Cyberinfrastructure for Undergraduate STEM Education[1]

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ABSTRACT

Cyberinfrastructure (CI) is a term that usually appears in scientific research, but rarely to be noticed as a scientific education tool. In this paper, I describe a transformative Cyberinfrastructure-based strategy to improve Science, Technology, Engineering and Mathematics (STEM) education at one of the historically black colleges. This strategy is built on two arms (i) infusing CI in STEM introductory courses and (ii) building a community of practice around CI among STEM faculty and students. The paper presents the framework of applying computational thinking elements as a pathway to use CI in education, and tactics put to create CI-based community of practice. Presented plan will be helpful for other to use computational thinking elements and CI resources for STEM disciplines.

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INTRODUCTION

Over the last two decades, new computational technologies, information, and communication, have evolved creating comprehensive cyberinfrastructure (CI) systems and resources. The term Cyberinfrastrurec (CI) was coined in late 1990 and then when the Atkins report was published in 2003, this term became the buzz word that explains many of the revolutionized advances in Science and Engineering (Atkins et al., 2003). Based on Berman(2005), CI is defined as

> "...the new research environments that support advanced data acquisition, data storage, data management, data integration, data mining, data visualization and other computing and information processing services over the Internet. In scientific usage, cyberinfrastructure is a technological solution to the problem of efficiently connecting data, computers, and people with the goal of enabling derivation of novel scientific theories and knowledge". (p. 1).

To clarify more what the term CI means, a joint report of the EDUCASE Campus Cyberinfrastructre Working Group and the Coalition for Academic Scientific Computation generated a broader definition of CI as:

> "Cyberinfrastrcutre consists of computational systems, data and information managements, advanced instruments, visualization environments, and people, all linked together by software and advanced networks to improve scholarly productivity and enable knowledge breakthroughs and discoveries not otherwise possible" (EDUCASE, 2009).

Recent reports show that CI-systems impact how Science, Technology, Engineering and Mathematics (STEM) research is conducted. However fewer applications are noticed in utilizing CI resources in classroom as a scientific education tool. As large number of agencies including the National Science Foundation (NSF), Department of Defense (DOD), Department of Energy (DOE), and Central Intelligence Agency (CIA) are leveraging this technology-based infrastructure as a tool for scientific discoveries, it has become clear that there is an urgent need to train the future STEM workforce on CI and its capabilities for profession, education and research. More importantly, it is crucial to broaden the participation of diverse groups of people as users of cyberinfrastructure and making sure under-presented populations are introduced to and trained on CI systems. This paper describes the strategy put by Philander Smith College, one of the historically black colleges and universities (HBCUs) in Arkansas, to transform STEM education via a CI-based strategy by (i) immerse CI resources and concepts in STEM education; and (ii) create a community of practice among STEM faculty and students. The rest of the paper in structured as follows. Next section describes the CI state at Philander Smith College. Then, I present the CI-based strategy in improving STEM education. Finally, the paper ends with conclusion.

CI STATE AT PHILANDER SMITH COLLEGE

Philander Smith College is a four-year liberal arts private college and the oldest Historically Colleges and Universities (HBCU) of Arkansas, established in 1877. The Division of Natural and Physical Sciences of Philander Smith has been actively engaged in CI-based efforts to improve STEM education. The division collaborated with University of Arkansas at Pine Bluff in implementing the Arkansas Cyberinfrastructure Minority Training Education Consortium (AMC-TEC) that was awarded from 2010 to 2012. The AMC-TEC project addressed the national challenge the nation faces with respect to producing a workforce that is capable of serious science using national CI resources (Walker et al., 2012). The backbone of the project is CI-based resource of Arkansas represented by the Arkansas Research and Education Optical Network (ARE-ON) project and other national resources. Arkansas invested 10 million dollars in implementing the ARE-ON as a statewide high speed optical networking services to all four-year public universities within Arkansas, for research, education, telehealth services and emergency preparedness. As most of the universities of Arkansas were aware of the ARE-ON as an advanced cyberinfrastructure, a limited number truly knew how to best utilize this resource for education. The AMC-TEC project was designed to engage the two HBCUs to participate in CI-based approach in teaching and research (for more details, see Walker et al., 2012). As Philander Smith implemented the core goals of the project, it became apparent that STEM faculties need more intensive training on other CI platforms and more customized strategy on how to best infuse CI Resources across STEM courses.

TRANSFORMATIVE CYBERINFRASTRUCTURE-BASED STRATEGY IN STEM

The Division of Natural and Physical Sciences offers degree programs in General Science, Biology, Chemistry, Applied Mathematics, and Computer Science, serving more than of 240 students. The division has an articulation agreement with the University of Arkansas at Fayetteville for the completion of a Bachelor of Science degree in any of Chemical Engineering, Civil Engineering, Computer Engineering, Electrical Engineering, Industrial Engineering, or Mechanical Engineering through the 3/2 Program. The Division strives to train and prepare its STEM students to pursue graduate studies or professional careers in STEM. The Division has a number of initiatives and projects to improve STEM education, students' academic performance and graduation rates. One key project is the National Science Foundation's HBCU-UP II project that is awarded on 2012 for five years. The project aims onto: (i) Provide multi-module interdisciplinary expository research opportunities for STEM students; (ii) Transform STEM education by CI-based strategy; (iii) Improve the readiness of incoming high school students in the areas of STEM via its Science Technology and Engineering Preparatory Program (STEPP). In this paper, I focus on the second goal and I describe a systematic framework to transform STEM education by using CI resources and concepts.

INJECT CI-RESOURCES IN GATE-KEEPING COURSES ACROSS STEM

A growing number of academic institutions are making extensive use of computational methods in STEM fields. Computational science has been recognized as the third leg of science for more than 30 years (Apon et al., 2010). To prepare students for a future of complex knowledge, reasoning, and problem solving with multidimensional data and sophisticated representations, students must acquire different kinds of knowledge and thinking skills than those emphasized previously (Biswas et al., 2001). Traditional instructional delivery that does not utilize computation was found to be linked significantly to students' low performance and thereby attrition. As such, in this project, they key component is to improve STEM education by using CI resources in STEM introductory courses. The framework is built as a two-phase implementation plan. Phase one aims to integrate Computational Thinking (CT) elements in introductory courses of STEM, while phase two introduces students and faculty to CI resources along with CT basic concepts simultaneously.

In her seminal article, Wing (2006), argues that Computational Thinking (CT) should be one of the fundamental intellectual skill set and an essential part in education. "Computational thinking is a fundamental skill for everyone, not just for computer scientists. To reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability" (Wing, 2006). CT is defined as "the thought and processes involved in formulating problems and their solutions so that the solutions are represented in a form that can effective carried out by an information processing agent (Wing, 2011). In using CT across different STEM courses, the following definition of CT is applied "Computational thinking is an approach to problem solving, which uses abstraction to create algorithmic solutions that can be automated with computational processes". Accordingly, the key elements of CT, which are: (i) Abstraction; (ii) Data, (iii) Retrieving; (iv)Algorithms; (v)Design; (vi)Evaluation and (vii) visualization, are integrated in STEM courses. Techniques to teach CT basic elements are: problem decomposition, pattern recognition, pattern generalization to define abstractions (The National Academies, 2011), algorithm design, and data analysis; design solutions, evaluation and visualization. For the first phase, the courses of Biology I, Biology II, Genetics, Chemistry I, Chemistry II, Applied Computer Science, Internet Resources , Programming I, Programming II, College Algebra, Calculus I, and Calculus II are delivered with CT in mind. Then, CI resources and concepts are integrated in STEM courses, along with the CT in pedagogical practices.

CREATE A CYBERINFRASTRUCTURE-BASED COMMUNITY OF PRACTICE AMONG STEM FACULTY

Research shows that student learning can be improved when instructors move from traditional style instruction to interactive instruction applying computational approaches (Handelsman et al., 2004). Also, it has been reported that creating communities of practice enhances sharing successful practices among community members. Communities of practice are defined as, "...groups of people who share a passion for something that they know how to do, and who interact regularly in order to learn how to do it better" (Wegner, 2004, p. 2). In Communities of Practice (COP), social learning systems are formed, where practitioners connect to solve problems, share ideas, set standards, build tools, and develop relationships with peers and stakeholders (Eckert, 2006). Because they are inherently boundary-crossing entities, COP are a particularly appropriate structural model for cross-agency and cross-sector collaborations within this domain (Wegner, 2009). Any COP has to have four common characteristics:(i) defined domain of the community and its practices; (ii) relationship building activities among members to form their community; (iii) shared practices to develop a shared repertoire of shared, resources, experiences, strategies, tools and any activity that can contribute to building the shared practice (Wegner, 2009); and (iv) community sphere, in which participants communicate, meet and collaborate. This sphere might be a physical one such as the case when teachers meet for professional development, virtual , as the case of CI-based platforms, or hybrid, when people meet face-t-face and virtually with their community peers to share practices and knowledge. Regardless of type, size, structure or domain, scope, dynamicity, and visibility of COP, it all should have these four characteristics in one form or another. The theory of COP forms a basis for understanding social learning systems (Wegner, 2000) and its application has been found in organizations, governments, businesses, education, professional associations, civic life, nations, and the web (Wegner, 2009). This influencing theory has become the foundation of creating social learning systems and managing shared knowledge. As Wegner et al. (2002) noted, one of the key issues to design successful communities of practice, is to nurture aliveness within these communities. This can be achieved through generating "... enough excitement, relevance, and value to attract and engage members".

Motivated by this approach, the project offers STEM faculty comprehensive training on CT elements and CI resources via a number of workshops. Additionally, an annual CI Day is held annually for the period of the project inviting speakers from industry, universities and research labs to present their use of CI and share their achievements. By this, it is expected that a human infrastructure (Lee et al., 2006) is built around CI, its concepts and resources. For 2013, Philander held its second CI Day inviting speakers from different local, regional and national organizations. Over 180 attendees attended the CI Day from STEM and non-STEM areas. The topics discussed are about the ARE-ON project and its use for teaching and research, visualization techniques and the use of CI for visualization in genetics research, CI application for medical sciences, CI use in engineering education and research, CI use in undergraduate education by minority servicing institutions, CI use in research in Arkansas and CI national resources and its use in STEM in multidisciplinary approach. In addition the Director of the Computer Information Services of Philander presented the Information Technology infrastructure and its capabilities. Also, STEM faculty shared their experiences in applying CT in their teaching and using CI resources (Swaid, 2013).

CONCLUSION

The value of CI to research has been reported (e.g., Bietz and Lee, 2011; Mukherejee et al., 2012), however, still the usage of these scientific informational infrastructure for education is not fully realized. This paper outlines the strategy of HBCU-UP II project of Philander Smith to improve STEM education by a transformative CI-Based strategy. The value of such resources holds great promise in improving the learning experiences for STEM students. By using available resources, reliable technology and robust services, an inquiry-based approach to learning can be the key to motivate students, and positively impact their achievements and enthusiasm for STEM. Computational thinking and cyberinfrastructure resources might be one way to prepare an adequate supply of quailed workers for employment in STEM fields, who are capable of solving complex problems. According to Albert Einstein, "[T]he significant problems we face cannot be solved at the same level of thinking we were at when created them. Yes, Indeed.

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