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Virtual labs: a substitute for traditional labs?

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ABSTRACT Current technologies give us the ability to enhance and replace developmental biology classes with computer-based resources, often called virtual labs. In the process of using these resources, teachers may be tempted to neglect the simpler technologies and lab bench activities, which can be labor intensive. In this paper, I take a critical look at the role of computer-based materials for the teaching of developmental biology in order to aid teachers in assessing their value. I conclude that while digital tools have value, they should not replace all of the traditional laboratory activities. Clearly, both computer-enhanced activities and traditional labs must be included in laboratory exercises. Reliance on only one or the other is inappropriate. In order to determine when it is appropriate to use a particular educational tool, the goals of the course and the needs of biology students for an education that gives them a realistic and engaged view of biology must be understood. In this paper, I dispel some of the myths of computer tools and give specific guidelines for assessing their usage, taking into account the special needs of a developmental biology class and the difficulties of observing all the developmental stages of subject organisms in the timescale of class meetings.

KEY WORDS: *World Wide Web, teaching, developmental biology, virtual, digital*

Background Information

Scholarly Interests of the Author

The author's fields of research are the social effects of instructional technology, issues of race, gender, and class in technology and science, and how digital technologies transact with the formation of community and situated learning. Previous careers in developmental psychology and computer science inform this essay as well as her latest research in instructional technology.

Representative Publications

BARAB, S., SCHATZ, S. and SCHECKLER, R.K. Using Activity Theory to Conceptualize Online Community and Using Online Community to Conceptualize Activity Theory. *Mind, Culture, and Activity* (In press).

HERRING, S., SLUDER, K., SCHECKLER, R. and BARAB, S. Searching for Safety Online: Managing "Trolling" on a Feminist Bulletin Board. *The Information Society* 18: 371-384.

HERRING, S., MARTINSON, A. and SCHECKLER, R. (2002). Designing for Community: The Effects of Gender Representation in Videos on a Web Site, *Proceedings of the Thirty-Fifth Hawaii International Conference on System Sciences*. IEEE Computer Society Press, Los Alamitos.

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Introduction

It is tempting to jettison traditional lab bench materials in favor of computer-based activities. Myths abound surrounding the economic, educational, and entertainment value of such tools. Professors wonder whether children weaned on Barney and Sesame Street will persevere with textbooks and microscope slides when they reach college age. Administrators claim that virtual labs save money. Occasional readers of John Dewey may even interpret his calls for experience in education (Dewey, 1938) as fulfilled by the experience of computer-mediated simulations. We are left wondering, if we have computers, is there any reason to also have microscopes, wet labs, and culture chambers and to go through the trouble and expense of preparing biological materials? The immediate answer is that totally online labs are rarely optimal, that both computer mediated and face-to-face types of activities have value, that hands-on labs are a very special type of engaged learning, and that clearly we need both computer-enhanced activities for their exposure to the activities that evade the time and space context of

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Fig. 1. Students working in a laboratory equipped for both virtual and lab bench exercises.

the lab as well as the more traditional lab activities that engage the body and emotions as well as the mind (Fig. 1). The reflective answer is that educational goals should drive the selection of materials (computer-mediated or traditional), and that learning to discriminate among the great array of materials is a necessary skill for teachers of developmental biology since these tools are not all equally valuable. To further complicate the professor's chore, new computer-based tools are being developed as you read this so that the task of sorting and discriminating will be an ongoing one.

It is easy to construe arguments about totally computerized labs as arguments about modeling and simulation since models and the computer tools that create them are often conflated. It is not my intent to argue for or against modeling *per se*. Modeling and simulation are common and necessary parts of a science education (Gilbert and Boulter, 2000). Here I argue for putting these and other tools in the context of face-to-face labs, understanding their limitations, and making their creation as transparent as possible. For me, a pragmatist, a useful heuristic for judging a model or other educational tool is how much active engagement it allows, both with other people grappling with the concept being modeled and with the materialism of biological systems. Models that are passive demonstrations of concepts are much less valuable than models that allow engagement, speculation, and manipulation of the model and of the tools that are used to create the model (i.e., the modeling software).

What Are Virtual Labs?

Virtual labs use the power of computerized models and simulations and a variety of other instructional technologies to replace face-to-face lab activities. An example of a virtual lab is a collection of digital simulations supported by discussion forums, video demonstrations, hyperlinked glossaries, and e-mail lists organized in a World Wide Web format or on a CD in a shell produced by an authoring language such as Authorware or Director. The most intricate virtual labs include highly interactive virtual reality simulations of lab exercises. I have not been able to find examples of totally virtual developmental biology labs. I have found distance education courses in general biology that provide lab kits and instructions on how to perform experiments in the student's kitchen and then support these efforts with e-mail lists and online discussion forums. I have found examples of the components of virtual labs, many of them such as discussion forums and e-mail lists are now common adjuncts to face-to-face classes. In addition, there are online tutorials, computerized "dissections," (http://curry.edschool.Virginia.EDU/go/frog/menu.html), Quicktime movies (Fig. 2; http://www.bio.unc.edu/faculty/goldstein/lab/movies.html), and virtual "experiments" (http://biologylab.awlonline.com).

Examining the Myths

Teachers are often pressured to adopt totally virtual labs on the basis of certain common myths and misconceptions of the economics, utility, and scale of instructional technologies. In this section, I enumerate several of these myths and give counter-evidence for these misconceptions.

Myth #1: Computer Activities should replace all other Developmental Biology Labs because of their Educational Advantages

Those making this argument frequently cite the literature on modeling and Dewey's conceptions of experience, often mixing both in a mélange of partially understood concepts (Schank and Cleary, 1995). Although Dewey clearly argued for the inclusion of experience in education (Dewey, 1938), recent critiques of computer-mediated simulations point out the fallacies of assuming that computer models fulfill the need for experience (Garrison and Scheckler, 2002; Waks, 2001).

Briefly stated, experience can be insensitive, inflexible, slack, or fragmented as well as educational (Dewey, 1938). Experience valuable to education is continuous and interactive. Many interactive virtual activities, no matter how "realistic," do not contain the elements of uncertainty and continuity that experience with traditional lab activities provide. Most importantly, in all cases of computerized exercises, a person or people designed the software that underlies the virtual lab. When they did this design work, they selected parts of the biological situation to model. Therefore, the model is fixed and definite and represents only a portion of the entire system. This partial model representing the entire situation (i.e., a synecdoche) is misleading to students who do not understand the process of modeling.

In the experience of a traditional lab, there is the feel and smell of science, and sometimes even the danger of science. There is the uncertainty of what will happen or what will be seen, and there is the sharing between peers of varying observations and findings. Instructors can respond to the dynamics of the lab, connect materials to current social problems (See Gilbert and Fausto-Sterling, this issue), and connect peers to each other in ways that are fluid and timely.

Myth #2: Virtual Labs are a New Phenomenon

Development of instructional technologies and aids is a continuum that could be extended back to the time of the invention of written language or before. I do not need to trace back that far to make the point that educational technologies are not new, and neither are they completely evolved. As new technologies such as the movie projector, the radio, the television, and the computer were introduced into educational settings, they were lauded as replacements for face-to-face teachers and schools (Connolly, 2001). What we should have learned as we progressed through the adoption of these other educational technologies is that they are all valuable aids to teaching and learning, that none of them are sufficient to replace the role of the teacher in the usual goings on of the classroom and lab, and that many more technologies are yet to come along that will deserve our attention and consideration.

Myth #3: Digital Labs save Money

Highly interactive online classes can be as much as 30 times more expensive than traditional lectures (Rumble, 1993). Virtual labs will save money only if they are not very interactive and are used by a large number of students (Threlkeld and Brzoska, 1994). Not estimating the continuing maintenance costs, looking at costs of low interactivity lessons, and assuming unrealistic economies of scale perpetuate the fallacy of inexpensive virtual labs.

Not only are development costs high, but also virtual labs require continual maintenance. Part of the maintenance is debugging as the rigors of usage reveal problems, changing content as research reveals different mechanisms, and routine backing up, maintaining servers, security measures, repair and upgrades on workstations, and training of users.

In addition, technologies that serve 20 students adequately do not necessarily scale up to serve larger numbers of students. For large classes, more robust servers are needed, more support staff, and more instructors answering e-mail and moderating discussion forums, thereby substantially increasing the costs.

Myth #4: Students require Edutainment to remain Engaged

This is a very demeaning view of students and one that is not supported. What engages students is confronting real-world problems in the lab (see Gilbert and Fausto-Sterling, this issue), joining in dialogue with enthusiastic teachers, and being encouraged to connect their life experiences with the goings on in the lab.

Myth #5: Only Digital Labs are Interactive and Self-Directed

Teachers at all levels and with varying degrees of materials engage in inquiry learning that is interactive and sometimes self-directed (National Research Council, 2000). Rather than the digitization of the teaching materials, it is the skill of the teacher that brings interactive material and self-directed activities into the classroom.

In a study of the use of the Internet for studying science (Feldman *et al.*, 2000), the authors concluded that the heart of inquiry teaching is reflective discourse and appropriate use of data. While the Internet brings many more resources to the student, it is the skilled teacher that ensures that students engage with these rich resources and reflect on them appropriately.

Separating the Wheat from the Chaff

How can the college professor determine where to put resources in terms of virtual labs and virtual lab activities? Part of this determination rests in knowing what tools are already well developed and part rests in knowing when to use them. As explained in *How people Learn*, there are five ways that technology is important in learning environments (Bransford *et al.*, 2000). These are bringing real world problems into classrooms, particularly the connection to real-world data and scientists; providing support for learning; increasing opportunities for support; building communities; and expanding opportunities for teacher's learning. In the next section, I mention the advantages of virtual labs and list some of the tools that support engaged learning in developmental biology. I take my examples from developmental biology, which has many good tools, except when a dearth of examples forces me to go further afield. Following the discussion of the advantages, I list and discuss the disadvantages of virtual labs, some of which have already been mentioned.

Advantages of Virtual Labs

Virtual labs allow students to repeat demonstrations that they do not understand or as a review for exams. Quicktime movies are a popular way of presenting virtual demonstrations. They present fewer technical challenges than many other technologies and have a high degree of detail and realism. This site, http://depts.washington.edu/fishscop/, has some interesting movies and augmented stills. In a sense, the online Quicktime movies are not much different than the old film loops except that the student has greater access and more control over the movies online.

Collaboration across time and space is an advantage of virtual labs that is seldom used. Margaret Riel uses this functionality to work with K-12 students across schools, state, countries, and continents (Riel, 1995; Riel and Levin, 1990). In a developmental

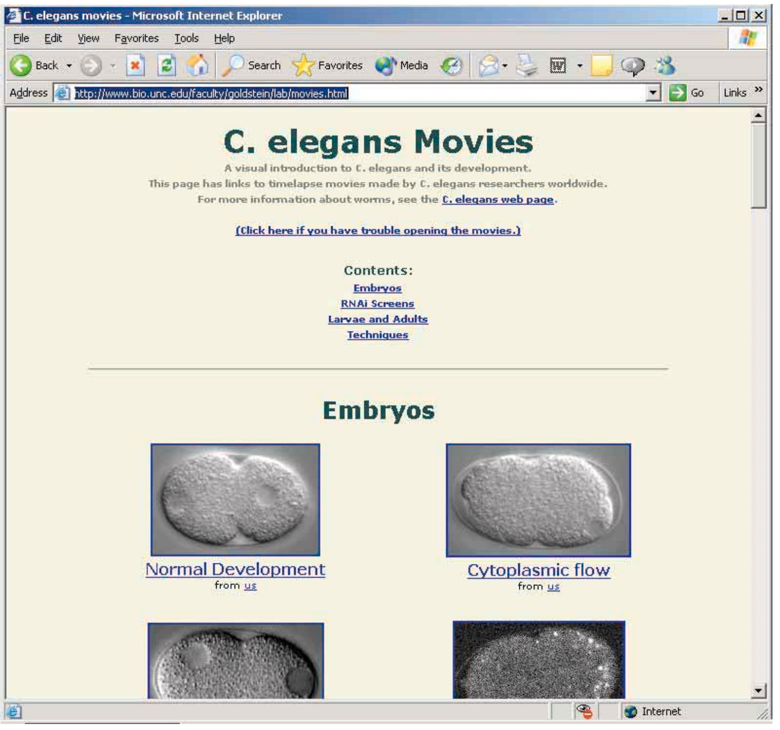

Fig. 2. Web site that allows students to repeatedly view videos of developmental processes.

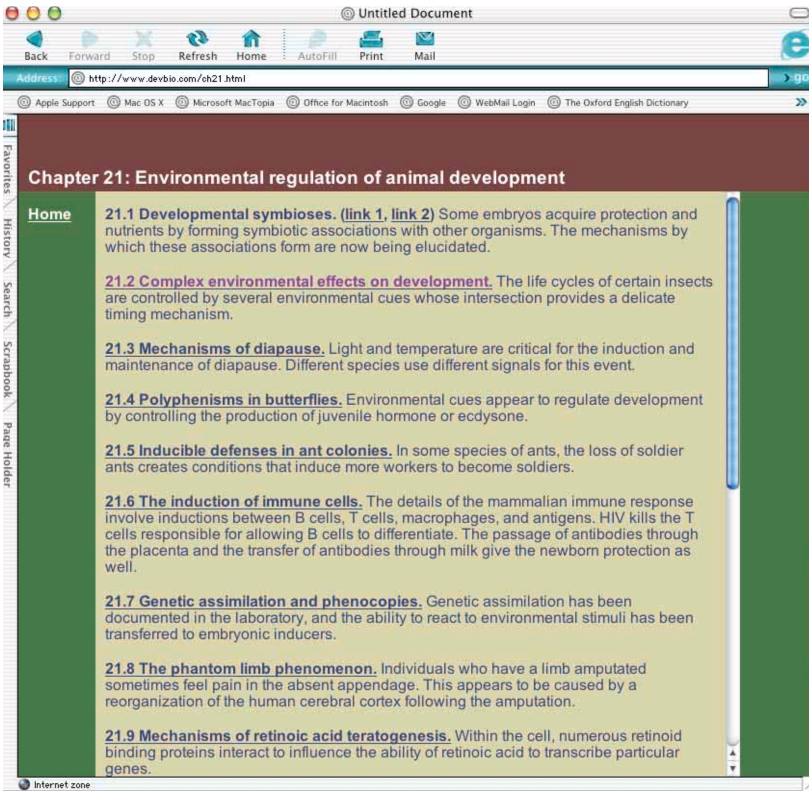

Fig. 3. Web site providing supplemental/enrichment materials in support of a textbook used for developmental biology courses.

biology class concerned with social issues this might be an interesting exercise.

Virtual sites supply supplementary material for text, lab, and lecture. An example is this site, which supports a popular textbook, (Fig. 3; http://www.devbio.com/). The materials on this web site are meant to update the textbook and enrich it with resources considered too difficult, too detailed, too medical, or too specialized for the average student. There are also philosophical, sociological, ethical, and historical studies in developmental biology, as well as interviews and opinion pieces. This site is clearly meant to supplement the lecture part of the class. Most of this site is textual, with hyperlinks to related sites and available online papers.

Virtual labs can support the ability to experiment with things that are too dangerous, too global, or too long term to do in a lab. The most sophisticated online technology involves java applets, small programs that download quickly and allow fully interactive simulations or Macromedia shockwave animations. Biology labs online (http://biologylab.awlonline.com/) is a commercial site that hosts interactive exercises coordinated with a popular introductory text book. The site is password protected but can be reviewed via a free three-day sample subscription. The simulations are very sophisticated, but many of the exercises could be done in a lab situation. A notable exception is an evolution lab that allows the students to observe how finch populations evolve over 300 years on two islands.

The Society for Developmental Biology site (http://sdb.bio.purdue.edu/SDBEduca/) has a very comprehensive list of virtual resources and examples of teachers that use web sites to fortify lectures and face-to-face labs. The best of these web sites give students ways to connect with other students and faculty as well as ways to review materials and to find enrichment materials. An example of a class web site (http://www.williams.edu/Biology/rsavage/BIOL 301.html) replaces neither lecture nor lab; rather it is an organizing point for all the resources and materials that students previously were given as handouts, with the addition of some more interactive tutorials and other resources.

Sites with tutorials such as http://worms.zoology.wisc.edu/embryology_main.html, provide remedial help or review material from earlier courses. Students in developmental biology might use these to review first-year biology or chemistry. Tutorials frequently have hyperlinks to glossaries, another way for students to review their understanding of biology. For instance, the Massachusetts Institute of Technology (MIT) has an online tutorial that reviews chemistry and molecular biology (http://esg-www.mit.edu/) for the biology student. Chemistry and molecular biology are topics that many students find difficult and they often stymie the students' further progress in biology. Worthington Biochemical Corporation has a course web site (http://www.worthington-biochem.com/best/Courses/biological_sciences/default.html) with tutorials that provide remedial help in general biology for the developmental biology student.

Web sites can provide access to research data, giving students the opportunity to manipulate experimental data sets. The University of Michigan hosts a site that has data sets from human embryos available for download (http://embryo.soad.umich.edu/)

Finally, virtual labs can give exposure to research scientists in the form of interviews and discussion forums. Swarthmore College (http://zygote.swarthmore.edu/) provides some interviews with research scientists. I was unable to locate examples of discussion forums with research scientists. I suspect that even though this seems like a good idea, few research scientists want to make themselves accessible for lengthy discussions or forums.

Disadvantages of Virtual Labs

The biggest disadvantage of virtual labs is that they are removed from the reality of the lab, which may already be removed from the reality of biology by fixing, staining, and thin sectioning (to name just a few of the technologies for the preparation of lab specimens). The quality of experience from virtual labs does not have the immediate and embodied impact of handling specimens and live organisms. Even prepared microscope slides engage the student in interpretation of structure in ways that photographs, movies, and animations can never do.

Another great disadvantage that is true of all virtual exercises is that they lack the immediacy of the supervision and contact with experienced teachers. Only mature and self-motivated learners do well in virtual environments where class meetings do not structure their time and they must actively seek help when confused.

Virtual labs have all the technological problems that plague any web site. They rely on servers that are not always in service.

Updates of server or browser software may put earlier versions of virtual lab software out of commission. Students require adequate bandwidth to access the most interactive virtual labs, and home modems may not be adequate. There are training issues involved with students using virtual labs without supervision. When virtual labs link to other web sites, these links must be constantly checked for accuracy and continued existence. Web materials become out of date and require updating on a regular basis.

Some of the advantages of virtual labs can also be disadvantages. The huge amount of material on the web is daunting to many students and certainly requires a critical eye to discriminate accurate from inaccurate web sites (MaKinster *et al.*, 2002). In the multitude of web sites mentioned throughout this paper, links frequently make large recursive loops, with the result that students are tempted to keep clicking on links without ever getting to any substantive material, just to more lists of links.

Web sites have a static and reified nature that may make them unsuitable for transnational or even transcultural learners. The language and style of language, the gender, race, and class of people appearing in the virtual lab affect who will feel comfortable and who will participate with these activities (Herring *et al.*, 2002). Those of us who design web sites feel a constant tension between the need to design with culture in mind and the irreconcilable needs that cultural differences often imply.

Models are only partial representations (a synecdoche) of reality. The viewpoint of the designer of the model or simulation is permanently inscribed in the model, but a level of realism is attempted that hides these design choices. Essentially, design choices are black boxed within the software and therefore hidden from recognition (Scheckler, 2000). Models and simulations can partially overcome the problems of synecdoche if they allow students control over the simulation and also allow students a role in creating the simulation (Garrison and Scheckler, 2002).

A Plan for Engaged and Technologically Enhanced Labs

Ideally, labs for developmental biology need to have facilities for both wet labs and computer activities in the same or adjacent rooms. An example of such a lab was implemented by Stephen Scheckler at Virginia Tech and assessed by educators (Ruberg *et al.*, 1996; Scheckler *et al.*, 1998), giving us insight into the methods and results of this innovation.

Scheckler *et al.* (1998) developed a CD to enhance plant biology labs. Their choice of a CD to deliver the material rather than the Internet was based on available technology at the time of development. Despite the burgeoning appeal and utility of the Internet as a way to deliver computer activities, a CD still has advantages. Students at universities often have adequate bandwidth to download computer-based activities in a timely way. Students at home and particularly in developing countries may lack the technology infrastructure to depend upon the Internet. This CD, developed with Director software, could now be put on the Internet by using Shockwave and some reorganization and thus be available both ways. Scheckler provides many well thought out and reasoned activities on the CD, in particular simulations that involve actions too global to observe in class and an extensive visual and textual glossary of plants and their functioning.

As interesting as is the CD, it is its usage that was and is innovative. Scheckler uses computers in the lab to deliver images and simulations where appropriate but also a wet lab nearby with microscopes and live and preserved plants. Furthermore, he engages his students in thought-provoking questions on the social implications of such issues as the destruction of the tropical rainforests, drainage of wetlands, pollution of marine environments, the effects of acid rain, and the melting of the polar ice caps. In short, he uses the larger context of botany to motivate discussion, leading to greater integration of facts into a student's cognitive frameworks, excitement about botany, and social responsibility. Some of these discussions occur on line in a lab-based network of computers using the software Daedulus. With this technology students are encouraged to collaborate on ideas, shy students are more apt to participate, and an instructor or graduate assistant is there to model and facilitate the discussion and reflective behaviors.

Conclusions

As with any educational tools, teaching goals must govern use of virtual labs. Many different types of Internet-delivered digital tools are used in developmental biology classes, and these tools fulfill a great range of teaching goals. Simplicity and the physical experience of the student should be balanced with the appeal and convenience of digital sources. As with many balanced solutions, a both/and solution gives the most satisfying results. I recommend hybrid approaches to the tools of developmental biology so that the benefits of both digital tools and lab bench exercises are used along with the careful analysis of the goals of different exercises. Most importantly, children of the digital game generation must understand that the study of biology always refers back to living organisms and the earthiness that entails. These issues are not new to the digital age. Analog tools such as films have clearly been misused in the past the same way digital simulations might be misused today.

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