Advances in Health Sciences Education (2005) 10:215–230
DOI 10.1007/s10459-005-7851-3

Evaluation of an Interactive Case-based Online Network (ICON) in a Problem Based Learning Environment

ARIF N. NATHOO[1,3], PATRICIA GOLDHOFF[2,3] and JAMES J. QUATTROCHI[1,3,*]

*[1]Francis Weld Peabody Society, Harvard Medical School, Tosteson Medical Education Center, 260 Longwood Ave, Suite 255, Boston, MA, 02115, USA; [2]Department of Molecular and Cellular Biology, Harvard College, Tosteson Medical Education Center, Boston, MA, 02115, USA; [3]Laboratory for Cellular and Molecular Neuroscience,Program in Neuroscience, Harvard Medical School, Harvard Medical School, Tosteson Medical Education Center, Boston, MA, 02115, USA (*author for correspondence, e-mail: jq@hms.harvard.edu; Phone: +1-617-432-2244; Fax: +1-508-300-5639)*

Received: 6 July 2004; Accepted: 24 May 2005

Abstract. *Purpose*: This study sought to assess the introduction of a web-based innovation in medical education that complements traditional problem-based learning curricula. Utilizing the case method as its fundamental educational approach, the Interactive Case-based Online Network (ICON) allows students to interact with each other, faculty and a virtual patient in difficult neurological cases. Given the paucity of available metrics to benchmark online systems, we complement user perceptions with data on system utilization. *Methods*: We describe a case study of distinct, small group tutorials over 2 years as part of the Human Nervous System and Behavior (HNSB) course at the Harvard Medical School. Participating students and faculty were interviewed following completion of the course and their utilization of the system was recorded and examined. *Results*: Students each spent 3.2 ± 1.3 h (mean $\pm$ SD) through 8.6 ± 2.8 accessions per week using ICON outside of required tutorial time. Faculty each spent 4.8 ± 3.4 h through 16.6 ± 8.9 accessions per week on ICON. Students identified real-time engagement, stronger relationships with faculty, increased accountability to the tutorial group and self-selected pace as the most beneficial characteristics of the ICON-based tutorial in comparison to traditional problem based learning (PBL) tutorials. Faculty identified enhanced collaboration with students and more realistic student experiences as the most beneficial characteristics. Both students and faculty reported that limitations of ICON included increased time investment for faculty and increased reliance on good faculty mentorship. *Conclusion*: This is the first study of the ICON learning system in undergraduate medical education, a platform designed to facilitate collaboration outside of the classroom. Data on user perceptions and system utilization suggest that both faculty and students chose to adopt this online learning system as a means for collaboration. The study also outlines future avenues for research in assessing novel online technologies.

Introduction

The 21st century is bringing considerable changes to the way that we approach both undergraduate and graduate medical education. An evolving environment of medical practice challenges our traditional views of professionalism, directing physicians to develop their abilities in decision analysis and information management (Blumenthal, 2002). The growing utilization of online resources in learning signals an important evolution in the delivery of medical information. While this transition has substantially altered medical practice, schools are faced with the challenge of restructuring undergraduate medical education to meet changing needs. In response, many institutions have quickly developed online curricula and web-based learning tools (Frisse, 1990; Hallgren, et al., 2002; Heidger et al., 2002; Fleiszer et al., 2004; Vozenilek et al., 2004; Shaffer, 2004; Parker and Seifter, 2001). At times, however, the excitement surrounding these novel tools often centers on content and the employed technology rather than their utility of purpose and accessibility in the process of learning.

Instead of fostering a rush to implement technology into our curriculum, a more thoughtful approach asks whether various technologies can indeed enhance areas of our curriculum. In this paper, we provide an initial assessment of a user-defined online network that facilitates the medical student's development of decision-making and team skills outside of the classroom and encourages the active participation of faculty in the student's learning. Utilizing the case method as its fundamental educational approach, the Interactive Case-based Online Network (ICON) enables students to interact with each other and virtual patients through a web-based system (Dewey, 1994). Rather than supplant the traditional case-method pedagogy of face-to-face tutorials, ICON exists as a virtual environment for students to continue collaborating outside of discussion sessions. In this regard, a user-defined community of practice continually evolves through student interactions with problems, solutions and insights, and by building a common domain of knowledge that can be accessed jointly by all members(Wenger, 1996; Wenger, 2001).

Educational context

ICON was initially designed and implemented as a network to enhance learning of neuroscience in the undergraduate neuroscience curriculum of the Harvard Faculty of Arts and Sciences (Quattrochi et al., 2002). Given the success of ICON in this context, we explored its utility for undergraduate medical education at Harvard Medical School (HMS) and selected the second-year course, Human Nervous System and Behavior (HNSB). HNSB is an eight-week interdisciplinary study of neuroscience that explores normal and abnormal structure and function in neurology, psychiatry, molecular biology, and clinical neuroscience. Bringing together a rich tradition of

scientific discovery and hypothesis-testing, problem based learning (PBL) in neuroscience affords students the opportunity to explore a range of goals, and challenges case developers to provide expert guidance without stifling student creativity (Glick and Armstrong, 1996). Therefore, each of the seven written cases studied in the HNSB course is composed of a dynamic array of issues and learning themes built around a patient presentation. Each faculty tutor in the course facilitates discussion during three weekly, 2-hour tutorial sessions with a group of $n = 8$ students. The remainder of weekly course time is divided between laboratory and lecture.

We identified a crucial gap in the integration of case discussion with learning content between tutorial sessions (Figure 1). To this point, we believe that a web-based network allows for continuous integration of information through interactive discussion, decision-making, hypotheses formation and self-assessment between faculty and students. As the patient's situation unfolds in ICON, students are responsible for the practice of the science, guiding the patient's care by communicating directly with the patient, coordinating the medical team's activities, and determining the course of action. Based on these interactions, we hypothesize that ICON offers advantages to students with respect to traditional problem based learning programs: (1) Enables students to engage in a hypothesis-driven, decision-making process and learn from the consequences of their decisions; (2) Improves their ability to communicate with teams of specialists and elicit information from patients; and (3) Strengthens the partnership between faculty and students. The aim of this study was to evaluate how often students independently engaged in the ICON component of the tutorial and gain a general understanding of student and faculty perceptions of ICON.

Structure

In an effort to create a user–computer interface that is intuitive and familiar to students and faculty, we investigated current web-based internet/intranet software. Web Crossing 5.0 (Web Crossing, Inc. 2002) was selected for its customizable, web-based conferencing capability and reusability. As a platform for developing the enhanced features of ICON, we installed Web Crossing on a secure HMS web server using the HMS portal, MyCourses (Educational Computing, 2003).

Users of ICON, including students, faculty mentors, and a faculty tutor, were assigned a user name and password. Each HNSB case is identified as a folder tab containing all discussions, resources, and related links in seven embedded modules: *Case, Working Papers, Neuroimaging, Learning Themes, Virtual Contact, Brainstorm* and *Self-Assessment* (Figure 2). Using menu toolbars and discussion icons, users navigate between the modules. Users also have the ability to create discussions, initiate dialogue with case

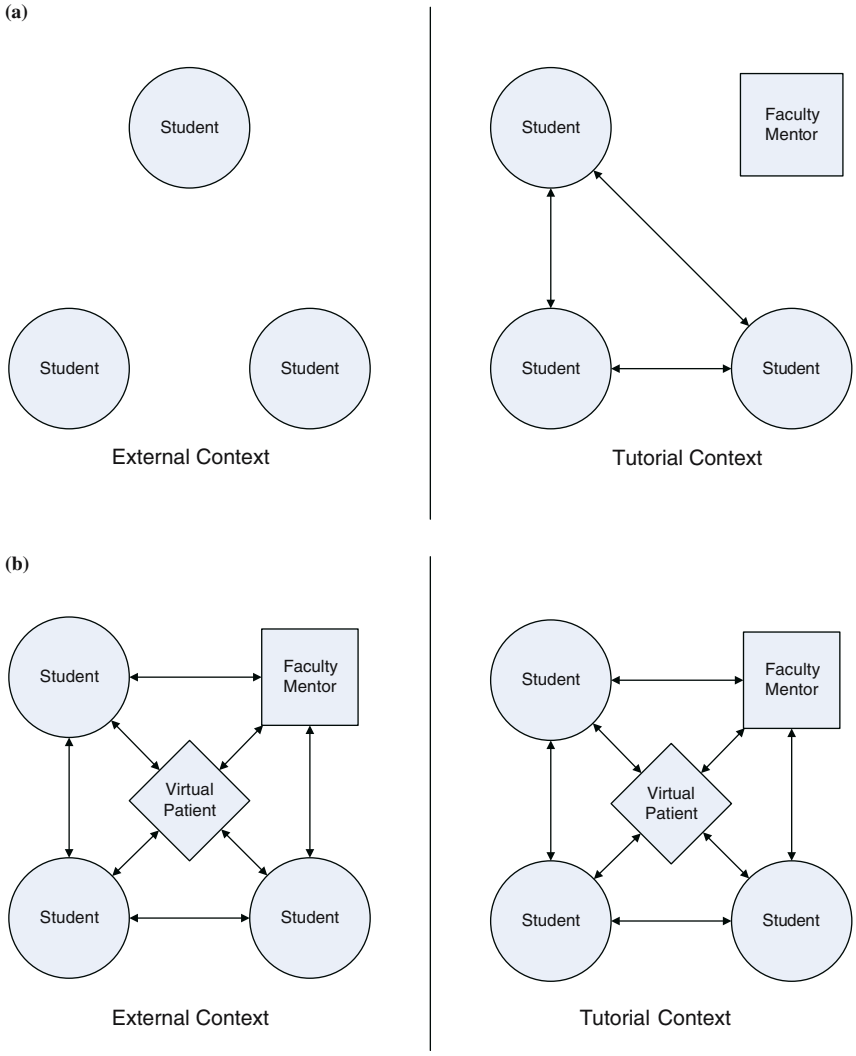

Figure 1. Model for Patient-centered interactivity in A, Traditional problem based learning systems and in B, The ICON tutorial system.

characters, open personal notebooks, transfer resources and communicate with other users concurrently online using Instant Message. Faculties were given access to additional modules used for feedback and development.

The framework of ICON consists of modules from which the students, faculty mentors and the faculty tutor build the case. Each of the case modules targets a unique aspect of the learning process and complements the face-to-face tutorial component of ICON.

Figure 2. ICON case folder with modules, Case 6: " All Sides of the Story."

MODULES

Case

The presentation of a patient case forms the basis for discussion in any problem-based learning session. Departing from the traditional distribution of written cases that often occurs in a manner of progressive disclosure, with students receiving printed material in usually 5–6 parts, cases unfold on ICON in real time as they happen. Hypertext references are embedded within the introductory part(s) of the case (Figure 3).

Working papers

The Working Papers module includes full text reference articles pertinent to the case and selected by both faculty and students. As the students progress through the cases, Working Papers becomes a database of online reference information, selected scientific articles, published commentary, and up to date media and science news.

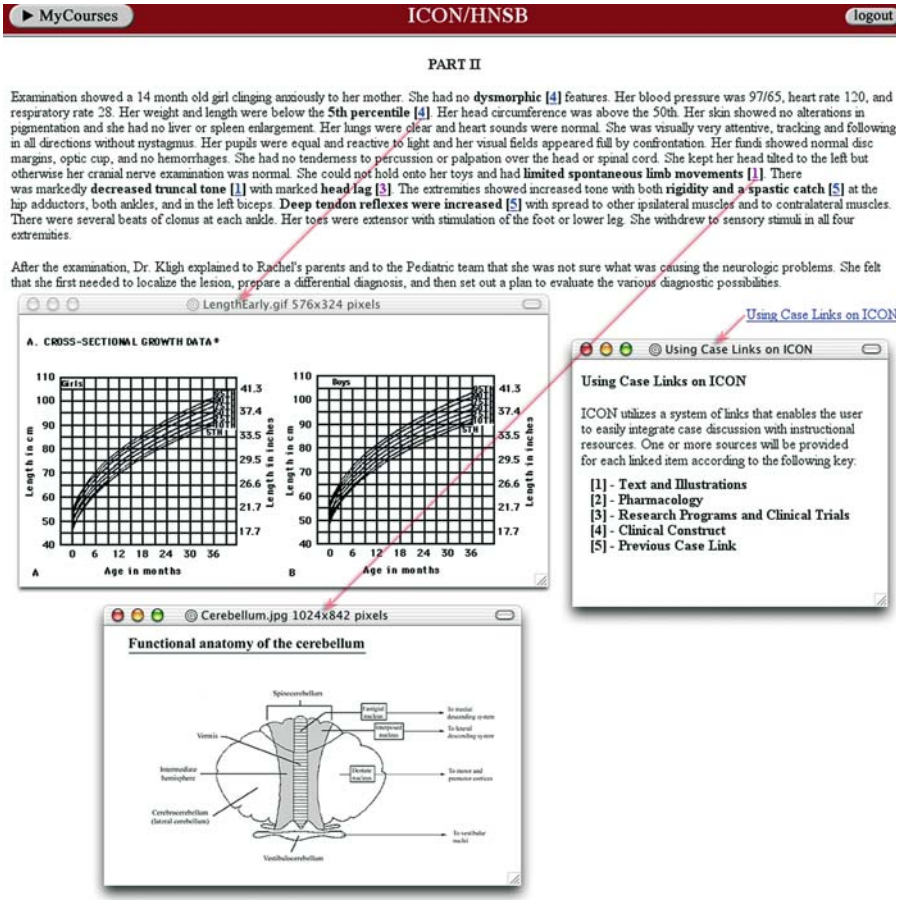

Figure 3. Hypertext links embedded in the case module.

Neuroimaging

The Neuroimaging module includes brain scan image files, online imaging tutorials, animations and interactive simulations pertinent to the case and selected by students and faculty. Similar to Working Papers, the learning content in Neuroimaging is user-driven, providing a multimedia study guide that illustrates various pathologies, different imaging techniques, neurotransmitter pharmacology, structure-function correlates, mind-brain behavioral states, clinical signs and useful features of the neurological exam.

Learning themes

The Learning Themes module includes the specific learning objectives and endpoints of the case. Themes are selected by faculty although not presented

to the students in ICON until the discussions of the case have been completed. In this way, students are provided feedback from faculty, self-assessment opportunities, and further refinement of their knowledge base.

Virtual contact

The Virtual Contact module introduces a virtual environment that allows faculty to participate as characters in the case. Given the sensitivities of medical students working with real patients in preclinical training, the module allows students to communicate and initiate dialogue at any time with the patient and other case characters (Figure 4). In some cases, videos are presented in the module of patient–doctor interviews and neurological examination. Faculty mentors are recruited specifically for their knowledge and experience working with patients that suffer from the disease being studied in the case.

Students are informed as the case begins which characters will be available for discussion, typically the patient and a health care provider. As the case progresses, students initiate dialogue within the module by posing thoughtful

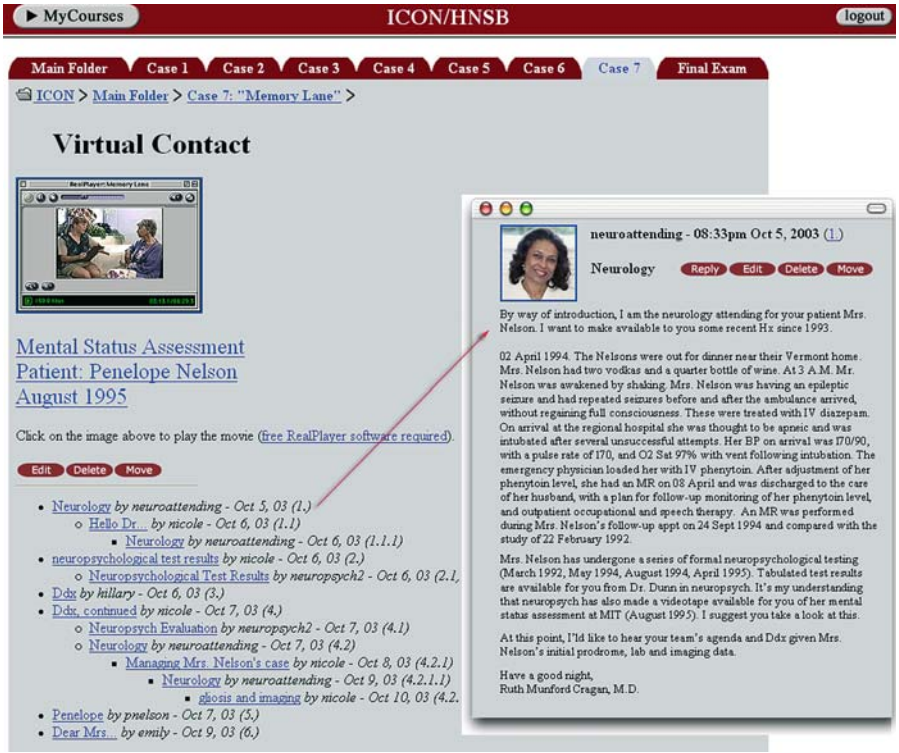

Figure 4. Virtual contact with interactive dialogue.

questions to the case characters. Students may also request consults from specialists and the involvement of additional characters. Faculty mentors who are assigned to the case enter the system with the username of the character and respond to student questions. Students are not evaluated by faculty mentors on the basis of their questions, and each mentor may select their own level of participation.

Brainstorm

The Brainstorm module is user-driven, providing an open discussion forum for students and faculty. The module is presented as threaded discussions, identified in chronological order. Students and faculty access separate sub-directories on the server in which images and other data can also be uploaded, stored and displayed as enclosures within discussions.

Using this interface, students discuss and integrate new information throughout the case. Much of the information and online resources provided by faculty in the other modules are guided and paced by the students' performance in Brainstorm.

Self-assessment

The Self-assessment module consists of additional resources and challenging questions that offer students an extension of their case synthesis to new areas of study. Students utilize this module by applying their understanding of basic science, diagnostic constructs, and management strategies toward a previously unstudied problem.

ICON TUTORIAL APPROACH

Case progression in the ICON tutorial followed a unique path that was driven by the students. Work on the case began on the Friday prior to the first face-to-face discussion on Monday. Students initiated dialogue with case characters online in Virtual Contact, formulated a framework of thinking in Brainstorm, and discussed their initial approach to the case. Following the first discussion session, students requested additional patient information from the online medical team, discussed issues of concern with the patient and other case characters, and continued to collaborate in the Brainstorm module. References of interest were shared by students and faculty during the week in the Working Papers and Neuroimaging modules. At the end of the week, students would conclude the case by synthesizing information discussed during the week and two students would prepare brief oral presentations focusing on specific learning themes and cornerstones of the case. Students often invited guest faculty to participate face-to-face in their final discussion of the case.

Self-assessment questions highlighting the basic science endpoints of the case became available online for students to work through on their own after the Friday tutorial. Students typically continued dialogue with the patient and care providers online even after the final discussion session for the case.

Methods

One tutorial in the HNSB course in Year I and one tutorial in Year II were selected to use the ICON method. Each of these tutorials consisted of $n = 8$ students and 1 faculty tutor (JQ). In addition, $n = 7$ faculty mentors participated in each of the two ICON programs, each mentor spending one week as a case character in the Virtual Contact module. Of these 14 faculty mentors for the two courses, $n = 9$ were unique individuals, resulting from the overlap of mentors from Year I and Year II. Student selection was conducted prior to the start of the HNSB course. An e-mail introducing ICON was sent to all students in one academic society ($n = 40$ in Year I; $n = 43$ in Year II). Students expressing an interest to participate in the ICON tutorial responded ($n = 10$ in Year I; $n = 16$ in Year II), and a randomization process was used to select $n = 8$ students for each tutorial. Students in the ICON tutorial attended all lectures and laboratories in the HNSB course and were evaluated in the same manner as their colleagues, independent of their participation in the online component.

Students were instructed in the use of ICON during the first tutorial session for 30 min of the 2-hour session. Each invited faculty participant was given a 30 min training session on the use of ICON prior to participation. The faculty tutor for both ICON courses in the study (JQ) assisted in the development of ICON and was trained in its methods prior to implementation.

User perceptions

Following completion of the course, student and faculty perceptions of ICON were elicited by interviews with independent educational specialists, J. Hafler and A. Peters, from the HMS Division of Educational Development. The interviews focused on the following: advantages and limitations of the ICON learning process, characteristics of effective online and real-time interaction and qualities of an effective faculty tutor. To promote evaluative feedback in a safe interview setting, confidentiality was stressed by the specialist and feedback given was not attributed to specific students. The anonymous transcript of the interview was then given to the authors, who then reduced the data and extrapolated dominant themes from the interviews.

Utilization of the online network

During each ICON course, a technical log was maintained that identified the date and time of each webpage accessed by students and members of the

faculty. These logs remained sealed until completion of the semester to ensure that student participation remained independent from faculty evaluations of their performance. Each system accession was recorded as follows: IP address, user name, date, time, accessed page and action (data sent or received). With greater than 30,000 individual webpage accessions per ICON course, data was reduced by individual and analyzed for time spent on the system and frequency of usage. Interactivity was further characterized by examining the number of online discussion in Brainstorm initiated by students and faculty. Users interacting online have a choice between initiating a new topic for discussion and continuing a previous discussion thread. The relative balance between new topics and collaborative discussions was also measured. The methods for assessing utilization and perceptions were repeated for the ICON tutorial in Year II.

Results

A total of 16 students, 1 faculty tutor, and 9 faculty mentors used the online system over two courses. Of the student participants, 56% were women and 44% men, reflecting the approximate class composition of the New Pathway curriculum at Harvard Medical School. System accession and course utilization was analyzed for all students and faculty participating in the course. One of the 16 students (6%) did not participate in the interview process out of choice. All nine faculty mentors participated in the interview.

Utilization of icon

Utilization of the system outside of the classroom by all users was measured by analysis of the technical log files (Table I. Each student spent 3.0 ± 1.0 h (mean $\pm$ SD) per week over 8 weeks accessing the online platform during the first implementation of the course and 3.2 ± 1.3 h per week in the second year. Accordingly, the amount of time spent online reflects 7.9 ± 2.0 weekly logons during the first year and 9.5 ± 3.5 logons during the second year. Each faculty member (faculty tutor and faculty mentors) spent 4.1 ± 1.1 h per week during the first year and 5.0 ± 1.8 h per week during the second. Similarly, they each accessed the system 15.7 ± 2.9 times during the first year and 16.7 ± 6.1 times during the second.

Interactivity was further measured by comparing the number of unique messages with collaborative discussions. Student and faculty participants initiated 1.5 ± 0.5 online discussions weekly and contributed to 1.8 ± 0.8 online discussions weekly during the first year. In the second year, participants initiated 2.0 ± 0.6 weekly online discussions and contributed to 2.0 ± 0.6 weekly online discussions.

Table I. Weekly usage of ICON by students and faculty

Year	Participant	ICON Access (logons/wk)	ICON Usage (hours/wk)	New topics (discussions/wk)	Collaborations (discussions/wk)
Year 1	Student	7.9 ± 2.0	3.0 ± 1.0	1.5 ± 0.5	1.8 ± 0.8
	Faculty Tutor	22.9 ± 6.3	6.8 ± 2.7		
	Faculty Mentor	6.9 ± 2.3	1.2 ± 0.7		
Year 2	Student	9.5 ± 3.5	3.2 ± 1.3	2.0 ± 0.6	2.0 ± 0.7
	Faculty Tutor	21.5 ± 6.9	8.5 ± 1.7		
	Faculty Mentor	12.4 ± 7.6	2.5 ± 0.9		
Total	Student	8.6 ± 2.8	3.2 ± 1.3	1.7 ± 0.5	1.9 ± 0.5
	Faculty	16.6 ± 8.9	4.8 ± 3.4		

Data reflect the weekly activities of each student, faculty mentor, and faculty tutor: number of accessions and time spent online (mean ± SD). The weekly number of new discussion topics introduced and follow-up collaborative discussions are reported for all participants. Totals are given for students and faculty across both courses.

Student perceptions

Several themes emerged in response to questions in the following three domains: the ICON learning process, characteristics of effective online interaction, and qualities of an effective faculty tutor.

Student assessment revealed four variables associated with ICON that are benefits to the learning process: (1) Urgency in caring for the virtual patient associated with real-time information transfer; (2) Establishment of longitudinal relationships with the faculty tutor and invited faculty mentors; (3) An increased sense of accountability to the tutorial group; and (4) The ability to work at a self-directed pace, given the permanency of online threaded discussions. Students also noted two limitations: (1) The reliance on of a well-invested faculty mentor and discussion leader; and (2) The increasing amount of time and resources required by faculty to successfully participate in the learning process.

Students reported that online interaction was most effective when participation by many students introduced the range of discussion early in the week, when the faculty tutor actively facilitated discussion, and when virtual patients responded promptly and in detail to student questions. Additionally, students revealed that the interactive modules (Brainstorm, Virtual Contact) were the most important mechanisms to facilitate learning in the online environment.

With regards to effective teaching, students identified several qualities of the faculty tutor that enhanced their learning in the ICON setting. Students described that faculty were most effective when they had an ability to effectively facilitate online and real-time discussion, had a desire to participate and were knowledgeable about the case. Students pointed out that their expectations of the tutor were largely similar to their expectations for tutors in traditional tutorials.

Faculty perceptions

Faculty mentors were asked to discuss the benefits and limitations of the ICON learning process. Faculty consistently pointed to two areas of benefit to the learning process, notably stronger collaboration with students and a more realistic experience for the students, given the real-time nature of the cases. Amongst notable limitations of the ICON approach, faculty mentors described an increase in the amount of time needed to participate and additional training required for educators using this system.

Discussion

Defining metrics for interactivity

While online communities of practice have begun to proliferate, few metrics have been developed to capture collaboration and system utilization (Swaak and De Jong, 2001; Hersh et al., 2001; National Education Agency, 2002). Given that students may be generally enthusiastic about any novel technology, we sought objective measurements to get beyond popular perception, a tool that frequently captures everything from utility to novelty. Assessing a collaborative process outside of the classroom with a traditional PBL curriculum would require observational studies; however, engaging in direct observation may lead the observed to modify their own behavior, a phenomenon frequently referred to as the Hawthorne effect (Franke and Kaul, 1978). The advent of online instructional technologies makes it possible to unobtrusively monitor particular behaviors. Leveraging this characteristic of web-based models, we recorded student interactions in the process of collaboration on ICON. We discovered that through the use of a collaborative online space, students spend additional time interacting with each other outside of the 6 h of requisite small group sessions.

Beyond evaluating time spent online, we examined interactivity regarding the type of discussion engaged by members of the tutorial. An online forum may serve as a space for individuals to simply generate and disseminate their own ideas. As an alternative, participants may contribute to discussions initiated by other individuals. We found each participant contributed equally between generating a new discussion topic and contributing to ideas of

colleagues. Because no explicit instructions were given to student or faculty participants, these results suggest that the ICON system enables dissemination of both new thinking and interactive collaboration among participants.

Faculty–student synergy

The modern revitalization of PBL is centered on bridging principles of shared learning with the recognition of team-based approaches to patient care (Glick and Moore, 2001). By allowing faculty to participate as virtual patients online, the ICON model enables dialogue outside of the classroom. Active participation by faculty mentors as case characters is necessary to create the virtual healthcare environment. Our results indicate that each faculty mentor spent an average of 1.2 ± 0.7 h per week during the first year and 2.5 ± 0.9 h per week during the second engaged in online discussion with the students. Though they were not additionally compensated for this work, faculty could access ICON from any computer with an internet connection (including web-enabled PDAs and mobile phones) and could do so on their own time. Faculty mentors expressed value in Virtual Contact as a module that opened a window of insight into how the student thinks. These individuals did not take part in the student evaluation process, and students reported comfort in asking virtual characters questions that they may not have otherwise done in an observational setting. Furthermore, students suggested bringing online additional characters of significant interest to them, including surgeons, dentists, nurses, social workers, physical therapists and family members.

The faculty tutor is an integral part of case discussion in small group tutorials at the Harvard Medical School. The faculty tutor in both ICON courses spent a considerable amount of time engaged in the online system outside of scheduled meetings. This total time spent includes providing content online, participating in group-discussion and further developing the curricular blueprint of the ICON platform. Since it is difficult to separate these functions solely on the basis of the technical logs, the number of weekly hours spent likely overestimates his involvement solely in the course. Further studies of faculty tutors who are trained to use the ICON system are being performed to better estimate faculty utilization of ICON.

Open collaboration

Risk-free participation in an innovative learning model is critical to providing the appropriate incentive structure for online participation, particularly focusing on the individual's engagement and desire to learn. Separating participation in ICON from the student assessment process allowed us to interpret online utilization as a proxy of utility, given a wide spectrum of alternative learning modalities available to students at Harvard Medical School. In this manner, we note that students do indeed spend a significant

amount of time engaging with each other in collaborative, online discussion when it is available.

The findings reported in this study are tempered by several contextual limitations. Students selected for this course had expressed a preference for enrolling in an innovative tutorial. It is not unreasonable to assume that these students would be more likely to adopt a web-based innovation than their colleagues. Students were also drawn from one academic society at one medical school. Specifically, these students have chosen to matriculate in a medical program that has a dominant problem-based learning curriculum and frequently presents alternative modalities of learning to its students. It is also significant to note that the faculty tutor for both ICON tutorials participated in the development of the web-based platform. Perceptions of the ICON tutorial were not elicited or reported about this individual, given his inherent interest in this system. Therefore, the faculty perceptions reported in this study come only from faculty mentors. Further research on this learning platform requires the training of faculty tutors and analysis of their perceptions and utilization. Finally, we do not utilize a survey instrument to elicit student and faculty preferences. Given this is a pilot study, we note that such an instrument would have been difficult to construct to capture perceptions with the same scope of a free-response focus group. However, we are encouraged that a large-scale implementation of this platform will require the use of other assessment instruments informed by the findings of this study.

Future directions

In this work, we propose the use of new metrics for measuring collaboration outside of the classroom with an online learning tool. While active collaboration may enhance the individual's perception of his or her own learning, metrics that test higher levels of abstraction need to be developed. We are working to develop evaluation methods that go beyond simple recall of medical information and reflect the challenges and competencies faced by practitioners of medical practice.

The constructive feedback provided by faculty and students has encouraged the continued use and implementation of ICON within the Harvard Medical School New Pathway curriculum. By centralizing content-driven modules and customizing user-driven modules for each tutorial, the ICON system should readily be upwardly scalable. Training faculty to use the web interface will allow for faculty tutors to facilitate online dialogue with their own groups.

Conclusion

ICON creates a space for collaborating outside of the face-to-face tutorial employed by traditional problem-based learning methods. We have found

that students and faculty selected for this program utilized this opportunity to collaborate around the case. Combined with an approach that enables cases to progress in real-time, students and faculty both recognize benefits of using ICON to advance collaboration and knowledge development.

The technology embraced by ICON was found to be accessible to the user, both student and faculty. The success of ICON resides in the dynamic created by the team. It is not a teaching tool, but rather a vehicle that facilitates active, patient-centered learning. In this study, we present utilization data to demonstrate that students and faculty engaged in such collaboration. Based on this investment, we argue that problem-based learning methods can benefit from a more rigorous structure for collaboration outside of the classroom. We demonstrate that a simple web-based architecture is a constructive method for utilizing potential resources vis-à-vis engaging outside faculty to participate in a limited fashion and keeping the faculty tutor abreast of student thinking between live tutorial sessions. By organizing student and faculty collaboration through ICON, we can see mutual investment into a partnership of practice, enabling true patient-centered learning.

Acknowledgments

We thank J. Alvarez, A. Carter, M. Cohn, C. Coughlin, R. Gillis, W. Ham, E. Hess, J. Lester, J. Meltzer, S. Salamone, M. Solon, M. Spidle, K. Wulfsberg for scholarly discussions and helpful assistance; the medical students of ICON: U. Blackstock, A. Chang, J. Chen, A. Child, D. Fishel, N. Johnstone, K. Ketlogetswe, B. King, C. Ledezma, J. Levison, N. Martin, N. Michaelson, A. Mostaghimi, R. Peragallo, E. Pinto-Wong, R. Roberson, H. Rolls, R. Romanow, M. Said, J. Shoe, A. Warren, B. White, M. Wrzosek, C. Wykoff; and Harvard faculty: T. Aretz, R. Arky, M. Badaracco, L. Barnes, J. Beck, P. Black, D. Cardozo, A. Counter, J. Da Silva, J. Dowling, D. Federman, J. Hafler, J. Halamka, G. Harper, S. Hyman, N. Karimbux, B. Kinane, R. Leffert, D. Lowenstein, J. Martin, A. Peters, C. Prout, L. Raymond, M. Samuels, D. Standaert, W. Taylor, G. Thibault, D. Tosteson, M. Tsuang, B. Woo. This work was supported in part by the Harvard Provost Award for Interfaculty Collaboration, the Harvard Provost Award for Innovations in Instructional Technology, the Harvard Interfaculty Neuroscience Program, the Francis Weld Peabody Society, and Harvard Medical School.

References

Blumenthal, D. (2002). Doctors in a wired world: Can professionalism survive connectivity?. *Milbank Quarterly* **80:** 525–546.

Dewey, J. (1994). Thinking in education. In L.B. Barnes, C.R. Christensen & A.J. Hansen (eds.) 3rd ed. Boston, MA: Harvard Business School Press.

Educational Computing (2003). *MyCourses Tutorial: A User Guide for Tutors; Using Educational Technology to Enhance Case-Based Learning*. < http://mycourses.med.harvard.edu/ResCourses/ MyCourses/ TutorialUserGuide.pdf > . Accessed 10/1/03. Cambridge, MA: Harvard Medical School.

Fleiszer, D.M., Posel, N.H. & Steacy, S.P. (2004). New directions in medical e-curricula and the use of digital repositories. *Academic Medicine* **79:** 229–235.

Franke, R.H. & Kaul, J.D. (1978). The Hawthorne experiments: First statistical interpretation. *American Sociology Review* **43:** 623–643.

Frisse, M.E. (1990). The case for hypermedia. *Academic Medicine* **65:** 17–19.

Glick, T.H. & Armstrong, E.G. (1996). Crafting cases for problem-based learning: Experience in a neuroscience course. *Medical Education* **30:** 24–30.

Glick, T.H. & Moore, G.T. (2001). Time to learn: The outlook for renewal of patient-centered education in the digital age. *Medical Education* **35:** 505–509.

Hallgren, R.C., Parkhurst, P.E., Monson, C.L. & Crewe, N.M. (2002). An interactive, web-based tool for learning anatomic landmarks. *Academic Medicine* **77:** 263–265.

Heidger, P.M., Dee, F., Consoer, D., Leaven, T., Duncan, J. & Kreiter, C. (2002). Integrated approach to teaching and testing in histology with real and virtual imaging. *Anatomical Record* **269:** 107–112.

Hersh, W.R., Junium, K., Mailhot, M. & Tidmarsh, P. (2001). Implementation and evaluation of a medical informatics distance education program. *Journal of the American Informatics Association* **8:** 570–584.

National Education Agency (2002). *Quality on the Line: Benchmarks for Success in Internet-based Distance Education*. < www.ihep.com/Pubs/PDF/Quality.pdf > . Accessed 10/1/03. Washington, DC: National Education Association.

Parker, M.J. & Seifter, J.L. (2001). An interactive,web-based learning environment for pathophysiology. *Academic Medicine* **76:** 550.

Quattrochi, J., Pasquale, S., Cerva, B. & Lester, J.E. (2002). Learning neuroscience: An interactive case-based online network (ICON). *Journal of Science, Education and Technology* **11:** 15–38.

Shaffer, K. (2004). Teaching anatomy in the digitized world. *New England Journal of Medicine* **351:** 1279–1281.

Swaak, J. & De Jong, T. (2001). Learner vs. system control in using online support for simulationbased discovery learning. *Learning Environment Research* **4:** 217–41.

Vozenilek, J., Huff, J.S., Reznek, M. & Gordon, J.A. (2004). See onedo one, teach one: Advanced technology in medical education. *Academic Emergency Medicine* **11:** 1149–1154.

Wenger, E. (1996). Communities of practice: The social fabric of a learning organization. *Healthcare Forum Journal* **39:** 20–26.

Wenger, E. (2001). *Supporting Communities of Practice: A Survey of Community-Oriented Technologies,* Version 1.3. < http://www.ewenger.com/tech > . Accessed 3/11/02.