Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 3 (2015) 3657 – 3662

Procedia MANUFACTURING

6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015

Bringing computational thinking to STEM education

Samar I. Swaid

Philander Smith College, Little Rock, Arkansas, USA

Abstract

Today, as advanced technologies and cloud computing tools emerge, it is imperative that such innovations are sustained with knowledge and skill set among STEM educators and practitioners. In this paper, the author reports on a project, HBCU-UP II, that works on bringing Computational Thinking to Science, Technology, Engineering, and Mathematics (STEM) disciplines. A Computational-Thinking based strategy is adopted to enforce thinking computationally in STEM gate-keeping courses. The paper presents framework, implementation and outcomes. This on-going project contributes to efforts to establish computational thinking as *a universally applicable attitude* that is meshed within STEM conversations, education, and curricula. This paper will be particularly useful for researchers interested in Computational Thinking and its applications in STEM education, in particular and higher education in general

© 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of AHFE Conference

Keywords: Computational thinking; STEM; Computational science; HBCU; Cyberinfrastructure

1. Introduction

Advanced computing technologies have made possible bolder leaps of innovations across a spectrum of human inquiries and fields, as it facilitates problem-solving, and understanding of complex systems. With such advances in computation, information and communication technologies, there has been a move toward creating cyberinfrastructure -based service systems that support and facilitate scientific research (i.e., e-science) [20]. These cyberinfrastructure systems are developed utilizing cloud technologies to enable computationally-intensive research that requires using large datasets, distributed grids, and/or visualization [4][5][8][16]. Similar to other service systems, e-science systems are formed of groups of people, networks, advanced cloud technologies, and other sub-systems [23][20], to provide researchers with services and resources to advanced research.

2351-9789 © 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of AHFE Conference
doi:10.1016/j.promfg.2015.07.761

A number of e-science systems has emerged (e.g., TeraGrid, XSEDE, and NBCI) to be used for research, however, limited number of attempts have been made to use e-science systems in Science, Technology, Engineering and Mathematics (STEM) education. According to NSF [15],

“[S]ustaining this revolution across all areas of science, engineering, and education requires the formation of a citizenry and workforce with the knowledge and skills needed to design and deploy as well as adopt and apply these cyber-based systems, tools and services over the long-term. The opportunity for such preparation should be available at all stages of formal and informal education (K-16 and lifelong), training and professional development, and must be extended to all individuals and communities”.

It is imperative to develop computational thinking skill set among STEM educators and students to sustain scientific revolution. Today, academic institutions, in attempt to prepare their graduate to computing-based workforce, work on injecting Computational Thinking (CT) across STEM fields to develop analysis and problem solving skills among their students [16]. According to Wing [27], "Computational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science. Computational thinking includes a range of mental tools that reflect the breadth of the field Computer Science"(p. 33). In this paper, I report on an on-going multi-phase project aims to bring Computational Thinking (CT) to STEM education at the undergraduate level. Key concepts within computations, termed here CT elements, are identified to be applied across different STEM disciplines. The rest of the paper is organized as follows. Next section would provide a background on CT, practices of CT and some example applications of CT in STEM education. Then, a multi-phase framework to bring CT to STEM education is described. Finally, vivid outcomes achieved in this on-going project are presented. The paper ends with conclusion and future work.

2. Background

Computer science is defined as " ... the body of knowledge of computing concerns the digital computer and the phenomena surrounding it- the structure and operation of computer systems, principles underlying computer system design and programming, effective methods for using computers for information processing tasks, and theoretical characterizations of their properties and limitations"[7]. Competences and knowledge areas that graduates of CS programs should demonstrate identified in the CS2013 curriculum guidelines (ACM, 2013). In establishing a definition for Computational Thinking(CT), Wing argues that CT is the new literacy of the 21st century as it is "[t]he thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can effectively be carried out by an information-processing agent"[6]. The National Academies (2011) pointed out that CT shares a number of practices with other disciplines that can be applied to STEM education. Lee and others (2011) suggest that CT can be applied with three practices of Modeling/Simulation, Robotics and Game Design. Others proposed that CT elements are: Data Collection, Data Analysis, Data Representation, Problem Decomposition, Abstractions, Algorithms, Automization, Parallization and Simulation [8]. Perkovi´c and Settle [17] identified elements of Automation, Communication, Computation, Coordination, Design, Evaluation and Recollection. The National Academies [14], identified key elements of CT as: (i) Abstraction; (ii) Data, (iii) Retrieving; (iv)Algorithms; (v)Design; (vi)Evaluation and (vii)Visualization. Regardless of CT definition adopted, the main purpose of applying CT and sharing its elements with other disciplines is to teach others how to better solve problems and discover new questions (Hemmendinger in [3]).

Although CT has been applied widely in STEM research, limited number of attempts have been made to introduce STEM students to CT concepts. For example, the Northwest Distributed Computer Science Department (NW-DCSD) project brings multi-disciplinary faculty from diverse colleges and universities to foster inter-institutional collaboration in a multi-disciplinary computing approach [10]. Others applied CT concepts in two minority serving institutions in Arkansas by implementing Cyberinfrastructure Minority Training Education Consortium (AMC-TEC) project [24]. A more recent project, HBCU-UP II, is developed and implemented as a two-phase project to inject CT in STEM education, as described next.

3. Bringing CT to STEM

Philander Smith College in Little Rock of Arkansas, is the oldest minority serving, four-year liberal arts institution with a total enrollment of more than 700 students. There are five academic divisions of: Education, Humanities, Social Sciences, Business and Economics, and Natural and Physical Sciences. The Division of Natural and Physical Sciences serves more than 240 students majoring in STEM disciplines of biology, chemistry, computer science, and mathematics. The division has an articulation agreement with the University of Arkansas, Fayetteville (UARK), to implement the 3/2 Engineering program, that allows students to receive an additional engineering degree from UARK. The mission of the Division of Natural and Physical Sciences is "*to graduate Science, Technology, and Mathematics (STM) students who are academically accomplished and equipped with: comprehensive knowledge in their science fields, modes of inquiry, quantitative reasoning, scientific communication , ethical values that guide their practice, and problem solving and decision making. Students are trained, as researchers, critical thinkers, social justice advocates, leaders and policymakers, to succeed in post STM-related graduate schools, to compete in the STM workplace, and to contribute to educational and economic advances in local, regional, national and international science and technology initiatives*"[18].

One key approach to support STEM education is to infuse CT elements within STEM topics. In the past, the division implemented the Arkansas Cyberinfrastructure Minority Training Education Consortium (AMC-TEC) project that was awarded to study the feasibility of using Cyberinfrastructure resources for STEM education [22][24]. As Philander Smith implemented the goals of the project, it became clear that an advanced strategy is needed to bring computational thinking to STEM education. A multi-phase project is designed to inject CT and Cyberinfrastructure in STEM education (see Figure 1).

4. Outcomes

4.1. STEM education

Gate-keeping courses provide students with their first and formal exposure to a deep understanding of science. Such courses influence students' decision to pursue STEM education and continue their college experience [11]. Usually, careful attention is paid to introductory STEM courses delivery methods and pedagogy approaches [2][14]. In this project introductory courses of Applied Computer Science, Introduction to Computer Science, Programming I, Biology I, Biology II, Chemistry I, Chemistry II, Calculus I, Calculus II, College Algebra and Introduction to Engineering, have been identified to include elements of CT. In addition courses of Genetics, Programming Languages, and Computer Science Research, have been selected to experiment the application of CT. Elements of CT adopted to be used are the ones identified by the National Academies [14]: (i) Abstraction; (ii)Data, (iii) Retrieving; (iv)Algorithms; (v)Design; (vi)Evaluation and (vii)Visualization (see Table 1).

Table 1. Computational Thinking Elements for STEM Courses.

	Computational Thinking Elements						
STEM Courses	Abstraction	Data	Retrieving	Algorithms	Design	Evaluation	Visualization
Biology I*		√	√	√		√	√
Biology II*		√	√	√		√	√
Applied CS*	√	√	√	√	√	√	√
Programming I*	√	√	√	√	√	√	√
Chemistry I*		√	√	√		√	√
Chemistry II*		√	√	√		√	√
College Algebra*	√	√	√				√
Calculus I*	√	√	√				√
Calculus II*	√	√	√				√
Genetics		√	√	√			√
Programming Languages	√	√	√	√	√	√	√
Object-Oriented Programming	√	√	√	√	√	√	√

** Gate-keeping STEM courses*

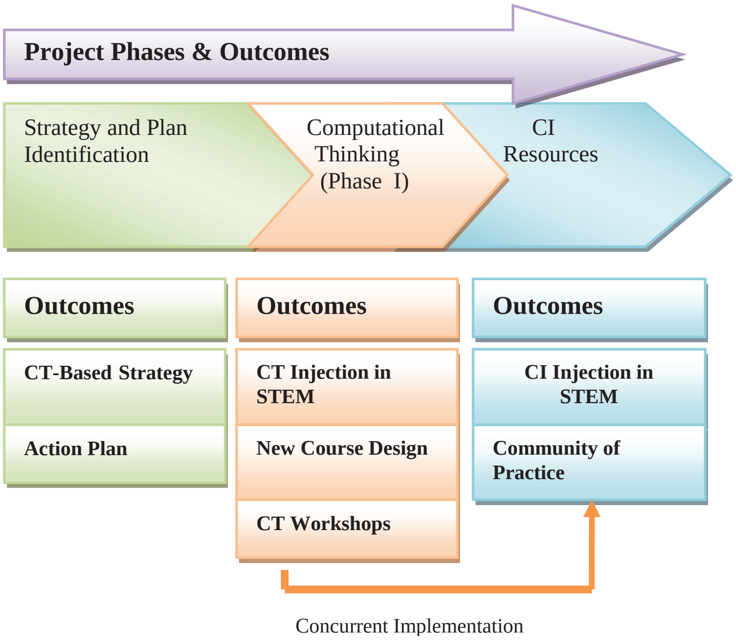

Fig. 1. Project Plan and Outcomes.

4.2. Road map: Intro to computational thinking course

A road map to a new course is developed that introduces CT to students. The course "Intro to Computational Thinking" emphasizes CT concepts through hands-on learning experiences, targeting freshmen and sophomore students. The map of this course is designed as two-part course: (i) part I introduces students to computational thinking, its concepts, applications in research (e.g., bioinformatics, financial markets, public health); while part II introduces students to CT elements via programming exercises. The course map was put, while in mind, the ultimate goal is to teach student CT in an attractive way, by:(i) selecting a programming languages that is easy to learn;(ii) course materials selected for this course, including text-book, self-guided labs and learning modules are to be online and accessible to students; (iii) co-curriculum detailed labs to be designed to enforce concepts of CT. For this course, Java is selected as it is easy to learn yet, effective as a programming language [19].

4.3. Computer literacy workshops

As CT is a universally applicable attitude and skill set, everyone, not just computer scientist, would be eager to learn and use [27], a number of workshops have been conducted to demonstrate the use CT. The author of this paper, arranged for total of six workshops to be offered with senior citizen centres, to expand the exposure to CT among adult learners. The workshops were supported with hands-on labs, and multimedia materials, utilizing Microsoft Office as the tool to enforce CT elements. Students are taught how to collect data, clean it, represent data using variables and macro, generate graphs and tables, and use of algorithmic thinking to solve problems. Until the moment of writing this paper, total of 14 senior citizens, whom ages range from 63-68 years, 30% of them females were introduced to CT and its elements.

5. Conclusion

Advanced technologies that are coupled with complex data would continue to arise. Therefore, STEM educators are encouraged to mesh CT with their conversations, curricula and teaching. By this, it is hoped that future investigators in STEM disciplines are well trained and prepared to face the challenge of complex problems that would not be solvable unless CT is practiced.

Acknowledgments

The HBCU-UP II project is supported in part by the National Science Foundation under Award Number 1238895. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author and do not necessarily reflect the views of the National Science Foundation.

References

[1] ACM. "Computer science curricula," 2013, retrieved from: http://www.acm.org/news/featured/cs-curricula-2013-feature, on March 10, 2014.
[2] D. Atkins, K. Droegemeier, H. Feldman, H. Garcia-Molina, M. Klein, D. Messerschmit, P. Messina, J. Ostriker, M. Wright, "Revolutionizing science and engineering through cyberinfrastructure," Report of the national science foundation blue-ribbon advisory panel on cyberinfrastructure. Arlington, VA: Office of Cyberinfrastructure, The National Science Foundation, 2013.
[3] V. Barr, and C. Stephenson," Brining computational thinking to K-12: What is involved and what is the role if computer Science community," ACM Inroads,2011, 2(1), 48-54
[4] M. Bietz and C. Lee, "Adapting cyber infrastructure for new science: Tension and strategies," iConfernce 2012, Feb 7- 10., 2012, Toronto, On, Canada
[5] G. Biswas, D. Schwartz, J. Bransford, & TAG-V,"Technology support for complex problem solving: From SAD Environments to AI," In K. Forbus & P. Feltovich (Eds.), Smart machines in education, 2001. (pp. 71-98). Menlo Park, CA: AAAI/MIT Press.
[6] ComputingEd." A definition of computational thinking from Jeannette Wing," 2011. Retrieved from: http://computinged.wordpress.com/2011/03/22/a-definition-of-computational-thinking-from-jeanette-wing/, on March 10, 2014.
[7] P. Denning," Great principles in computing curricula,"2004. Retrieved from: http://denninginstitute.com/pjd/PUBS/GP_curr_sigcse.pdf, on March 10, 2014
[8] EDUCASE Campus Cyberinfrastrutre Working Group and Coalition for Academic Scientific Computation." Developing a coherent cyberinfrastrute from local campus to national facilities: Challenges and strategies," 2009. Retrieved from: http://www.educause.edu/library/resources/developing-coherent-cyberinfrastructure-local-campuses-national-facilities-challenges-and-strategies; on March 10, 2014.
[9] J. Handelsma, D. Ebert-May,R. Beichner,P. Bruns, A. Chang,R. DeHaan, J. Jim Gentile,S. Lauffer, J. Stewart, S. Tilghman,W. Wood,"Policy forum: scientific teaching", Science. 2004. 304(23), 521-522
[10] A. Kranov, R. Bryant, G. Orr, S. Waalace, and M. Zhang," Developing a community definition and teaching modules for computational thinking: Accomplishments and challenges," SIGITE'10, October 7-9, 2010, Midland, Michigan, USA.
[11] J. Labov. "From the National Academies: The challenges and opportunities for improving undergraduate science education through introductory courses," Cell Biology Education, 2004, 3(4), 212-214
[12] C. Lee, P. Dourish and G. Mark,"The human infrastructure of Cyberinfrastructure,". Proceedings of Conference on Computer Supported Cooperative Work (CSCW '06), ACM Press, New York, NY, 2006, 483-492
[13] I. Lee, F. Martin, J. Denner, B. Coulter, W. Allan, J. Erickson, J. Malyn-Smith, J., and L. Werner," Computational Thinking for Youth in Practice," Journal of Computational Science Education, 2011, 2(1), 1-10
[14] National Research Council. "How people learn: Brain, mind, experience and school. Expanded Edition," 2011. Retrieved from: http://www.csun.edu/~sb4310/How%20People%20Learn.pdf, on March 10,2014.
[15] NSF. "NSF Cyberinfrastructure Council provides its cyberinfrastructure vision for the 21 st century," 2007. Retrieved from: http://www.nsf.gov/pubs/2007/nsf0728/nsf0728.pdf, on March 10, 2014
[16] NSF. "Cyberinfrastructure training, education, advancement, and mentoring for Our 21st Century Workforce (CI-TEAM),"2013. Retrieved from: http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=12782, on March 10, 2014
[17] L. Perkovi´c, and A. Settle, "A computational thinking across the curriculum: A conceptual framework", Proceedings of the 15th Annual SIGCSE Conference on Innovation and Technology in Computer Science Education, ITiCSE 2010, Bilkent, Ankara, Turkey, June 26-30, 2010
[18] PhilanderSmith. "Division of natural and physical sciences: Mission," 2014. Retrieved from: http://www.philander.edu/divisions/natural_physical_sciences/, on March 10, 2014

[19] A. Radenski." Python First: A Lab-based digital introduction to computer science," Proceedings of the Eleventh Annual Conference on Innovation and Technology in Computer Science Education, ITiCSE 06, University of Bologna, Italy, June 26-28 2006, 197-201
[20] S. Swaid." A novel strategy to improve STEM education: The E-science approach," In Wang, V. (Ed.),Encyclopedia of Education and Technology in a Changing Society.IGI Global, http://bit.ly,
[21] S. Swaid," Cyberinfrastructure for undergraduate STEM education," International Conference on Learning and Administration in Higher Education, Journal of Learning in Higher Education. 2013, Fall-2013, 61-64.
[22] S. Swaid, J. Walker and M. Mortazavi," Creating a cyberinfrastructure-based community of practice," Proceedings of International Conference on Learning and Administration in Higher Education. 2012. Retrieved from http://iclahe.org/Proceedings/2012/Proceedings-2012.pdf, on March 10, 2013
[23] S. Swaid, and R. Wigand," An online oriented service quality: An aspect of multichannel retailing," 2009. 245-260. In Chiu, D., Hung, P., and Leung, H. 2009. Service Intelligence and Service Science: Evolutionary Technologies and Challenges. Information Science Publishing(IGI Group). Hershey, Pennsylvania
[24] J. Walker, S. Swaid, and M. Mortazavi, "E-learning using Cyberinfrastructure," International Journal of Emerging Technologies in Learning (iJET),2011, 7 (2). 53-5
[25] J. Wing," Research notebook: Computational thinking- What and Why?," 2011. Retrieved from: http://www.cs.cmu.edu/~CompThink/resources/TheLinkWing.pdf on March 15, 2013
[26] J. Wing, "Computational thinking and thinking about computers. Philosophical transaction of the royal society," 2008, 366, 3717-3725
[27] J. Wing, "Computational thinking," Communication of the ACM, 2006, 49