Schooling excellence

The Center for Discrete Mathematics and Theoretical Computer Science is working to develop and deploy dynamic interdisciplinary high school education modules to support improved outcomes. Director **Professor Rebecca Wright** and Project Lead **Dr Margaret Cozzens** discuss how the Center is achieving its aims

What are the broad objectives of your current educational venture?

The Center for Discrete Mathematics and Theoretical Computer Science (DIMACS) has a portfolio of projects that develop innovative instructional modules, mini-modules and books for use in a variety of high school classes. Three current projects, The Value of Computational Thinking Across Grade Levels (VCTAL), The Challenge of Interdisciplinary Mathematics and Biology (IMB) and Mathematical and Computational Methods for Planning for a Sustainable Future (PS-Future), are multidisciplinary in content and provide a learning environment for problem solving, modelling complex problems and applying a wide range of tools from computer science, mathematics and the sciences. All project materials are thoroughly evaluated for teaching quality, understandability and technical accuracy in multiple ways. A selection of modules can be used in different kinds of classes, ranging across the sciences, mathematics, social sciences, computer science and even humanities. The ultimate goal is to prepare high school students with the thinking and tools necessary to solve the complex problems of the 21st Century.

In what capacity could teaching in high schools be improved?

High school teaching has remained primarily attentive to individual disciplines for 200 years, since the days of one-room schoolhouses. This single focus is not sufficient for jobs and civic engagement in the 21st Century. For example, advances in human genomics research and its applications to improve treatments of disease have occurred at the interface of mathematics, biology and computer science using methods, tools and knowledge bases from all three disciplines in conjunction with each other. Similarly, planning for a sustainable future requires the use of methods, tools and knowledge bases in those three disciplines, as well as physics, chemistry, environmental science, social sciences and public policy. The modules developed in our curriculum projects provide a multidisciplinary problem-solving environment to enhance disciplinary-specific learning in a way that reflects the multidisciplinary needs of an increasing proportion of current and future jobs.

Can you share an example of how your projects will assist in integrating mathematics with science topics into the curriculum?

The key goals of the IMB project are to provide teachers with curricular materials that highlight the interconnections between the mathematical and biological sciences and to provide help for teachers in using these new materials. We have developed a set of 20 high quality bio-math modules, and online 'books' that combine modules into one-semester and full-year courses, including teacher-support materials that can be flexibly adapted for use in a variety of courses at a variety of grade levels in either biology or mathematics, or coordinated between both classes simultaneously. Each module seamlessly discusses a particular topic, often by posing an initial question whose solutions require the use of content knowledge and methods from both mathematics and biology. A module on Imperfect Testing uses a case-study approach to determine the best course of action when a mammogram shows an abnormality. Students learn the biology of benign and cancerous tumours, as well as how to understand false positives and false negatives and compute their probabilities, run simulations and pose additional questions.

Do you hope that the educational modules will inspire students to pursue a career in mathematics or the sciences?

We hope to inspire more students to pursue careers in computer science, technology, mathematics and other sciences, especially students from populations traditionally underrepresented in these fields. At the same time, recognising that computing, problem-solving and mathematical thinking play an increasingly important role outside of the traditional sciences (such as public policy, journalism, manufacturing and marketing), we also hope that by exposing many students to these topics and skills and their widespread applicability, our modules will inspire even those not planning to pursue careers in the sciences or mathematics to consider some further study in these fields, thereby enhancing our contribution to a more informed workforce.

How do you see the future progressing for these projects?

Completed VCTAL and IMB modules are already being used in schools throughout the US, even as they are being tested. Red River High School in Grand Forks, North Dakota is pilot testing the full-year biomathematics book this academic year, with the intent of going state-wide in North Dakota in the autum of 2013. PS-Future is a newer project. The first two modules are currently in development, and we expect to develop a total of 14 modules as well as an online book for a full-year course. The innovativeness of these multidisciplinary projects is a key to the ongoing success of our work. We see an increasing need to look at education as a whole and not be content in thinking of different education environments in isolation.

Preparing students for a **multidisciplinary future**

Driven by a desire to bring excitement and multidisciplinary engagement into high schools, The Center for Discrete Mathematics and Theoretical Computer Science at **Rutgers University** is developing and deploying valuable resources related to mathematics, computer science and the sciences, along with their integrated applications

THE HIGHLY INTERDISCIPLINARY nature of the modern-day workforce is one of the greatest challenges facing high school education; further, we face a deficit of students pursuing higher education in the science, technology, engineering and mathematics (STEM) fields, which are critical to innovation and advancement in today's world. Rarely is knowledge of just a single discipline adequate for today's job market: a reality that is forcing students to explore means to better equip themselves with an understanding of the full gambit of disciplines needed to make an effective and valuable contribution. Based at Rutgers University and directed by Professor Rebecca Wright, The Center for Discrete Mathematics and Theoretical Computer Science (DIMACS) is carrying out a portfolio of projects to improve student engagement in STEM fields, bridge the current gap in the curriculum between seemingly disparate subjects, and provide students with versatility that will smoothen their transitions from education to career. DIMACS currently has three projects, each funded by the National Science Foundation, to develop three series of curricular modules that offer students insights into mathematics, computer sciences, and their interrelationships. These are The Value of Computational Thinking Across Grade Levels (VCTAL), The Challenge of Interdisciplinary Mathematics and Biology (IMB) and Mathematical and Computational Methods for Planning for a Sustainable Future (PS-Future). DIMACS and its partners are working with over 100 high schools across the country to field test these materials. The modules offer students exposure to a range of science topics and learning environments and highlight the value of a cross-disciplinary curriculum.

DIMACS is carrying out a portfolio of projects to improve student engagement in STEM fields and versatility for their transition from education to career

THE VALUE OF COMPUTATIONAL THINKING

The VCTAL project is creating one-week modules designed to be used in a variety of non-computer science high school classes to support the introduction of computational thinking concepts. VCTAL modules are student-centred and built around activities that involve computational thinking. In order to ensure that the modules and examples are broadly accessible, there is no computer programming needed. In some modules, students use apps, spreadsheets or other similar computational software to help solve problems and identify key concepts, while some modules are done entirely 'unplugged', without requiring any use of computing devices. There are also practical activities to help engage students with problem solving. "Each module aims to engage students by applying computational thinking in a context that is meaningful, relevant and generally open-ended, and challenge them to work creatively and collaboratively to solve some problem," highlights Wright.

A common goal across all VCTAL modules is to achieve personal student involvement in finding and evaluating solutions. One of the real values of these resources is that they can be used across a variety of subjects and courses as 'drop-in' modules. In addition, DIMACS is preparing a virtual book that brings together all of the modules in a course that runs over one semester.

Through VCTAL modules, students are encouraged to use and develop computational algorithms to gain insights about problems. "This part of computational thinking is especially important when solving problems that are, for example, too large to solve by hand," points out Margaret Cozzens, DIMACS research faculty and project lead for VCTAL and PS-Future. She offers the example of the module which introduces students to privacy issues that can be created, worsened, or solved by computer technology. 'Privacy' is a classroom module authored by Wright and Paul Kehle driven by a series of case studies drawn from real life examples.

The case studies are structured similarly: first, an initial scenario is presented along with some general prompts for discussion. Then further detail of the case is provided, and finally some open-ended questions are posed to stimulate analysis. The prompts and questions are meant to be suggestive and not exhaustive. Although they focus on key issues, teachers might find other useful questions and approaches to the case studies.

Responses can vary and create topics for quality discussion. Following each case study are key ideas that will help teachers understand issues with privacy and the role of computational thinking in solving the associated problems.

Examples of case studies include: Netflix, who is watching what you watch?; Are loyalty cards loyal to you?; and Google autocomplete. The module concludes with an activity that examines a computational strategy to protect privacy. The 'Secure Computing Activity' leads teachers through the development of an algorithm for determining the average of a group of numbers without any person knowing more than his or her numbers or learning anything more than the resulting average and applies an algorithm to the pricing of sugar beets in Denmark.

In the preparation of these materials, DIMACS has gathered feedback from user groups, including prototyping workshops to explore the use of early versions and improve them based on the results. "For example, in one prototyping workshop, students were randomly given nametags and then asked to design an efficient algorithm to swap and match each student with the proper nametag," continues Wright. "The students collaboratively developed such an algorithm and then analysed it by repeatedly enacting it as a group. The Matching module was then updated to include this kind of activity."

THE CHALLENGE OF INTERDISCIPLINARY MATHEMATICS AND BIOLOGY

IMB is based on its predecessor BioMath Connection (BMC), which pioneered the linking of biology and mathematics in high schools. IMB includes a number of individual modules which can be used in either biology or mathematics classes, as well as a senior-year course on biomathematics. There are 15 BMC biomath instructional modules aimed at grade levels 9-12, which have the flexibility to be adapted to variety of courses and levels. IMB expands the BMC modules to include additional classes, as well as combines all the modules into a textbook that serves as the cornerstone of a new biomathematics course for high school seniors.

PLANNING FOR A SUSTAINABLE FUTURE

The newest project in the DIMACS portfolio, PS-Future, aims to develop resources which students can use to play an active role in the emerging issues of sustainability. This involves a number of one week modules where sustainability topics are brought into the classroom through real life examples to show how mathematics and computer science tools can be applied across sustainability and natural resource management planning. Teachers use the PS-Future materials to educate about foundational and emerging concepts in mathematical and computational sciences that are relevant to physical, biological, environmental and social sciences.

Student project posters from Red River High School, Grand Forks, North Dakota for BMC modules 'Drawing Lines - Voronoi Diagrams' and 'Home Range Analysis'.

"Through these modules," describes Tamra Carpenter, research faculty at DIMACS and a key contributor to VCTAL and PS-Future, "students will develop an understanding of the ways that disciplines interact with their inquiries, driven by real problems such as the design of energy-efficient buildings." By being involved in personally relevant sustainability topics, students begin to see the importance of developing cross-cutting skills in mathematical and computational methods. Authors have developed first drafts of two modules and they will be used for the first time in a prototyping workshop in mid-2013.

EDUCATION FOR THE 21ST CENTURY

Through these high school education projects that assist teacher/student engagement and apply multidisciplinary mathematical, computational, and scientific thinking to a variety of familiar and unfamiliar applications, DIMACS seeks to broaden participation in mathematics, computing and related science disciplines. There is great potential for these initiatives to provide an important building block in enhancing the STEM curriculum in schools and preparing students for careers of the 21st Century.

INTELLIGENCE

THE CENTER FOR DISCRETE MATHEMATICS AND THEORETICAL COMPUTER SCIENCE (DIMACS) HIGH SCHOOL EDUCATIONAL MODULES

OBJECTIVES

To develop and test materials for the introduction of interdisciplinary themes into a wide variety of high school courses. This includes the development of curriculum modules and course books at the interface of mathematics and biology, in computational thinking and sustainability.

KEY COLLABORATORS

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BMC-IMB

PS-Future

VCTAL