Int. J. Engng Ed. Vol. 26, No. 1, pp. 52–58, 2010
Printed in Great Britain.

0949-149X/91 $3.00+0.00

GIS Learning Tool for Civil Engineers*

RONALDO LUNA
Department of Civil, Architectural, and Environmental Engineering, Missouri S&T, Rolla, Missouri 65409, USA. E-mail: rluna@mst.edu

RICHARD HALL
Department of Information Science and Technology, Missouri S&T, Rolla, Missouri 65409, USA. E-mail: rhall@mst.edu

MICHAEL HILGERS
Department of Information Science and Technology, Missouri S&T, Rolla, Missouri 65409, USA. E-mail: mhilgers@mst.edu

LOUIS GE
Department of Civil, Architectural, and Environmental Engineering, Missouri S&T, Rolla, Missouri 65409, USA. E-mail: geyun@mst.edu

A geographic information system (GIS) learning tool was developed using a series of learning objects. These learning objects were designed to support supplemental instruction in GIS and were integrated seamlessly into the course curriculum. Developed over one academic year and used in the next, this learning technology was part of a problem-based, open-ended, laboratory exercise. To evaluate the effectiveness of the GIS learning objects, the class was separated into two groups. The two groups were exposed to the same fundamental civil engineering curriculum. However, one of the groups also received supplemental instruction using the GIS learning objects. The students in the section who used the learning tool scored significantly higher on a quiz covering the basic curriculum elements. This paper summarizes the development process, testing and evaluation of one of the modules (topic: geotechnical engineering).

Keywords: GIS; web-based; learning system; scaffolding; usability

1. INTRODUCTION

A GEOGRAPHIC INFORMATION SYSTEM (GIS) is a computerized database management system that provides geographic access (capture, storage, retrieval, analysis and display) to spatial data. Because the potential uses for GIS in civil engineering practice are numerous, interest in and utilization of GIS technology is increasing rapidly. Hence, employers have expressed a need for civil engineering graduates who are versed in GIS and able to apply GIS tools to civil engineering problems in innovative ways. While civil engineering industry has begun the process of integrating GIS, the academic world has been slower to respond. This National Science Foundation (NSF) sponsored project was charged to develop a web-based learning system to introduce GIS to undergraduate civil engineering students. The approach was to decompose the basic elements of GIS applications and encapsulate them into sharable content objects using progressive scaffolding that integrated seamlessly into the curriculum. This learning technology design method should permit a high level of reuse and interoperability within most distributed learning environments.

* Accepted 28 October 2009.

Approximately 80–90% of all information used by civil engineers has some spatial content. For example, civil engineers must have, and must be able to apply knowledge of land use, cope with environmental and socio-economic considerations, and manage administrative data. These kinds of information may be integrated using GIS tools [1]. Yet, there exists a lack of qualified specialists with the ability to create and use GIS in academic institutions, companies and organizations. Hence, the responsibility for creating and using GIS is shifting towards professionals knowledgeable in GIS technology and its implementation in non-GIS specialties such as civil engineering. Given the dramatic advances in data capture made in the last five years and the increasing complexities involved in civil engineering problems, students' ability to work from a systems perspective is more critical than ever.

1.1 Identifying the need

Joseph Bordogna, a former NSF director, summarized his view on how civil systems engineers will play an ever more significant societal role this century [2]. He observes that the current civil infrastructure is based on interconnected and complex civil engineering systems. These civil systems are spatially distributed in urban or rural settings and many of the decisions regarding maintenance, rehabilitation and new construction require spatial reasoning. It is his claim that civil engineers are positioned to be master integrators of these civil systems [2] and they need to be educated to have such a global perspective. Geographic information systems are ideal computer-based tools to facilitate the engineer's design of comprehensive spatially-distributed infrastructure. Traditional civil engineering curricula have not emphasized integrated perspectives. Instead, they offer a series of courses within areas of emphasis (e.g., geotechnical, transportation, environmental, water resources, construction, structures, surveying, etc.) and these are integrated in the final design (capstone) course. However, making comprehensive design decisions regarding realistic, complex and spatially distributed problems earlier in the curriculum is critical if civil engineers are to rise to the demands of being master integrators [1].

Hence, leaders in the field believe that there is a strategic need for civil engineering (CE) to incorporate GIS knowledge into the undergraduate curriculum in foundation courses. Furthermore, programme accreditation standards are also recognizing and enforcing this need. The Accreditation Board for Engineers and Technologists (ABET) lists outcomes under Criterion 3 (k) 'demonstrate... an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice' [3]. This criterion directly relates to the skills gained by the students using GIS. The integration of GIS into the classroom can also help CE programmes to meet ABET criteria.

1.2 Learning system

Integrating any concept throughout a curriculum is a large undertaking requiring the cooperation of many people. Building this type of consensus is best approached in a progressive fashion. Educators may begin small by focusing on one part of the curriculum, demonstrate the success of the approach, and then widen the circle of influence by entraining more participants and then expanding to other portions of the curriculum. Our study began by implementing the GIS learning system as a module in the laboratory portion of a regular undergraduate course in the CE programme—CE 215 Fundamentals of Geotechnical Engineering. This course is typically required for undergraduate students in a CE programme in the United States. The engineering decision-making process of selecting borrow sites is complex and required more than one source of information. The desired type of soil needed to be determined. The decision depends on the engineering application (i.e., landfill liner, structural fill, drainage blanket, etc.). Potential borrow sites are located at different geographic locations and different factors affect their suitability for use as borrow material (i.e., access, soil type available, cost, distance from construction site, etc.). The learning system emphasized the principles of reliable and cost effective solutions, which are very important to civil engineers. Since the critical learning objective is to decide which soil borrow site to use for a particular construction objective, the issues of distance to the site, truck hauling costs and quality of material must be considered before the final selection is made. This information is provided via the GIS data learning objects incorporated into the learning system object repository. In combination, the complete set of learning objects provided an educational experience that exceeded traditional textbook instruction supplemented with laboratory experimentation, and led to an understanding of wider issues in problem solving.

The learning objectives for the system can broadly be classified into three groups: foundational knowledge in civil engineering, training in the use of GIS, and application of concepts to modern engineering problems. The system was designed for use in courses where students are learning civil engineering concepts and had a first order working knowledge of these concepts. The students' knowledge of GIS could be diverse when they enrol on the course. In the course where this system was first implemented, there were students enrolled from three different majors, including civil engineering, architectural engineering and geological engineering. The diversity of previous knowledge was an important factor in guiding the system design, but it is our opinion that the concepts would also be applicable to students with previous GIS knowledge.

From a technological perspective, GIS learning tools that are developed should be reusable, highly interoperable, and possess a fine enough level of detail. Furthermore, it is desirable for them to be viewable via a web browser and packaged to allow easy import into learning management systems. The prototype in our study consisted of a comprehensive problem and an associated repository of learning objects organized using a progressive scaffolding [4] approach (both discussed in more detail below). The applied problem was at the heart of the system, with the GIS learning objects providing support as needed. One of the common learning objects for this learning system is the '*ArcView*™ Basics' topic, which was created using several content objects. These content objects consist of a text and video representation of the following topics: opening a map, displaying labels, *ArcView*™ navigation bar, and adding layers. The video demos were created with *Macromedia's Robodemo*©, and they are web-viewable via *Flash*©. Figure 1 is a screen shot from one of the screens of the learning system displaying a learning object, and Figure 2 shows an example of the corresponding captured video. The spatial data layers required for the geotechnical project, located in St Louis, Missouri, were collected and assembled as a data package for the students to use in a laboratory session. The application was designed using a SCORM (shareable content

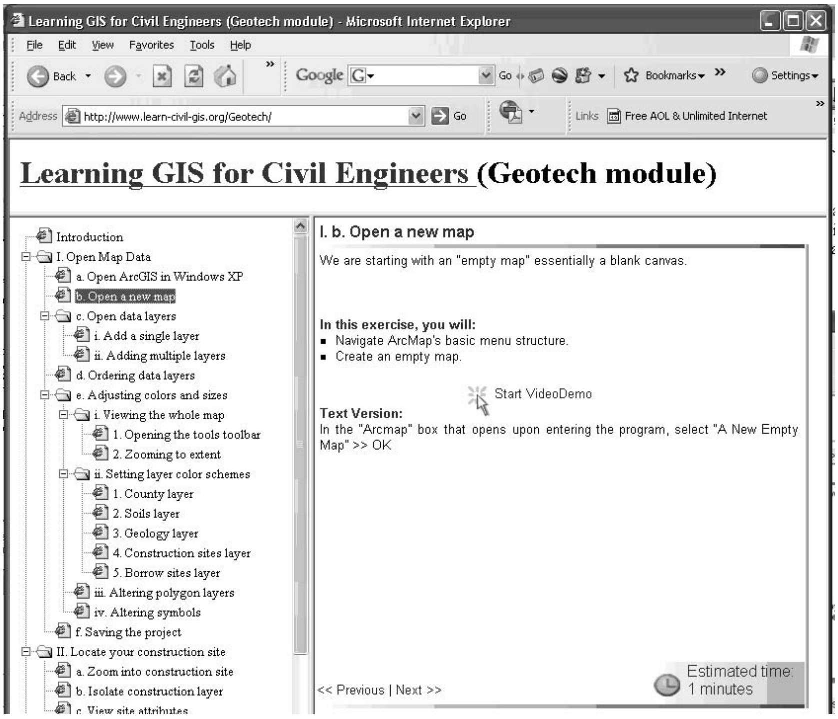

Fig. 1. Typical web-based window of the learning management system (Geotech module).

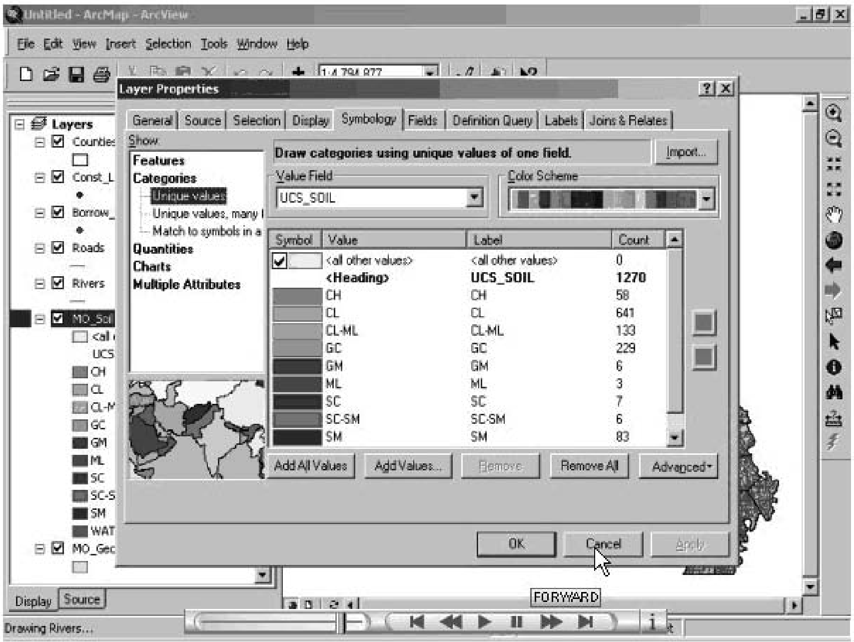

Fig. 2. Video demo showing an example of the particular learning object.

object reference model) compliant protocol. A series of videos were developed and tested prior to launching the application and their usability tested iteratively during development [5, 6].

The web-based application is available at the URL listed below and has been made available to select university professors for use and comment. Readers are encouraged to access this website at: http://www.learn-civil-gis.org.

2. METHODS

2.1 System development

Two important concepts were instrumental in the design of the prototype system, and they will also guide development in the next phase of the project, an expansion project. First, information was decomposed into sharable content objects compliant with ADL/SCORM (ADL = advanced distributed learning) requirements. Second, a progressive scaffolding approach was used for presenting different types of media.

2.2 Shareable content objects

The goal of distributed learning networks is to provide a repository of sharable learning objects facilitated by information networks. Conceptually, this means that educators decompose their courses into a collection of fundamental elements, called *learning objects,* and make them available to an information network. A learning object is a collection of web displayable material that has an associated learning objective. There are several goals to such a system. For the objects themselves, it is desired that they be *interoperable, accessible, durable* and *reusable* [7].

The key to the success of a distributed learning environment is having a common architecture shared across the network to ensure the interoperability and accessibility of the learning objects. In 1999, Executive Order 131111 tasked the Department of Defense (DoD) 'to develop common specifications and standards for technology–based learning' [8] resulting in the first draft of the *Sharable Content Object Reference Model* via the DoD's Advanced Distributed Learning Initiative.

The primary user of SCORM–compliant distributed learning networks has been the military. The Army has seen remarkable success with its Distributed Learning System, with cost savings resulting in millions of dollars. However, university educational information networks have been slow to adopt and use these standards. This may be because of the fundamental difference that the military tends to train whereas professors strive to educate. The GIS project proved to be an excellent translation project because it is a mixture of education and training.

2.3 Progressive scaffolding

Progressive scaffolding is a term used to refer to a systematic method of providing users with an optimal level of assistance. Within such a system, different levels or tiers of help are provided to match the optimal levels of assistance required. The level could be set by the learner, an instructor or automatically, based on learner response. We conducted two previous studies, which indicated that the approach provides a flexible and viable learning environment. Learners tend to select the most minimal level of assistance first, in order to minimize their interaction with the learning scaffold and maximize their interaction with the fundamental problem to be solved [9, 10]. This behaviour is indicative of the basic principle that the learning system is simply a tool to help facilitate problem solving.

It is important to note that scaffolding, as defined within this framework, refers to guidance that supports the core content, which remains constant across differing levels of scaffolding. Therefore, the degree of scaffolding is not equivalent to the difficulty of the content; rather, it refers to the degree of supportive context provided. More specifically, the scaffolding dimension in our research was represented by the media in which the content is embedded: plain text, text with graphics, or video. Thus, the scaffolding differs in the degree of abstraction, fidelity and richness.

2.4 Evaluation of the learning system

The evaluation of the prototype system consisted of a set of three usability tests performed iteratively during development. User testing involved a small number of engineering students with appropriate background knowledge at different stages of development [11] and modifications were made at each stage to optimize the system. Once the final prototype system was completed, it was used in a group setting in the classroom.

Evaluation was also completed in a classroom setting and a laboratory session where the learning system was implemented successfully and the faculty instructors assessed the learners. Learning groups were formed based on the afternoon laboratory sessions of the undergraduate course in geotechnical engineering (CE 215 Fundamentals of Geotechnical Engineering). A total of 56 participants were involved in the evaluation. Twenty-nine of the students experienced the GIS learning system in groups of two in front of a computer, and twenty-seven experienced an activity resembling a table game. The group using the GIS learning system was termed the treatment group, and the table game group was termed the control group. The control group was necessary to ensure that the entire group of fifty-six students were exposed to the same amount of pedagogical material before the assessment phase. The table game involved solving the same type of problem but working with paper maps, cards and play money. The students participated in role-play as an engineering contractor, geotechnical laboratory; borrow site owner or hauling trucker. The students were to identify a borrow soil source near their site, purchase soils lab results from a third party, and then prepare a cost estimate including hauling costs to identify the most favourable borrow site. This game activity involved more social exchange among the students than the GIS group because they were required to interact with several students in the classroom to arrive at their solution.

Two instruments were used for the assessment of learning (see Appendix A). First, a quiz was administered with objective items over the content of the subject matter to see how much was retained two days after the laboratory session. A questionnaire was also administered asking general questions regarding the learning, motivation and engineering application.

3. RESULTS

3.1 Learning group comparisons

Interpretation of the data collected in the evaluation and assessment allowed for compari-

Table 1. Mean test and rating outcomes as a function of experimental group

Item	Group*	
	GIS	**Game**
Learning rating	5.93	6.22
Motivation rating**	5.17	6.56
'Real world' rating	7.62	7.85

Notes: * based on a 9-point agree–disagree scale; ** $p < 0.05$.

Table 2. Knowledge ratings for before and after lab

Group	Knowledge rating**	
	Before lab	**After lab**
GIS	3.59	6.35
Game	4.33	6.93

Notes: * based on a 9-point agree–disagree scale ** $p < 0.05$

Table 3. Ratings comparing lab with other course components (GIS group only)

Item rated	Course component *			Contrast with lab
	Lab	**Lecture**	**Text**	
Learning **	5.93	5.17	4.14	> Text
Motivation	5.17	4.45	3.55	> Lecture & Text
'Real world'***	7.62	5.76	4.97	> Lecture & Text

Notes: * based on a 9-point agree–disagree scale; ** $p < 0.01$, *** $p < 0.001$.

sons between the two groups. The group that used the GIS Learning system in pairs will subsequently be called *GIS* and the group the used the role playing game will subsequently be called *Game*. The quiz (Appendix A) contained objective and technical questions on the topic of earthwork operations, soil borrow sites and compaction. On the quiz, the average score for the *GIS* group was 82% and for the *Game* group was 70%. It is our opinion that the difference of 12% was statistically significant.

Next, we compared a series of four subjective questions in which the students rated the laboratory activity on: (a) learning, (b) motivation and (c) application to the 'real world' (9-point agree–disagree scale). Interestingly, the *Game* group rated the activity significantly higher on motivation. On the other two items, the *Game* group also had higher ratings, though not significantly so.

Additionally, a two-way analysis (group [*GIS* vs. *Game*] and time [rating of knowledge before vs. after]) indicated that the knowledge ratings for both groups were significantly higher after the lab session. Before the lab, they had only attended lectures and had access to the textbook. The ratings did not differ significantly as a function of group as shown in Table 2.

In addition, we compared items on the questionnaire that referred to different course components (i.e., lab vs. lecture vs. text). This analysis was only carried out for the *GIS* group. The questions were again related to Learning, Motivation and 'Real world' application and rated accordingly (see Table 3). In each case, the laboratory received the highest rating. In the case of learning, the lab group was rated significantly higher than the text (but not the lecture). However, in both motivation and application, the lab was rated significantly higher than both the lecture and lab.

4. CONCLUSIONS

Overall, the GIS Learning system proved to be a successful pedagogical tool at the undergraduate level. Although those in the control condition, which used a game, reported higher levels of motivation, those who used the learning tool scored significantly higher on objective learning outcomes. Based on the results of this proof-of-concept project, there is a strong probability that the learning modules can be effectively expanded to other disciplines within civil engineering. Students who follow the curriculum will significantly benefit from multiple exposures to GIS within different applied contexts. The problem solving approach to the exercises that involve spatial reasoning and looking at the bigger picture of engineering will form engineers who are more aware of the broad impact of sustainable solutions.

Acknowledgements—The authors would like to thank the students in the respective academic departments and the CTEL and LITE centers at Missouri S&T, particularly Mr. Matt Buechler. The work presented in this paper is based upon work supported by the National Science Foundation under Grant No. DUE-0341014 and Grant No. DUE-071241. Opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

1. A. Parker An introduction to GIS and the impact on civil engineering, in Institution of Civil Engineering, Geographic Information Systems, 1996.
2. J. Bordogna Tomorrow's civil systems engineering—the master integrator, *Journal of Professional Issues in Engineering Education and Practice*, **124**, 1998, pp. 48–50.
3. ABET Criteria for Accrediting Engineering Programs (2007–08), Accreditation Board for Engineers and Technologists, Baltimore, MD, 2006, 29 pp.
4. J. M. Sullivan, R. H. Hall, R. Luna, R., M. G. Hilgers, A. J. Taylor and M. R. Buechler, Degree of scaffolding as learning object metadata: a prototype learning system design for integrating GIS into a civil engineering curriculum, *Learning Technology*, **6**(2), 2004, pp. 60–64.

5. R. Luna, W. T. Lawrence, J. M. Sullivan, R. H. Hall, M. G. Hilgers and M. R. Buechler, Development of a learning system to introduce GIS to civil engineers, Proceedings of the ACM Symposium on Applied Computing, 2005, pp. 1737–1738.
6. J. M. Sullivan, R. H. Hall, R. Luna, M. G. Hilgers, M. R. Buechler and W. T. Lawrence, Iterative Usability Evaluation Methods Applied to Learning Technology Development. *Proceedings of the World Conference on Education Multimedia, Hypermedia & Telecommunications (EdMedia)*, 2005.
7. J. Englebrecht, Implementing SCORM in enterprise distributed learning environments, *Proceedings of the Interservice/Industry Training, Simulation, and Education Conference*, 2003.
8. ADL, SCORM 2004 4th Edition: Content Aggregation Model Version 1.1, 2004. http://www.adlnet.gov/Technologies/scorm/SCORMSDocuments/2004%204th%20Edition/Documentation.aspx.
9. R. H. Hall, S. Stark, M. Hilgers and P. Chang, A comparison of scaffolding media in a learning system for teaching web development, *Proceedings of the AACE E-Learn Conference*, 2004, pp. 1906–1913.
10. R. H. Hall, A. Digennaro, J. Ward, N. Havens and J. Ricca, Development of a web-based learning system for teaching web design and development: a problem-based progressive-scaffolding approach, *Proceedings of the AACE E-Learning Conference* 2002, 2005, pp. 1562–1565.
11. J. M. Sullivan, R. H. Hall, M. G. Hilgers, R. Luna, W. T. Lawrence and M. R. Buechler Iterative usability evaluation methods applied to learning technology development, *Proceedings of the World Conference on Educational Multimedia, Hypermedia, & Telecommunications* 2005, 2005, pp. 1188–1193.

APPENDIX A

QUIZ used regarding learning (objective format), total students *GIS* = 29; *Game* = 27

Questions:	**Correct**		**Incorrect**	
	GIS	*Game*	*GIS*	*Game*
1. A borrow site is always located at quarries. (True/False)	28	26	1	1
2. A rock quarry could serve as a borrow site is granular fills are desired. (True/False)	24	23	5	4
3. The acronym GIS stands for: Geologic Inspection Standards. (True/False)	19	5	10	22
4. The following disciplines make use of GIS: a. City Planning b. Water Resources c. Geology d. Anthropology e. All of the above	25	19	4	8
5. Which of the following is not needed to estimate the cost of imported soils to a site: a. Delivery cost b. Cost of material per cubic yard c. Soil type d. Compaction testing	14	19	15	8
6. The geology at a site is not important when making a selection for soil borrow sites. (True/False)	26	24	3	3
7. GIS can be used for the following: a. Composing letters b. Purchases online c. Locating sites d. Soil testing	24	6	5	21
8. Results of the Plastic and Liquid Limits can be obtained without running lab tests. (True/False)	26	23	3	4
9. If fill is required for a construction site, the soil type is not important as long as there is enough material available at reasonable cost. (True/False)	28	24	1	3
10. The Plastic and Liquid limits are important geotechnical lab tests to run on a granular backfill. (True/False)	15	6	14	21
11. The usefulness of GIS in geotechnical projects lies in the spatial analysis and attribute storage capabilities of the GIS. (True/False)	21	13	8	13
12. Other factors that may increase costs when a material is used at a project site are: a. Labor costs b. Equipment costs c. Shrink/Swell of the material	varies			

Questionnaire used regarding learning (subjective)

Please use the scale below to respond to each of the statements and explain your answers in the space following, if appropriate.

Strongly Disagree 1 . . . 2 . . . 3 . . . 4 . . . 5 . . . 6 . . . 7 . . . 8 . . . 9 Strongly Agree

1. I learned a great deal of information about soil borrow site selection from **this week's lab**. Explain:
2. I learned a great deal of information about soil borrow site selection from **class lectures**. Explain:
3. I learned a great deal of information about soil borrow site selection from **the class text**. Explain:
4. I found **this week's lab** on soil borrow site selection to be very motivational. Explain:
5. I found **the class lectures** over soil borrow site selection to be very motivational. Explain:
6. I found **the class textbook's** coverage of soil borrow site selection to be very motivational. Explain:
7. **This week's lab activity** over soil borrow sites was applicable to 'real world' engineering. Explain:
8. The **class lecture** over soil borrow sites was applicable to 'real world' engineering. Explain:
9. The **text book coverage** of soil borrow sites was applicable to 'real world' engineering. Explain:
10. Before the lab activity that covered soil borrow sites, I knew a great deal about the subject. Explain:
11. After the lab activity that covered soil borrow sites, I knew a great deal about the subject. Explain:
12. Please list the strengths of the lab activity that covered soil borrow sites, in terms of it's effect on learning and motivation, and it's applicability to 'real world' engineering.
13. Please list ways in which the lab activity that covered soil borrow sites could be improved.

Ronaldo Luna is an associate professor of Civil Engineering at the Missouri S&T, Rolla. He received his Ph.D. from the Georgia Institute of Technology in 1995. His research interests include: engineering education, geotechnical and earthquake engineering, and hazard mitigation.

Richard Hall is a professor of Information Science & Technology and Co-Director of the Laboratory for Information Technology Evaluation at the Missouri S&T, Rolla. He received his Ph.D. from the Texas Christian University in 1988. His research and teaching focus on the creation, exploration, and evaluation of web and new media technologies.

Michael Hilgers is a professor and associate chair of Information Science & Technology as well as Director of the Center for Technology-Enhanced Learning at the Missouri S&T, Rolla. He received his Ph.D. from Brown University in 1992. His research interests include modelling and simulation with applications in educational technology.

Louis Ge is an assistant professor of Civil Engineering at the Missouri S&T, Rolla. He received his Ph.D. from the University of Colorado at Boulder in 2003. His research interests include: constitutive modelling, finite-element methods and geotechnical earthquake engineering.