36 RESEARCH AND INFORMATION SYSTEMS: How Information Systems Are Transforming the Nature of Science (And What Does This Mean for IS Researchers)

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It is well known that information systems and technology can facilitate innovation in organizations. For example, companies in the automotive industry are leveraging product lifecycle management systems and advanced information technologies such as automated product design and testing tools, digital simulation and visualization, knowledge repositories of best practices, and collaboration tools linking globally distributed design teams. These technologies are revolutionizing the automotive product development process, facilitating the development of novel products, significantly reducing product development time and eliminating inconsistencies in product design, creation, and production (Rosencrance 2002).

What is perhaps less well recognized is the impact that IT is having on the very nature of science. In fields as diverse as particle physics, education, oceanography, and engineering, information systems and technology are having a profound effect on how researchers and scientists go about their work. Moreover, many government agencies are

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encouraging this transformation by funding the development and diffusion of innovative information and computing technologies. In the UK, for example, an "e-Science" initiative was launched in 2001 to nurture the development of grid and other high-performance computing, and to foster and encourage research activities that utilize such technologies in a wide range of disciplines including astronomy, particle physics, environmental science, and biology.[1] Similar initiatives can be found in the US as well as other regions of the world.

In this position paper, we first briefly examine how the diffusion of innovative technologies is transforming the way in which science is conducted. We then explore the implications of these changes for the Information Systems community. We suggest there are many avenues for IS researchers to pursue. Further, we propose that IS researchers are missing an enormous opportunity to play a significant role in the larger scientific community, as many in this community are struggling, sometimes successfully but other times not as successfully, in diffusing information systems and technologies into their research practices. We also suggest that IS researchers should envision how information systems and technologies can be leveraged to transform how IS research itself is conducted.

Although scientists espouse different epistemologies, there is a large degree of consensus across scientific communities about the purpose of science and the nature of the scientific process. Broadly speaking, the purpose of science is to understand, describe, and explain some aspect of the world; the goal is to produce knowledge. The scientific process is a cycle involving theories, predictions, observations, and generalizations (Creswell 2003; Singleton et al. 1988). Thus, scientists in many fields develop hypotheses from a theory, collect data to test the hypotheses, and draw conclusions based on the hypothesis testing. The role of data in this process is critical as science is based on empiricism (Singleton et al. 1998). Although the role of data in research hasn't changed, information technology has changed the way in which data are often collected. With information technology, researchers can now collect and store vast amounts of data. Moreover, IT allows researchers to collect data remotely. For example, oceanographers and environmental researchers can now place sensors and monitors in the field and, instead of traveling to field sites, they can access data that is streamed directly from the sensors and monitors. In addition, scientists can leverage data mining and simulation technologies to conduct "virtual" experiments and to explore conditions that would be difficult, if not impossible, to replicate or control in the field.

Besides impacting the way data are collected and analyzed, IT has had another radical change on the nature of science for many communities: it has enabled the growth of extremely large, complex, distributed projects that are undertaken by a large community of geographically dispersed scientists and technicians. GENI (Global Environment for Network Innovations) is an example of such a project.[2] GENI is an ambitious, ground-breaking initiative of the National Science Foundation (NSF) in the United States. The goal of GENI is to enable the computer science and engineering research communities to invent and build novel and revolutionary networks and architectures of the future. A critical component of GENI is the development of a large-

[1]See the website http://www.rcuk.ac.uk/escience/default.htm for more information.

[2]For additional information on GENI, see http://www.geni.net.

scale "cyber" network that connects researchers and experimental apparatus around the world. The project to create this network requires the development of a significant and large software system, which contributes enormously to its risk and complexity as software projects are often prone to mismanagement and failure.

Projects such as GENI are huge, spanning years, even decades, and costing millions of dollars. But these projects can also have significant impacts on a variety of stakeholders. GENI, for example, will ultimately affect many areas of computer science and engineering research, in addition to networking and distributed systems. Projects such as GENI are intended to promote innovation because they connect individuals and equipment. However, the deployment of the technologies created in the GENI project have the potential to fundamentally alter the nature of scientific research from small research projects conducted by individual computer scientists to large, collaborative research efforts performed by a distributed community of scientists. With the help of IT, these projects help to break barriers by cutting across geographic and disciplinary boundaries.

The transformational effect of IT on scientific communities is not limited to the hard sciences or to huge projects such as GENI. Information technology is also changing the way educational research is conducted. For example, the Pittsburgh Science of Learning Center (PSLC), funded by the NSF, is creating an international resource for the study of robust learning by developing IT tools that enable educational research combining the rigor of experimental research with the realism of a classroom setting, deploying these tools in highly instrumented LearnLab courses, and storing structured longitudinal data on student learning interactions.[3]

PSLC authoring tools facilitate the creation of interactive computer-based tutors that enable the administration of systematic educational treatments and logging of fine-grained data on student interactions with the tutors, categorized by a hierarchical structure of knowledge components, to a central data repository (Data Shop). The PSLC is using these technologies to establish LearnLab courses, which are real courses for which a large percentage of student learning interactions is logged to the Data Shop. The Data Shop is enhanced with a selection of data analysis and reporting tools, all of which are accessible to instructors and researchers via the web. The analysis and reporting tools enable researchers to quickly view data on student interactions with the learning tools, such as error rates and learning curves at the individual exercise level or at the level of knowledge components. Researchers around the world are invited to use the authoring tools, to submit projects for conducting learning experiments in the PSLC LearnLab courses, or to analyze data on student interactions that is stored in the Data Shop.

Clearly, information technology and systems are impacting how many scientists approach and conduct their research. What are the implications of these changes for the IS research community? We see at least three areas of implication. **First**, because more large projects like GENI are being proposed, there is a need for research that investigates project management in this context. Understanding how to manage information technology projects that are large, complex, dynamic, and distributed is crucial to the success of these efforts. **Second**, while many scientific fields are experimenting with information systems and technologies to facilitate data collection and analysis and new

[3]See http://www.learnlab.org for more information on the PSLC.

ways of conducting research, few IS researchers seem to be engaged with these efforts. The IS community has examined innovation and diffusion, implementation, and technology-enabled change for years, yet little of this research has made its way to physicists, educators, engineers, and other scientific communities. Thus, IS researchers need to find a way to participate in cross-disciplinary work and bring our expertise to researchers in other fields. These efforts would potentially enhance our reputation, facilitate the use and deployment of technology in these communities, and enable the innovations promised by technology usage. **Third**, it is interesting to consider the question of whether and how information technology might transform the nature of IS research itself. Will we see large, complex, distributed research projects being undertaken by the IS community, as the computer science community is undertaking with GENI? Will IS scholars learn how to work as a united community in order to secure large-scale funding and projects from government agencies to build the technological infrastructure needed to support such research, in the way that the particle physics community has? In short, how will IS research and the IS research community evolve as information technology and systems become increasingly sophisticated and widespread in science?

In this paper, we have argued that information systems and technologies have already begun to transform how science is being conducted in a range of communities. We have speculated on the implications of those changes for the IS research community, and have proposed that IS researchers become more engaged in the efforts to diffuse information technology and systems into scientific research.

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