Ohio Educators Respond to Governor Taft's Initiative for the Third Frontier: A Call for Action[1]

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ABSTRACT. The new science frontier requires training students who have the knowledge and skills to work on scientific problems that transcend specific scientific disciplines. A computational studies curriculum integrated into undergraduate science majors can provide the experiences that students need to succeed in the new science frontier. Computational studies is the use of mathematical modeling and computer visualization to solve problems in biological, physical, medical, and behavioral sciences as well as economics, finance, and engineering. A computational studies curriculum is characterized by: 1) the use of computer visualization techniques and mathematical modeling to answer contemporary questions in science, 2) participation in undergraduate research experiences that includes real-world problem-solving with industry partners, 3) engagement in interdisciplinary conversations within cross-functional teams, 4) development of a computational studies thought process, 5) exploration of the creative nature of science, mathematics, and computer science, and 6) communication of science problems and solutions to a variety of audiences. Opportunities for integrating computational studies into science curricula are explored.

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INTRODUCTION

> "If we are to succeed as a state, terms like fuel cells, bioscience, polymers, IT, liquid crystals and advanced manufacturing must become part of our everyday vocabulary. Ohio must be the place where new knowledge is used to create new products, new businesses, new companies and new jobs" (Taft 2003, p 1).

> "In the coming decades, the number of jobs in the technology sector will continue their overall exponential growth-globally, nationally, in Ohio and in Columbus" (White 2003, p 13).

Thus, the challenge facing Ohio educators is to prepare the future scientists who can fill these jobs, excel in this new science environment, and usher the Third Frontier into Ohio. The Third Frontier is the science of the future-science that transcends traditional disciplinary boundaries. Bruce Johnson, Director of the Ohio Department of Development, asserted that Ohio's Third Frontier Project is about building a "knowledge economy" in Ohio, which includes bioscience, medical imaging, regenerative medicine, fuel cell research, and technology-based businesses (Johnson 2003). The Third Frontier is the integration of technology, computer visualization, mathematical modeling and science.

The Third Frontier requires scientists who can move beyond traditional disciplinary boundaries and effectively function in cross-disciplinary teams. These scientists must speak a common language and have a shared understanding of the current and future possibilities of science and technology. Computational studies—the integration of computer science, mathematics, and science—provides the foundation for developing the requisite skills to succeed in the new science frontier. A computational studies curriculum includes six key characteristics.

Use of Computer Visualization Techniques and Mathematical Modeling to Answer Contemporary Questions in Science: As an emerging field, computational studies is concerned with examining scientific questions that are currently relevant. Applied mathematical modeling and computer visualization are the tools used to answer scientific questions. This means that students must have experience with many different software packages so that they can choose the appropriate method for a given problem. This is consistent with the recommendation of the Mathematical Association of America (MAA 2003), which identified as one goal of curriculum change: ". . . experience with a variety of technological tools, such as computer algebra systems, visualization software, statistical packages, and computer programming languages" (p 54).

Participation in Undergraduate Research Experiences that Includes Real-World Problem Solving with Industry Partners: Undergraduate research is one of the most powerful tools that educators have to help students achieve a profound understanding of the scientific method and develop a passion about scientific issues; it is also the purest form of teaching and learning (Hakim 2000; James 1998). Through undergraduate research, students learn to do research as professionals do it, not as it is simulated in a classroom (Kardash 2000; Landrum and Nelsen 2002). Undergraduate research experiences draw students into the scientific community and serve as a catalyst for students to pursue careers in science (Schowen 1998). Additionally, in order to introduce students to emerging technologies, educators and industry must engage in ongoing dialog. Having students work directly with industry partners during their undergraduate research helps to maintain that dialog, even as student engagement deepens through work that is personally meaningful. The mentoring relationships that

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develop from these experiences afford benefits to both the students and the mentors (Linnehan 2003; Noe and others 2002).

Engagement in Interdisciplinary Conversations within Cross-Functional Teams: Science as it is conducted in industry includes collaboration by individuals from different disciplinary backgrounds. The National Research Council (2003) encourages re-conceptualizing the undergraduate biology curriculum so that it includes "a strong foundation in mathematics and the physical and information sciences to prepare students for research that is increasingly interdisciplinary in character" (p 8). For example, nano-technology research on drug design often includes individuals with backgrounds in physics, medicine, chemistry, biology, and engineering. Educational experiences that mirror these cross-functional teams best prepare students for lives in industry.

Development of a Computational Studies Thought Process : This thought process is characterized by: Problem → Model → Method → Implementation → Assessment. The focus on application within computational studies means that the work that is done begins with a real world problem, such as: "Who contaminated the water supply?" "How can MRI data be used to provide a three-dimensional image of the brain?" "How can we predict the spread of disease?" Computational models are applied to the situation and a method (that is, analytic, numeric, graphic) is selected that is appropriate for solving the problem. Following the implementation of the computational model, the result is assessed to determine how well the model fits with data. Throughout this process, assumptions of the model are examined and reexamined so that the limitations of the model can surface. The feedback looping mechanism that assessment provides is essential for refining the model to better reflect and approximate reality.

Exploration of the Creative Nature of Science, Mathematics, and Computer Science : Think about it for a moment, science is the *creation* of new knowledge. That is, science, through its very nature, is a creative endeavor. Sadly, the popular conception of science is that it is dry and lacking in imagination and ingenuity. When students must memorize a list of "facts" during their science classes, they miss the inherent creativity that was necessary to derive those "facts." Articulating meaningful research questions, developing methods for answering those research questions, and deriving meaning from the data all require vision and inventiveness. Scientific advances occur when individuals take an established body of research and either extend it in ways not thought of previously or make connections that had been missed by others. Computational studies specifically targets creativity as students and scientists are required to make new connections and use visualization and modeling tools in novel ways to solve new problems.

Communication of Science Problems and Solutions to a Variety of Audiences : "Communicating mathematical ideas with understanding and clarity is not only evidence of comprehension, it is essential for learning and using mathematics after graduation, whether in the workforce or in a graduate program" (MAA 2003, p 53; see also Ware and others 2002). While it is important for students to learn to write technical reports of their scientific work, it is no longer sufficient for students to learn to write reports only for their professors or for the scientific community. Students must also learn to communicate their work to their future supervisors and to the general public. It is an unfortunate reality that funding for much scientific research is indirectly linked to popular conceptions of science; thus, attracting and retaining grant money is dependent on the ability of scientists to "sell" their work to the general public so that there is continued support for scientific research.

Why is it imperative to push computational studies curriculum at the undergraduate level? The undergraduate curriculum feeds the educational pipeline in two ways (see Fig. 1). First, colleges and universities produce future graduate students who can obtain advanced degrees incorporating computational studies and thus work toward further advancing the new science frontier and/or become the faculty who will continue to propel the new science frontier into the undergraduate curriculum. Second, the undergraduate curriculum produces teachers for primary and secondary school who can work to better prepare prospective college students for the future of science. Additionally, by feeding the educational pipeline in these two ways, the undergraduate curriculum also works to better prepare individuals to work in the science and technology industry. Therefore, integrating computational studies into the undergraduate curriculum is a necessary starting point for changing science education to meet the needs of the new science frontier at all levels of the educational pipeline and within industry.

A Call for Action

A paradigm shift is never easy. There are significant barriers that must be addressed in order to make the educational changes necessary for the new science frontier. These barriers include: 1) limited materials for teaching

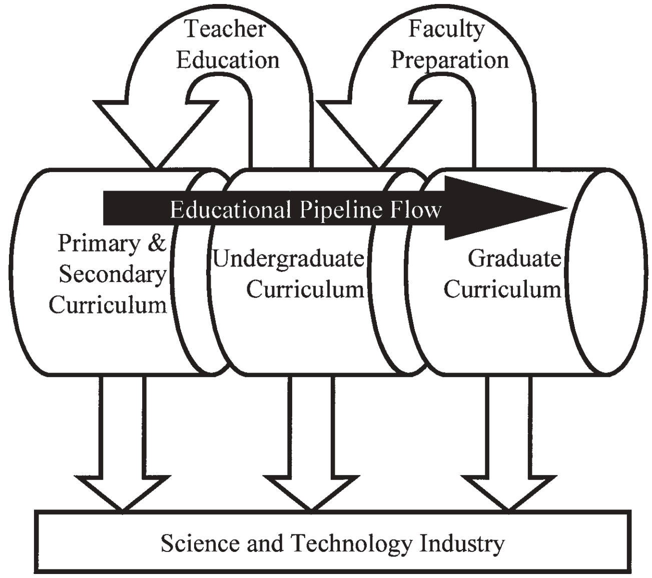

FIGURE 1. Educational pipeline.

undergraduate computational studies, 2) a lack of time to redesign a course or curriculum to include computational studies, 3) limited financial and infrastructure resources, and 4) professors who are not trained in computational studies.

Fortunately, several initiatives are attempting to address these barriers. For example, educational materials for computational studies are now available from a variety of different sources, such as the Shodor Foundation (www.shodor.org); the Computational Science Across the Curriculum program at Capital University (www.capital.edu/acad/as/csac/) that includes partnerships with several other institutions across the nation; the National Computational Science Institute (NCSI, www.ncsi.org); the Education, Outreach, and Training Partnership for Advanced Computational Infrastructure (EOT-PACI, www.eot.org); and BIOquest (www.bioquest.org). Organizations such as the Shodor Foundation and Project Kaleidoscope (www.pkal.org) offer workshops for faculty who are interested in building their own computational studies repertoire.

The materials developed by these organizations are in modular format; faculty can pick and choose the materials that they want to integrate into their courses based on their interests and expertise, students' level of preparedness, and the goals of the course. The flexibility of the modular format also means that faculty can start slowly to build computational studies activities into the curriculum by including a computational studies activity or two into each course. Alternatively, there are now enough materials available for faculty to design an entire course or sequence of courses for a particular curriculum.

In addition to the modular format, the materials were also designed with the financial and infrastructure limitations in mind. Much of the software that is used in the materials is either widely used or freely available and many of the applications cut across computing platforms. Consideration was also given toward using software packages that are used in industry so that students are learning the tools that they will need after graduation.

CONCLUSION

Ohio educators must come together to prepare students to be competitive in the Third Frontier. One way to do this is through integration of computational studies into the undergraduate science curriculum.

LITERATURE CITED

Hakim TM. 2000. At the interface of scholarship and teaching: how to develop and administer institutional undergraduate research programs. Washington (DC): Council on Undergraduate Research.

James P. 1998. Progressive development of deep learning skills through undergraduate and postgraduate dissertations. Educational Studies 24(1):95-105.

Johnson B. 2003. What is the Third Frontier? In: Cook H, editor. Ohio's Third Frontier Project: Creating Jobs for Ohioans. Columbus (OH): Columbus CEO Magazine. p 15.

Kardash CM. 2000. Evaluation of an undergraduate research experience: perceptions of undergraduate interns and their faculty mentors. J Educational Psychology 92(1):191-201.

Landrum RE, Nelsen LR. 2002. The undergraduate research assistantship: an analysis of the benefits. Teaching of Psychology 29(1):15-9.

Linnehan F. 2003. A longitudinal study of work-based, adult-youth mentoring. J Vocational Behavior 63(1):40-54.

[MAA] Mathematical Association of America. 2003. Undergraduate programs and courses in the mathematical sciences: CUPM Curriculum Guide 2004. Washington (DC): Mathematical Association of America.

National Research Council. 2003. Bio 2010: transforming undergraduate education for future research biologists. Washington (DC): The National Academies Pr.

Noe RA, Greenberger DB, Wang S. 2002. Mentoring: what we know and where we might go. In: Ferris GR, Martocchio JJ, editors. Research in personnel and human resources management. USA: Elsevier Science/JAI Pr. p 129-73.

Schowen KB. 1998. Research as a Critical Component of the Undergraduate Educational Experience. Washington (DC): National Academy Pr.

Taft B. 2003. Letter. In: Cook H, editor. Ohio's Third Frontier Project: Creating Jobs for Ohioans. Columbus (OH): Columbus CEO Magazine. p 1.

Ware ME, Badura AS, Davis SF. 2002. Using student scholarship to develop student research and writing skills. Teaching of Psychology 29(2):151-4.

White S. 2003. Third frontier programs 'come to life' with integrated local efforts. In: Cook H, editor. Ohio's Third Frontier Project: Creating Jobs for Ohioans. Columbus (OH): Columbus CEO Magazine. p 13.