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INTEGRATING COMPUTATIONAL THINKING INTO INFORMATION SYSTEMS AND OTHER CURRICULA

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Abstract:

Computational thinking (CT) is a fundamental skill needed to function in modern society. Despite widespread use of computers as productivity tools, existing curricula in information systems (IS) and other disciplines have not fully embraced CT concepts and skills. Increasing cross-disciplinary integration of CT into these curricula can help develop students' problem-solving ability and provide educators with useful resources. Our collaborative initiative, named the "Living in the Knowledge Society" (LIKES) community building project, supports the integration of CT into college-level curricula by building a community of scholars and educators who will define the way to make systemic changes in how computing and IT concepts are taught and applied in both computing and other fields, thus better preparing the next-generation Knowledge Society builders. We describe the workshops, community-building activities, outcomes achieved, and case studies of developing teaching modules, curriculum guidelines, and teacher adoption strategies. Our work should benefit educators interested in integrating CT in their curricula, computing researchers interested in collaborating with other domain experts, and current students who aspire to become educators.

Keywords: computational thinking, information systems, curriculum, cross-disciplinary, interdisciplinary, multidisciplinary.

I. INTRODUCTION

Computational thinking (CT) takes an approach to solving problems, designing systems, understanding human behavior, and conducting research in many disciplines [Bundy, 2007, Wing, 2006]. Regarded as an "intellectual revolution" happening all around the world [Bundy, 2007] and a "21st century literacy" [Guzdial, 2008], computational thinking contributes to new knowledge discovery in nearly all disciplines by abstraction and automation [Wing, 2008]. The concepts and tools that support abstraction and automation relate strongly to the information systems (IS) discipline, which is concerned with the design, implementation, management, and use of innovative artifacts, as well as the surrounding organizational and human phenomena [Hevner et al., 2004]. Because of the importance and prevalence of CT in the society, proper integration of these concepts and tools into the IS curriculum could enhance the education quality and strengthen students' analytical skills.

While CT is increasingly integrated into the research and education [Qualls et al., 2010] of some disciplines such as biology [Priami, 2009], history [Turkel and MacEachern, 2008], geography [Kinzel and Wright, 2008], and statistics [Oldford, 1998], the IS and other disciplines still lack concerted efforts and formal guidelines for integrating CT into their curricula. As the society relies more heavily on knowledge workers in all professions, the curricula in information systems and technology as well as other disciplines have strong impacts on students' future capability to shape the world. In this paper, we describe our effort of integrating CT into the IS and other curricula. Our collaborative initiative, named the "Living in the Knowledge Society" (LIKES) community building project, supports the integration of CT into college-level curricula by building a community of scholars and educators who will define the way to make systemic changes in how computing and IT concepts are taught and applied in both computing and other fields, thus better preparing the next-generation Knowledge Society builders. We describe the workshops and activities held in 2009 and 2010 and describe the outcomes achieved and case studies of developing teaching modules, curriculum guidelines, and teacher adoption strategies. We are compiling a book that will contain a set of comprehensive curricular guidelines to be deployed nationwide for integrating CT into different disciplines.

II. RELATED WORK

"Computational thinking is a fundamental skill needed to function in modern society" [Wing, 2008]. CT involves solving problems, designing systems, and understanding human behavior (for a more complete description about CT, please refer to [Wing, 2006]). It has been argued that CT should be integrated into the curricula of all disciplines, which reflect the many domains of today's society. Peter Drucker, widely recognized as the father of modern management, said that the society emerging in the 21st century relies heavily on knowledge workers, such as software designers, clinical lab analysts, and paralegals [Drucker, 2001]. Scattered in different domains, these workers will collectively form the dominant social force in the coming decades. Educating today's college students is therefore paramount for developing and sustaining the Knowledge Society. As a result, efforts of integrating CT into the curricula of different disciplines would help prepare today's students to build the Knowledge Society. We review below these efforts with a view to identify needs for further curricular development and integration of CT.

Computational Thinking in Professional Disciplines

The information systems (IS) discipline is among many professional disciplines such as engineering, law, and medicine. The IS curriculum focuses primarily on the needs of business and industries. In the 2010 model IS curriculum developed by the Association for Computing Machinery and the Association for Information Systems [Topi et al., 2010], the curriculum was designed with a focus on career target of interest to the IS community. While key computing areas such as data management and systems analysis are covered in the curriculum, there is no guide on integrating CT into different disciplines (especially for non-business domains). It also provides no pedagogical suggestions and curricular resources for such integration. By providing better skill set and career opportunities, such integration would help to improve the IS student enrollment that is still low in many schools.

An example of integrating computing in professional disciplines is an engineering course at North Carolina A&T University called Web Engineering. It focuses on Web technologies, object oriented programming and design, social and economic aspects of the Web, and Web services. The course uses DyKnow, an interactive teaching tool for fostering collaborative learning. Classroom Presenter is another tool used in this course as an open source Tablet PC-based interactive system that supports the sharing of digital ink on slides between instructors and students. While computing tools are used in these courses, CT skills are only indirectly acquired in the courses.

Computational Thinking in Natural Sciences

Computational thinking is used in natural science courses including Biology, Chemistry, Physics, Ecology, and Statistics. One science course at Purdue University uses computational tools such as MatPlotLib, VPython, NumPy, and the Monte Carlo methods. The course utilizes Python and Python libraries to teach computational thinking by the use of basic programming concepts, data management concepts, simulation, and visualization [Hambrusch et al., 2009]. A project called Making Sense of Complex Phenomena (MSCP) has been established to teach students about complex systems through construction of agent-based models of these systems. The goals of the project are to construct computational toolkits that enable students to model complex systems and to understand their behavioral dynamic. The project also uses c, a modeling language and integrated environment to provide framework of simulated systems. MSCP was used as a project in Tufts University biology course to educate the students about computing concepts [Wilensky and Reisman, 2006]. The Centre for Highly-Interactive Computing in Education at the University of Michigan developed a set of tools and a curriculum called ScienceWare to support science students investigate water quality issues in their community and link their data to national scientific investigations. ScienceWare is a tool that supports the students' investigation. The curriculum integrates software use and modeling with science [Dede, 2000]. Despite the use of software and tools, CT needs higher integration in curricula such that students would acquire the thinking methods rather than just the mechanics of using the tools.

Computational Thinking in Performing Arts

An example of integrating CT in a performing arts curriculum is the music courses offered at Stanford University and Villanova University. The courses use a programming language called ChuCK to "import music into computers, read music notation, and understand music theory." The course incorporates important computing concepts to expand the possibilities of music to the world. By using machine learning in advanced signal processing and learning to create websites to distribute music online students not only further their music knowledge, but also increase their understanding of computational thinking. The way CT concepts are incorporated in music is highly valued but seldom found in many other art disciplines.

Computational Thinking in Language and Humanities

Though less strongly connected to CT concepts, the languages and humanities disciplines increasingly embrace CT into their curricula. For example, CT tools such as text processing and analysis tools help increase students' ability to create English composition and to evaluate their written essays [Perkovic and Settle, 2009]. Nevertheless, CT is seldom treated as thinking methods to benefit students' life-long learning.

We found from the above review a number of research gaps that need to be filled. Although the aforementioned efforts use computing tools and software to support course teaching and student learning, computational thinking is not widely integrated into the curricula to emphasize high-level thinking skills and abstraction. In most cases, computing is used just as a tool to automate certain tasks without any enhancement on students' computational thinking skills. Moreover, previous efforts are mostly discipline-specific and applicable only to their respective domains. Since the sharing of CT curricula resources can achieve economies of scale, cross-disciplinary integration and collaboration are highly desirable and beneficial to multiple disciplines. Unfortunately, there is no large-scale effort to foster such cross-disciplinary collaboration of CT integration into the curricula.

III. THE LIKES PROJECT

To address the aforementioned needs, we have conducted a collaborative project that is filling the gaps by a series of workshops, community-building activities, and curricular developments. Begun in 2007, the Living In the KnowlEdge Society (LIKES) Community Building Project, led by four sites (Virginia Polytechnic Institute and State University (Virginia Tech, VT), Villanova University, North Carolina A&T University (NC A&T), and Santa Clara University (SCU)), aims to transform undergraduate computing education for the 21st century [Chung et al., 2009]. The vision of LIKES is to build a community that will define the way to make systemic changes in how computing and IT concepts are taught and applied in both computing and other fields, thus better preparing the next-generation Knowledge Society builders. Then, these graduates will be well-equipped with the IT competencies and skills required for the nation's health, security, and prosperity in the 21st century. We report the workshops, activities, and outcomes of the LIKES project during 2009 and 2010. These workshops were held in Villanova University, Virginia Tech, and Durham (previous LIKES workshops are reported in [Chung et al., 2009]).

LIKES Workshop at Villanova University

The fourth workshop was held at Villanova University on March 19-21, 2009. The workshop goals include:

- Developing and testing course modules and tools in computer science and other disciplines. The pedagogy and disciplinary connections identified in previous workshops will form the foundation for the modules and tools.

- Describing an iterative methodology of module and tool development that supports assessments of learning and continuous improvement.
- Investigating the feasibility of a curriculum definition document that shows the connections between computing and other disciplines.

Thirty-four scholars and educators participated in the workshop actively through six breakout sessions to discuss the workshop goals (Table 1). The discussion results were shared among all participants through seven group sessions, where a representative of each group presented their findings and plans. A total of six discussion groups were formed based on the mixture of people from both computing and non-computing fields. Whenever possible, at least one project team member joined each group to facilitate the discussions utilizing their experience from the previous workshops. The discussion group details are presented below with group members' research fields.

Table 1: Group members' research area distribution (numbers denote the number of participants).

Group	Members in computing areas	Members in other areas
Humanities	3: computer science	1: evaluation 1: business information technology
Arts	5: computer science	1: music
Environmental Science I	1: accounting and information science 1: computer science	2: environmental science 1: geology
Environmental Science II	1: management information systems	4: environmental science
Social Science	1: management information systems 2: computer science	1: anthropology 1: communication 2: political science
Archaeology	2: computer science	1: archaeology

Since 'developing and testing course modules and tools in computer science and other disciplines…' was one of the goals, Carol Weiss, who is the director of the Villanova Institute for Teaching and Learning (VITAL), was invited to help the attendees to focus on issues of learning and their connection to successful participation in the Knowledge Society, which would be important for module development. Various active learning settings such as problem-based learning, problem-centered learning, project-based learning, case-based learning, scenarios and pedagogies of engagement were explained. Their similarities and differences were compared and contrasted. Also, issues in interdisciplinary instruction including the meaning of 'integrative learning' were discussed.

LIKES Workshop at Virginia Tech

The fifth LIKES workshop was hosted by Virginia Tech in Blacksburg, VA, November 12-13, 2009. The workshop titled "Curricular Guidelines Connecting Computing with Other Disciplines" reflects the project team's long-term aim to prepare CT curricular guidelines, possibly to be published by ACM and IEEE-CS, so that computing related courses or course modules can help promote interdisciplinary education and collaboration. The disciplines selected for this workshop (based on the consideration of the previous workshops) were Business, Biology, Ecology, Environmental Sciences, English, Music, and Sociology (See Table 2 for groups and members' disciplines). The main topic of the workshop was to connect four computing concepts below to other disciplines:

- Data, information, and knowledge, including their representation and management, and including data structures, databases, document collections, and knowledge management.

- Algorithms, analysis, problem solving, programming, work flows, and software engineering.
- Interaction, interfaces, graphics, games, visualization, and virtual environments.
- Modeling and simulation.

Twenty scholars and educators participated in the workshop. They were divided into five groups as shown in Table 2. Each group had people from both computing and other areas except for 'Business' group, which was composed of members from computing areas. In the course of three breakout sessions and five group sessions, participants had developed interdisciplinary modules and discussed about the organization of the LIKES book, currently a work-in-progress which will include curricular guidelines to be deployed nationwide for integrating CT into different disciplines.

Table 2: Groups and members' research areas (numbers denote the number of participants).

Group	Members in computing areas	Members in other areas
Business	2: computer science 1: management information systems 1: accounting information systems	None
Biology, Ecology, and Environmental Sciences	1: computer science	2: ecology 1: oceanography
English	3: computer science	1: English
Music	2: computer science	2: music
Sociology	1: computer science	2: sociology 1: learning technology

LIKES Workshop at Durham

The 6th LIKES workshop took place in Durham, NC, on February 25-26. The workshop theme, "Development and Adoption of Computational Thinking Curricular Guidelines Across Disciplines," was elaborated with achievements from previous workshops. It was further extended to other disciplines through breakout session discussions, where all the participants presented diverse examples.

A total of twenty people attended the workshop. Table 3 shows the number of participants for their disciplines. Seven people came from computing fields. Eleven people were from other disciplines and two people from the interdisciplinary fields of computing and other fields.

Table 3: Participants and their disciplines (numbers denote the number of participants).

Computing disciplines	Computing + other	Other disciplines
5: computer science 1: management information systems 1: accounting information systems	1: computational mathematics 1: computational science	1: history 4: chemistry 3: physics 2: biology 1: communication studies

IV. HIGHLIGHTS OF PROJECT FINDINGS

CT Instructional Modules

In the Villanova workshop, one of the goals was to produce detailed instructional modules or courses that exemplified the fusion of computer science and another discipline. The various breakout groups met over several sessions. These meetings resulted in module outlines for:

- **Ecology** that connected the observable ecological cycles to the formal description of general systems theory
- **Communication** that connected styles of information transmission to social network analysis and to the construction of ad hoc networks.

An Example of IS Curriculum Guidelines

In the Virginia Tech LIKES Workshop, the business discipline was one of the foci in developing sample curriculum guidelines. The information systems discipline was chosen to be the target for developing curriculum guidelines. An IS course titled “Business intelligence and data mining” was selected by the group participants to develop the guidelines (shown in Figure 1) that try to integrate CT concepts into the course.

Module name: Business data mining with decision tree induction
Scope: Motivation, representations, process, applications
Learning objectives:

a. Students will be able to describe the motivation of using decision tree induction for data mining.
b. Students will be able to represent a problem scenario using decision trees
c. Students will be able to explain the process of decision tree induction
d. Students will be able to use a data mining tool to classify data records using decision tree techniques

Level of effort required:

a. inclass time – three hours
b. prior to class – three hours reading
c. after class exercises – three hours

Relationship with other modules:

a. Prerequisite – introduction to business data mining (to be developed)

Prerequisite knowledge/skills required

a. Database management systems
b. Introduction to information systems

Introductory remedial instruction

a. None

Body of knowledge

a. Motivation of use of decision trees
b. Decision tree representation
c. The ID3 algorithm, information theory, entropy
d. Evaluation of the classification results
e. Use of a data mining tool to perform decision tree induction

Resources

- Turban et al., *Business Intelligence: A Managerial Approach,”* Pearson Prentice Hall, 2008.
- Quinlan, J.R., Learning efficient classification procedure and their application to chess end games, in *Machine Learning: An AI Approach*, eds Michalski, R.S, Carbonell, J.G., and Mitchell, T.M., Tioga Publishing Company, Palo Alto, 1983: 463-471.

Exercises / Learning activities

- Manual creation of decision tree and manual application of ID3 algorithm (satisfies objectives a, b, c and knowledge units a, b, c).
- Use DM tool with existing large datasets (ex. UCI data repository) to apply decision tree induction and evaluate the results.

Evaluation of learning objective achievement (ex. grading criteria)

- Assignment of exercises similar to a and b under Exercises above are graded.
- Exam question on manual creation of decision tree and application of ID3 algorithm.

Glossary
ID3 algorithm, decision tree, entropy, information theory, classification

Figure 1: An example of IS educational module

The group also identified a number of strategies to attract teachers to adopt the guidelines:

- Identify instructors who teach these courses and seek endorsements for the modules
- Market modules through professional LISTSERV, message boards, and mailing lists
- Conduct and organize LIKES mini-track sessions in business academic conferences
- Contact business education journal editors
- Promote it within business schools and IS department
- Promote through Wall Street Journal editors/writers

Other results include mapping of computing concepts to the group members' area of research and identifying professional organizations in those areas.

Integrating CT into Natural Sciences Curricula

Multiple deliverables have been produced at the Durham LIKES Workshop, which focused on the natural sciences curricula. Ratings of importance of computing concepts in different disciplines were summarized in the following table. Each of the participant was asked to rate on a scale from 1 (least important) to 10 (most important) the importance of CT concepts in their own disciplines.

Rating of importance of computing concepts in different disciplines													
Discipline	Logic	Data Structure	Programming	Algorithms/Problem Solving	Communications/networking	HCI	Graphics/Viz	Knowledge representation, IR	Databases/data modeling	Social context	Intellectual property rights	Computer literacy	Software engineering
Chemistry	2	10	7	8	5	6	10	8	9	1	6	8	2
Chemistry	10	7	5	10	5	5	9	10	8	5	5	8	5
Chemistry	2	3	9	1	5	10	1	5	8	10	3	1	5
Chemistry	7	8	3	10	5	10	10	10	8	5	2	10	3
Digital Libraries	1	6	6	8	4	8	7	10	7	6	3	3	5
Economics	6	8	7	8	3	3	8	7	7	6	1	1	3
History	2	2	2	2	2	2	8	3	8	5	10	10	??
Biology	9	10	9	9	8	8	9	9	10	7	7	7	6
Biology	5	5	3	4	4	??	10	9	8	9	3	9	3
Physics	8	5	10	10	3	3	8	6	3	1	3	5	7
Physics	6	3	10	10	4	3	6	5	4	3	3	10	4
Mathematics	10	10	7	10	6	4	8	6	6	6	4	6	2
Computational math	10	10	10	10	9	10	10	10	9	9	9	10	10
Music	1	7	10	7	6	8	8	7	3	2	6	1	1
Social science	10	10	6	6	5	10	10	8	8	10	9	10	6
Business	8	9	9	7	8	6	5	8	10	9	7	8	7
Average-ALL	6.1	7.1	7.1	7.5	5.1	6.4	7.9	7.6	7.3	5.9	5.1	6.7	4.6

Figure 2: Rating of importance of computing concepts in different disciplines.

In addition, four computing concept categories: (1) algorithms, processing, analysis, work flow, programming languages; (2) data, information, knowledge; (3) graphics, visualization, games, HCI; and (4) modeling and simulation are mapped to examples in four disciplines such as chemistry, biology, physics and history/social science. Those might promote wider adoption of the computing concepts in other disciplines by providing concrete and already existing examples.

V. CONCLUSION AND FUTURE WORKS

Like other fundamental skills such as reading and writing, computational thinking is becoming a basic literacy in the knowledge society 21st century. Despite widespread use of computing software as productivity tools (e.g., spreadsheet and word processing), the IS and many other disciplines have not yet fully embraced CT concepts and skills into their curriculum. The Living in the KnowlEdge Society (LIKES) project is addressing the needs by building a group of inter-disciplinary scholars and educators to make systemic changes to the way CT concepts are taught in different disciplines. Our six workshops and many collaborative activities have produced curricular guidelines and have built a cross-disciplinary community for integrating CT concepts into IS and other disciplines. We identified CT concepts and mapped these concepts into the curriculum topics of different disciplines. Sample curricular guidelines and teaching modules have been produced by disciplinary scholars and computing educators. Our ongoing works include further collaborating with various communities to develop CT curricular modules, guidelines, and strategies for adoption of these modules and guidelines. We will also seek support at both the college level and other levels. The results should be useful to teachers, curriculum developers, and educators in integrating CT concepts, skills, and tools in their disciplines.

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