learning objectives presented.

IId. Student/scientist collaboration

Communication with colleagues is a critical component of the scientific process. In the same way, a link between the student and scientists working in the particular field via email discussions is an essential piece of the model. This email interaction can cover issues directly related to the site or other pertinent topics, depending upon student interest.

III. The Internet Plasma Physics Educational eXperience

Overview

Fusion energy is the power source for our sun and all the stars in the universe. If captured for use here on Earth, controlled fusion would provide nearly unlimited energy. This huge potential payoff has attracted scientists from around the world. In a fusion reactor, nuclei of hydrogen isotopes are heated to a temperature sufficient (100,000,000°C) to overcome the repulsion of their like charges and fuse into a helium nucleus and a neutron. At such extreme temperatures, all of the electrons are knocked off of the atomic nuclei and the gas, called a plasma, consists of a mix of positively and negatively charged particles. The interaction of these charges with each other and with external electromagnetic fields leads to the designation of plasma as a fourth state of matter. One of the most common ways to contain the plasma uses magnetic fields, and the fusion configuration most studied is the “tokamak”. The primary purpose of the (I)nternet (P)lasma (P)hysics (E)ducation e(X)perience (Figure 2; IPPEX - http://ippex.pppl.gov/ippex/) is to explain these concepts in detail. What follows is an outline of the primary sections of the site.

IIIa. Interactive Physics

This section includes four stand-alone modules designed to provide background information for the student. The modules include "Matter", "Electricity and Magnetism", "Energy", and "Fusion" and make extensive use of Shockwave (http://www.macromedia.com/shockwave/) to create a multimedia and interactive learning experience. Shockwave is a free browser plug-in and allows the use of animation and sound in a WWW. Most importantly, Shockwave allows the WWW page to "react" to the user. Pages can be linked together based upon the click of a user's mouse or a response to a question. The result is that the learning environment is "dynamic" and each student may see a different series of pages and questions based upon previous responses.

The use of Shockwave also gives the user the ability to dynamically create and manipulate data. In the "Fusion" module, for example, users study the "Forces of Fusion" by going through a series of interactive exercises that look at the relationship between kinetic energy and the repulsive force for similarly charged particles. Three consecutive "snapshots" of the module are shown in Figure 3. Notice that the user can control the kinetic energy and charge on each particle and then either step through each frame or play the movie at once. The program utilizes the student's initial values and calculates whether the particles will collide (as shown) or whether the natural repulsion will overcome the initial kinetic energy and cause them to reverse direction. Also displayed are the time and position of each particle to facilitate graphing the data. The result is that the student has a "virtual laboratory" where data is collected and experiments repeated or changed.

IIIb. Virtual Tokamak

The Virtual Tokamak is a Java-based applet (http://www.javasoft.com) pictured in Figure 4. The user controls the input variables (density, input power and magnetic field strength) via three slider bars. The applet calculates both the output temperature and a "score" related to efficiency (output power divided by input power). The results are based on a simplified version of a research-grade computer code used to design and predict future reactor performance[Stotler et al., 1994]. The applet also keeps track of each run of the code by the user and displays the score versus the number of attempts in tabular and/or graphical form.. Included with the virtual tokamak module is an extensive help section including a glossary of terms introduced in the associated exercises. The questions ask the student to use the virtual tokamak to explore limits on the input variables. Students can also directly compare the predicted results from the applet with data collected in the data analysis section in order to study differences between the actual data and the computer predictions.

The complexities of fusion research in particular, and scientific research in general, are well illustrated by this multivariable applet. The effect of each of the three input variables on reactor performance depends on the value of the other two, forcing students to systematically probe each to fully understand the system. Simply setting the input variables to their maximum value results in a score of zero, as it would in an actual reactor due to limits on plasma stability. The typical user begins by randomly setting the variables, treating the challenge of getting the highest score as if it were a video game. Trial and error quickly results in the realization that the role of each variable must be understood before significant increases in the score are possible. At that point, the learning process begins.

IIIc. Fusion Data Analysis

Students have access to data from one of the leading fusion energy experimental facilities in the world, the Tokamak Fusion Test Reactor (TFTR). During TFTR operations, any student connected to the

WWW could see the data moments after it appeared on the monitors in the TFTR control room. (Note: Experiments on TFTR were recently stopped due to funding constraints but the data remain on-line. Data from a new experiment will be available once it begins operating in early 1999.)

The data-centered curriculum consists of three exercises that increase in difficulty as the student gains experience and confidence in the data analysis. The first exercise is straightforward and is used as a initial check of the students' understanding of the graphical interface, the importance of the variables studied, and the analysis procedures. The second exercise probes and tests misconceptions by confronting students with a data set that conflicts with student expectations. The last exercise gives the student a research question and a subset of data to analyze. Purposely open-ended, it mimics the exact process research scientists use for their own data analysis.

For all three exercises, students study "input variables" such as plasma density or heating power and output variables (also called "performance" variables in the exercises) such as fusion power or energy confinement time. The student interface for each exercise is shown in Figure 5, along with an example of the plotted output. New terms are hyperlinked to a glossary for quick reference. After completing the analysis and the questions for each exercise, students submit their answers to the "Fusion Wizard" via email for correction and comments. Questions are a mixture of multiple choice, numerical calculations, and short answer. An example of the form used to submit answers is shown is Figure 6.

IIId. Ask a Scientist

While working on the various sections of IPPEX, students always have the opportunity to ask a question about some aspect of plasma physics or fusion energy. A team of researchers takes turns answering questions from all grade levels. The best questions (and answers) are archived and available for browsing.

IV. An Example of Classroom Use of IPPEX

In order to demonstrate the power and effectiveness of using actual data and an interactive WWW site to teach, IPPEX was used by an 11th grade class and filmed as part of the PBS series, "The Internet in Action". Classroom discussions and demonstrations supplemented the web-based material with the expectation that the entire curriculum was approximately one week of class time.

The lesson began with a discussion of energy in general and fusion in particular. Students then moved to the computer and worked in teams as they studied the interactive background modules. They made predictions based upon their new knowledge and were able to test these predictions and receive immediate feedback. This resulted in an increased confidence in what they learned and triggered related questions to investigate with the modules.

Next was a classroom demonstration using a fluorescent light bulb and strong magnets to demonstrate why a fusion reactor uses magnetic fields to control the plasma. The demonstrations are an important part of the overall lesson plan since they provide the students with something they can touch and feel which no WWW site can provide.

Students then returned to their teams to begin working on the computer with the Virtual Tokamak. Based upon their previous work, they were asked to compete for the best score and to determine how each variable affected the score. Students struggled to understand why small changes in an input variable could have a large effect on the output. These effects, while based upon experimental data, were not always intuitive to the students. This resulted in discussions within each group of the "best" way to increase the score. Information was shared, new ideas were debated and the challenge of friendly competition resulted in a lively and engaging learning environment.

When these exercises were completed, they moved on to the data analysis section. Here the students had to first understand how to interpret data in a graphical context before attempting to answer the exercises. In all of their previous work, the data was presented either numerically or was animated. Now the students were confronted with x-y plots of a particular variable versus time and asked to compare and contrast trends in the variables. Since this was actual data, it was not necessarily "clean" meaning that the trends were often partially obscured by the "noise" of a signal due to statistical fluctuations of data. Thus, students also gained experience distinguishing the relevant part of a particular data set.

Finally, students had the opportunity to ask questions of a scientist via the WWW based upon what they had learned. This not only enabled them to obtain answers that their teacher could not explain but increased their confidence when their assumptions were validated by an "expert".

V. Assessment of IPPEX as an Educational Tool

During this class time, students were observed and evaluated based upon their interactions with the site, their conversations with their team members, and the questions asked of their teacher and the scientist. The preliminary data, based upon the classroom observations, suggests that IPPEX works well as a teaching tool in introducing students to a subject that is not normally found in the curriculum. Students engaged in higher-order thinking and made connections between the different sections. Group communication and group learning was remarkable, often leaving the teacher with nothing to do but stay out of the way of the learning process. Students asked questions that showed not just an understanding of the material presented, but expanded upon this knowledge to suggest possible future research. Most importantly, perhaps, they had fun while learning.

As more students from a variety of grades and backgrounds utilize the site, it will be possible to obtain further data on the effectiveness of IPPEX. A small number of workshops for teachers who want to incorporate the site into their lesson plans have been offered and a teacher's manual is planned. In a typical month, approximately 1800 people visit IPPEX, 6-7 students analyze data from TFTR and submit their analysis for correction, and nearly 35 people ask a question about plasmas and fusion energy. These numbers increase each month as the number of teachers and students using IPPEX in their classroom increases.

VI. Conclusions

The power of the WWW as a teaching tool increases daily. It has the unique capability of allowing students access to data on topics that are not normally found in an introductory course. The WWW provides one of the only ways for a student to learn about contemporary physics by mimicking the process used by scientists in their own research. To be effective, a WWW site should have four key components: access to actual data; virtual experiments; interactive background material; and student/scientist collaboration. With these in place, a rich and unique learning environment can be created.

ACKNOWLEDGMENTS
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REFERENCES

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Figure Captions

Figure 1. A schematic of the four primary components of scientific research (in bold) and the corresponding sections of the web site based upon this model (in italics).

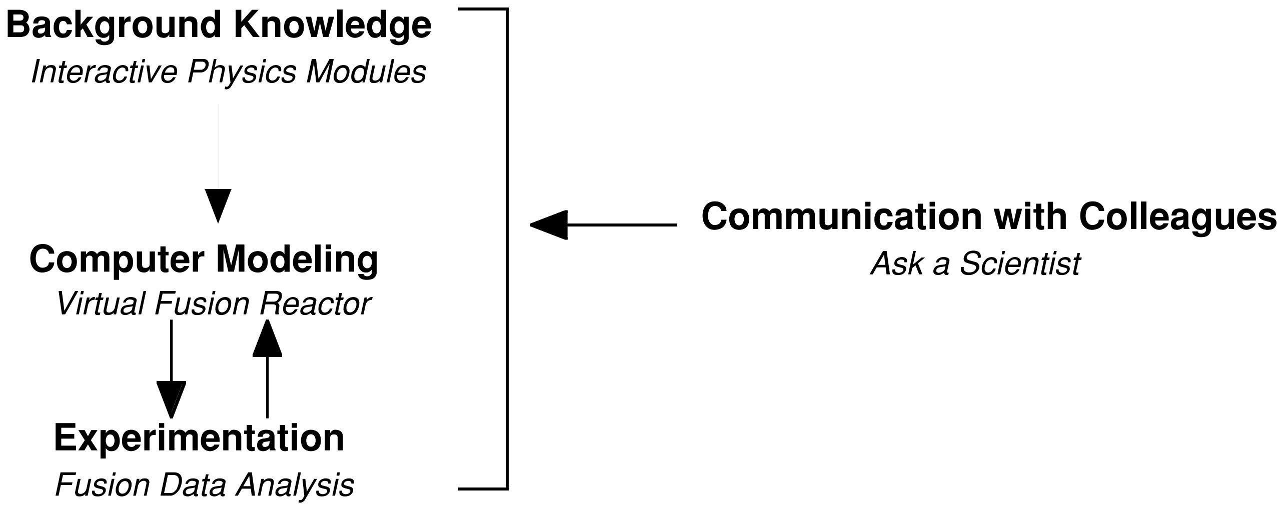
Figure 2. The home page of the Internet Plasma Physics Education eXperience.

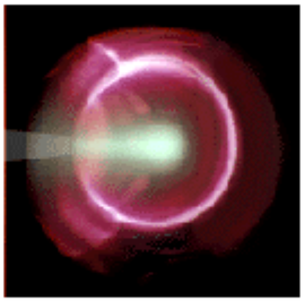
Figure 3. Three consecutive "snapshots" from the interactive physics module on fusion.

Figure 4 The Virtual Tokamak showing the input variables, the calculated "score", and plasma temperature.

Figure 5. (a) The data analysis interface and (b) an example of the plotted output.

Figure 6. An example of the questions asked (multiple choice and short answer) in the form used to submit answers for correction in the data analysis section.

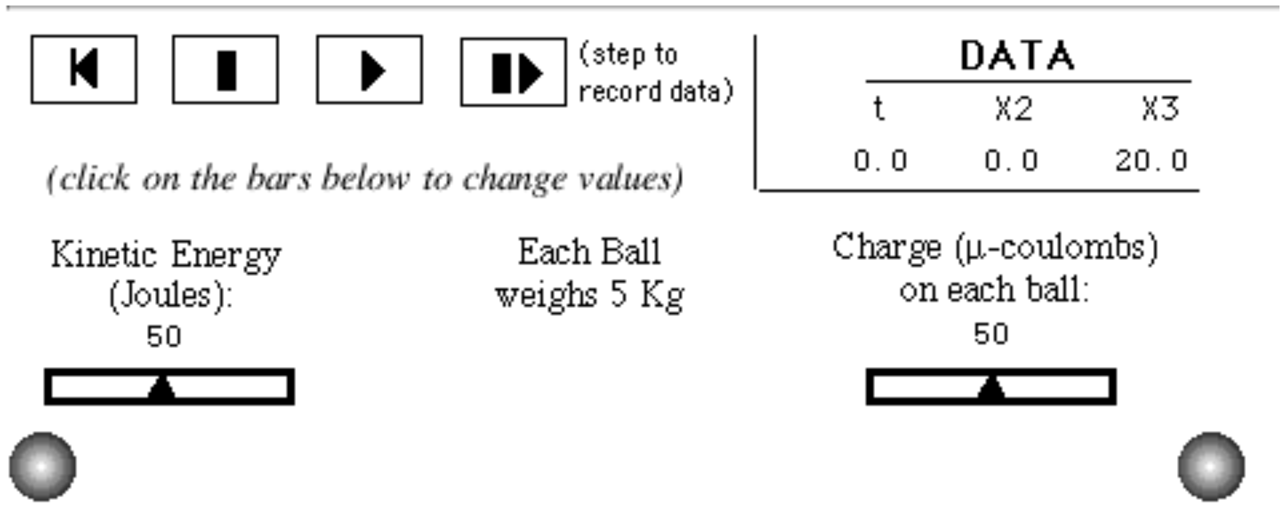

Background Knowledge
Interactive Physics Modules
Computer Modeling
Virtual Fusion Reactor
Experimentation
Fusion Data Analysis
Communication with Colleagues
Ask a Scientist



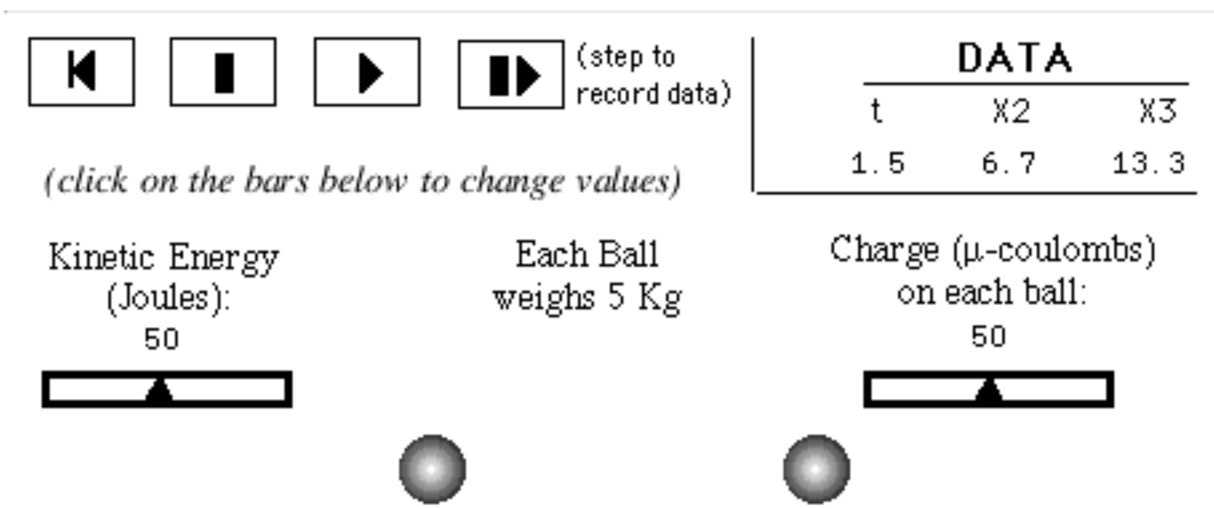
IPPEX

This site includes **INTERACTIVE** pages on matter, electricity, magnetism, energy and fusion. There is a virtual fusion reactor, the "**Virtual Tokamak**", and a virtual magnetic stability module. You can **analyze actual data** from past and current fusion experiments. If you have a question, you can "**Ask a Scientist**" via e-mail.

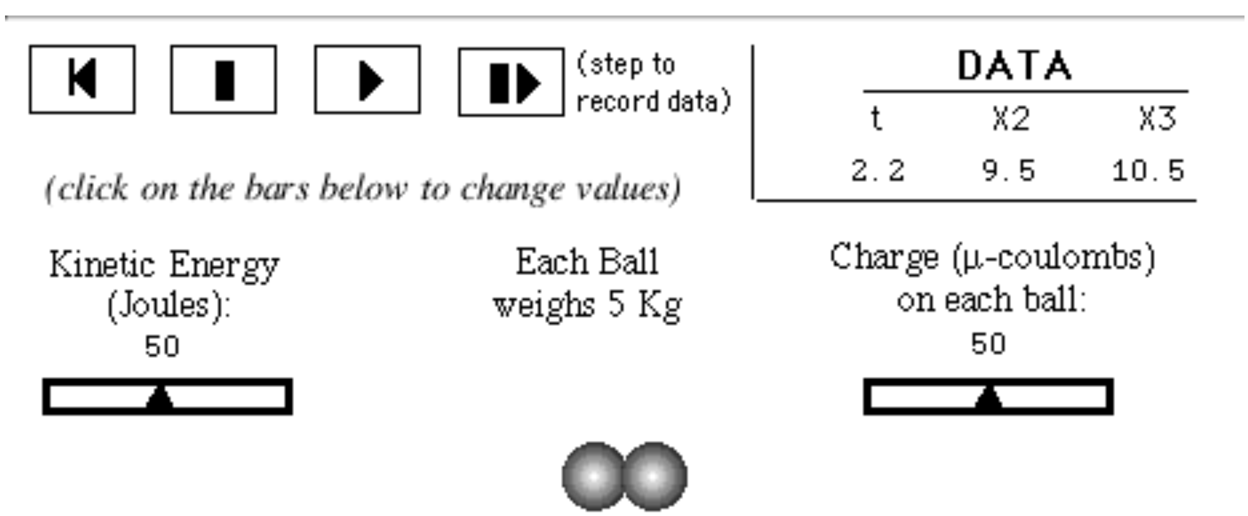
ENJOY!



(step to record data)
DATA
t X2 X3
0.0 0.0 20.0
(click on the bars below to change values)
Kinetic Energy (Joules):
50
Each Ball weighs 5 Kg
Charge (μ-coulombs) on each ball:
50



(step to record data)
DATA
t X2 X3
1.5 6.7 13.3
(click on the bars below to change values)
Kinetic Energy (Joules):
50
Each Ball weighs 5 Kg
Charge (μ-coulombs) on each ball:
50

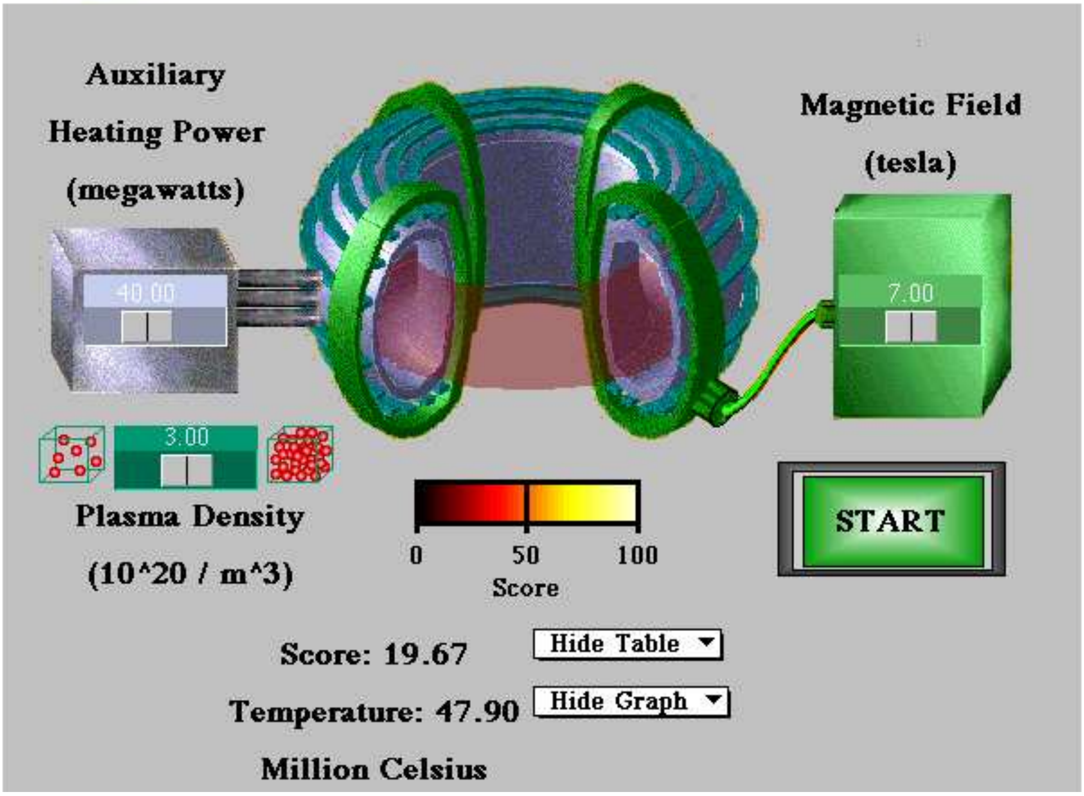


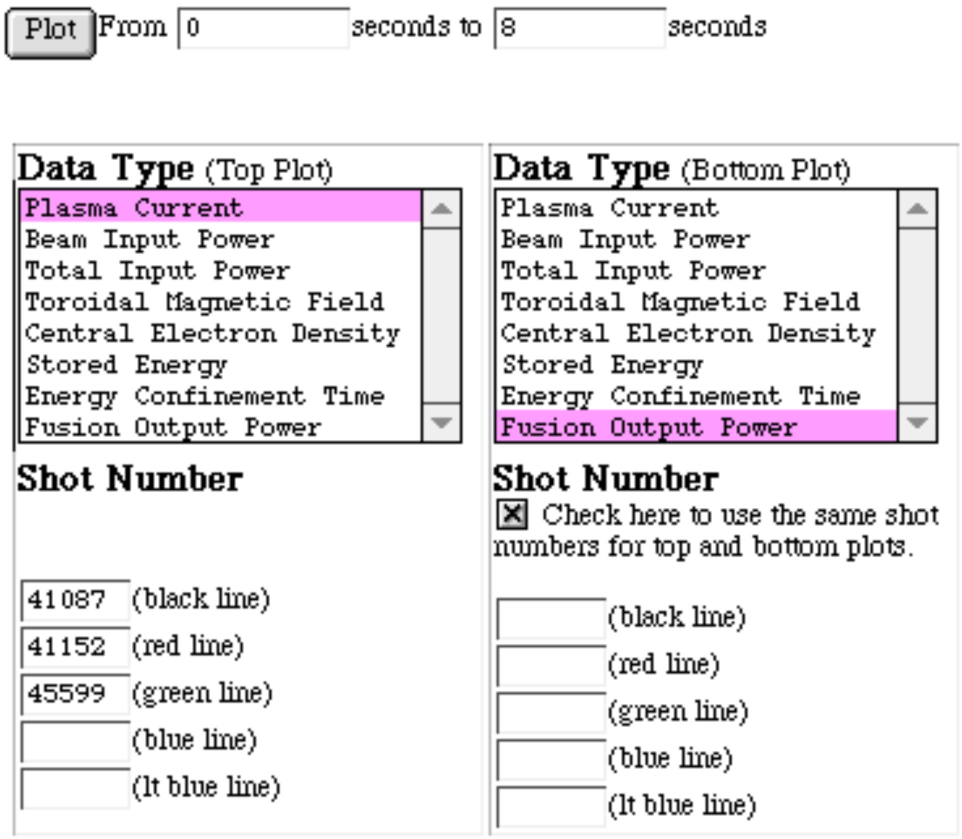
(step to record data)
DATA
t X2 X3
2.2 9.5 10.5
(click on the bars below to change values)
Kinetic Energy (Joules):
50
Each Ball weighs 5 Kg
Charge (μ-coulombs) on each ball:
50

Operate Your Own Tokamak Reactor

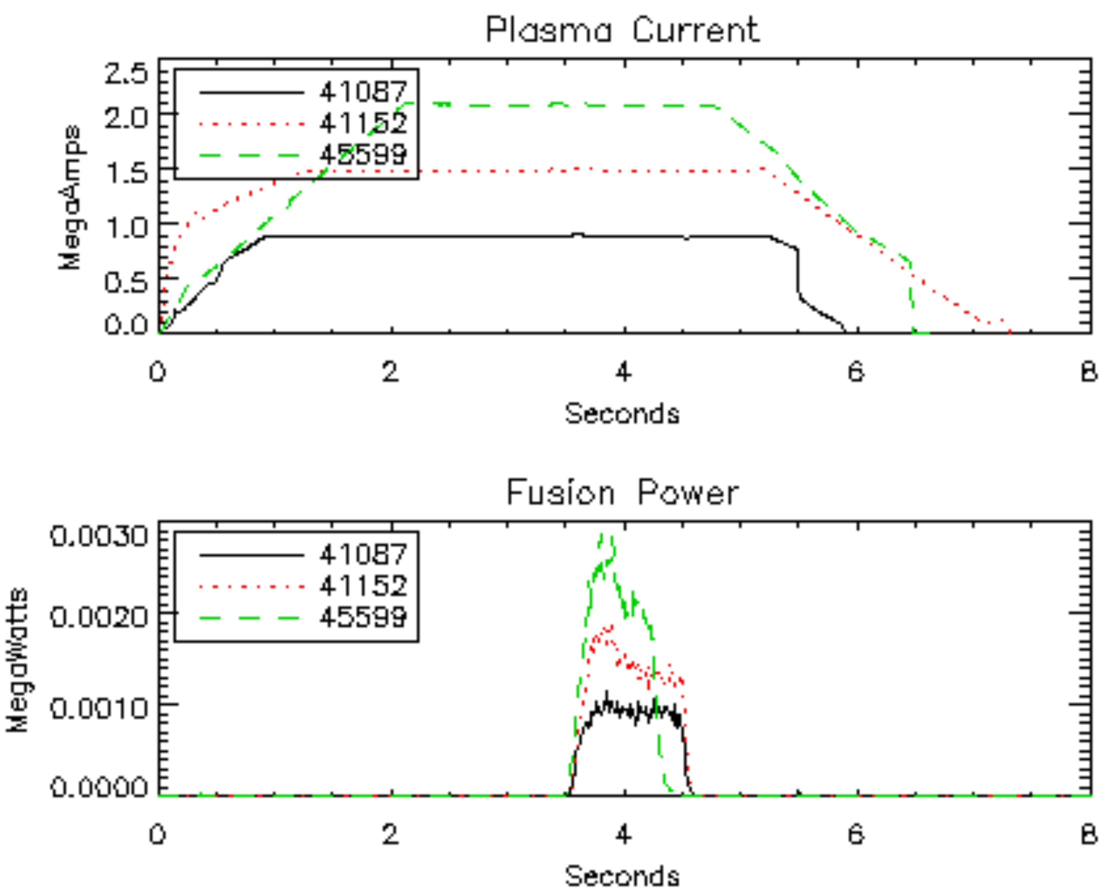
As part of the Internet Plasma Physics Education eXperience (IPPEX) project, this Java applet is designed to illustrate the basic principles of magnetically confined fusion.

Anxious to get started? Just move the 3 slider bars, press the START button and see what Score (0 to 100) you get. If you're the patient type, you can read the help page first. And for those of you who know the basics of our Virtual Tokamak and would like to play physicist for awhile, try these exercises.




Plot From 0 seconds to 8 seconds
Data Type (Top Plot)
Plasma Current
Beam Input Power
Total Input Power
Toroidal Magnetic Field
Central Electron Density
Stored Energy
Energy Confinement Time
Fusion Output Power
Shot Number
41087 (black line)
41152 (red line)
45599 (green line)
(blue line)
(lt blue line)
Data Type (Bottom Plot)
Plasma Current
Beam Input Power
Total Input Power
Toroidal Magnetic Field
Central Electron Density
Stored Energy
Energy Confinement Time
Fusion Output Power
Shot Number
Check here to use the same shot numbers for top and bottom plots.
(black line)
(red line)
(green line)
(blue line)
(lt blue line)

(a)


Plasma Current
MegaAmps
0.0
0.5
1.0
1.5
2.0
2.5
41087
41152
45599
0
2
4
6
8
Seconds
Fusion Power
MegaWatts
0.0000
0.0010
0.0020
0.0030
41087
41152
45599
0
2
4
6
8
Seconds

(b)

Question 3: The plasma which had the largest stored energy AT 4 SECONDS had approximately ___________ times more stored energy than the plasma with the smallest amount of stored energy?

a) 1.5
b) 2.6
c) 3.7
d) 4.1

Answer 3

Question 4: Compare and contrast the similarities and differences between the three performance variables (output fusion power, stored energy, and energy confinement time) as the total input power is increased. If one variable is consistently larger (or smaller) than the others, state this and calculate by how much.

Name (Optional)

E-mail (Mandatory)

Send Answers to Fusion Wizard