

## Article

# Globalizing the Science Curriculum: An Undergraduate Course on Traditional Chinese Medicine as a Complementary Approach to Western Medicine

Robert Yuan\* and Yuan Lin<sup>†</sup>

\*Department of Cell Biology and Molecular Genetics, University of Maryland, College Park, MD 20742;

<sup>†</sup>Marco Polo Technologies, Bethesda, MD 20817

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A course has been created to examine the ways in which China and the West have approached human health and medicine. Though fundamentally different, these two systems are complementary in a number of ways. This course is a model for a global science course in an educational initiative that incorporates Asian themes into science and engineering courses. The course is designed around an active-learning platform that has as major components: team research projects, oral presentations, role play, and peer-review. The students investigate concepts of scientific proof, clinical efficacy, and the functional structure of two very different systems of health and medical care.

## INTRODUCTION

The globalization of science and technology and all of their myriad applications is a reality of today's world. This sea change represents a major challenge for the education of U.S. scientists and engineers. A recent report on the Science and Engineering Workforce by the National Science Board (National Science Board, 2003) states that "the U.S. Government should move expeditiously to ensure the development of a more effective, coordinated framework for its international science and engineering research and education activities." The report specifically recommends that future U.S. policies should:

- Strengthen the capacity of U.S. research universities to sustain their leadership role in increasingly competitive international S&E education;
- Strongly support opportunities for American students and faculty to participate in international S&E education and research.

It remains to individual universities to convert such lofty policy recommendations into new educational initiatives.

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Address correspondence to: Robert Yuan (ryuan@umd.edu).

One approach developed by the University of Maryland, College Park, a R1 research university, is the East Asia Science and Technology project (abbreviated EAST) ([www.oit.umd.edu/AS/EAST/ABOUT.HTM](http://www.oit.umd.edu/AS/EAST/ABOUT.HTM)) which has introduced East Asian themes into science, technology, engineering, and mathematics (STEM) courses.

EAST used various pedagogical approaches that included: new Asian theme modules within existing courses, new courses that provide an East Asian perspective to STEM, and transnational courses that were developed in collaboration with Asian universities. During the period 2002 to 2004, EAST fellows modified or created 18 courses, with an additional five courses under development. The total enrollment in those courses was around 1600 students (Yuan *et al.*, 2007).

This article describes the development of one such course, Traditional Chinese Medicine. A Complementary Approach to Modern Medicine. This was an interdisciplinary, cross-cultural course that examined the philosophical underpinnings, theoretical assumptions, and practical therapeutic approaches of traditional Chinese medicine (TCM) in contrast to modern Western medicine. In this context interdisciplinary included the social sciences and humanities. Medicine also needs to be understood in the context of social, legal, and economic factors. This TCM course was crafted as a model not only for EAST but for other globalized STEM courses.

## TCM: A PEDAGOGICAL APPROACH

The principal objective of this course was to create a robust learning platform that uses active learning to provide a window into the interface between science and society. This learning platform drew on much of the recent research on how students learn and integrate knowledge from different disciplines (National Research Council [NRC], 2000, 2003; Narum, 2004). Incorporating diversity into STEM courses has been approached by teaching the science process (Dirks and Cunningham, 2006). We have used extensive experience in two previous courses, *Biology and Culture*, and *Biotechnology in Asia*, to create a much more complex course design. *Biology and Culture* used problem-based learning to look into the use of biology to solve major problems in developing countries. *Biotechnology in Asia* used research projects to examine how key Asian countries used biotechnology to promote economic development. The biggest challenge in the TCM course was that most students were at least familiar and comfortable with Western medicine, and found it difficult to conceive of alternative systems of medicine.

This course was designed and taught as an honors seminar. It had a limited enrollment of 20 students who came from a variety of majors (science and nonscience). Its pedagogical approach was directed to raising the biology literacy of a group of science and nonscience majors (Klymkowsky, 2006). Honor students are among the best students at the university. Science majors can use this course to fulfill a diversity requirement whereas nonscience majors can use it to fulfill a nonlab biology requirement. The semester-long course met twice a week for 1.25 h each time.

Our course construct had a number of essential features:

1. A teaching team: two principal instructors covered most of the conceptual, scientific, and health delivery aspects of the material. Both had experience in the creation of a biotech company that used TCM as a basis for new drug discovery. In addition, there were four practitioners who were involved in specific aspects of TCM, e.g., Tai Chi, medicinal foods, acupuncture, a lecturer in Asian art, and a librarian.
2. Experiencing TCM: certain class sessions were designed to expose students to Asian culture and to some of the TCM practices, e.g., participating in Tai Chi exercises, the tasting of medicinal foods, the application of needles to specific body points, and the preparation of a TCM herbal formulation.
3. Interdisciplinary research: student teams did research into a variety of therapeutic approaches to disease, their mechanism of action, and their efficacy on patients. These tasks also included an examination of the broader framework of the medical system. Team research was the basis for the course assignments.
4. Evaluation: this was divided into two components. One was intrinsic to the course. The three student team research projects ramped up in complexity and difficulty during the semester, providing a measure of student learning. This was also true of the scenarios for role playing. If students had not mastered the material in the earlier tasks, they would be unlikely to perform well in the later ones. The other component involved a pre- and postcourse questionnaire about the course as well as a focus group. This provided valuable

information on the effectiveness of the course and student response to the methods used.

Supplemental Material A shows the course schedule, which is divided into four major modules. The first one (classes 1 to 6) examines the cultural differences between China and the West and reviews the development of modern Western medicine, particularly over the past 300 yr. A major conceptual hurdle for American students is to recognize that history and culture mold the development and application of science (medicine in this particular case). A successful solution was a lecture on Asian art where visual images of Asian landscapes and black bulls, and prose images of haiku showed how the conventions and values of a culture defined artistic expression. Acceptance of this truth makes it easier to look at science from different philosophical perspectives. The second module (classes 8 to 15) reviewed the history of TCM, its conceptual framework, and its practices. The third module (classes 17 to 19) looked at the efforts made to modernize TCM using Western science. And the final module (classes 21 to 25) looked into the social, legal, and economic hurdles that face TCM in the United States. Of 30 class sessions, 18.5 were dedicated to lectures and demonstrations, 6.5 to student presentations, five to role play, and a final session to course evaluation.

### *A Course Design Based on Active Learning*

Work in teams is often used in STEM courses (McInerney and Fink, 2003). We have deliberately selected our four-person teams so that they were mixed by gender, race, ethnicity, and field of study. We have used this approach successfully both in microbiology and honors courses (Yuan et al., 1997; Yuan and Benson, 1998; Yuan, 2000). The learning platform is less dependent on lectures (Knight and Wood, 2003), and is built around powerful active-learning techniques. Problem-based learning (Wilkerson and Gijsselaers, 1996) and case studies (Herreid, 1994) enabled students to develop solutions to scientific problems. Writing assignments have been shown to improve critical-thinking skills (Taylor and Sobota, 1998; Kokkala and Gessell, 2003; Quitadamo and Kurtz, 2007), which can be maximized when used in conjunction with oral presentations (Yuan, 2000). Role plays have been found to be powerful tools in law and business education, and perhaps more relevantly in medical education (Joyner and Young, 2006). However, role plays have rarely been used in STEM courses. We made a major effort to adapt these techniques to enable students to gain an interdisciplinary and cross-cultural perspective. Furthermore, all of these were integrated into a single course design that incorporated role play as a major element.

Table 1 summarizes the major active-learning components of the TCM course with their objectives and targeted skills.

### *Class Demonstrations*

One way in which students can experience some of the key elements of TCM is from TCM practitioners. All of these sessions by practitioners combined the conceptual framework with a demonstration. In the latter, students experienced tastes and smells, body movements, acupuncture, and preparation of a herbal formulation. An instructor familiar with the TCM theories about the health and medicinal ef-

fects of various foods not only talked about them but also provided samples of various food categories. To experience Tai Chi, which combines physical exercise with holistic balance and meditation, a Tai Chi master had the class practice selected movements for a whole class session. The manipulation of precise points along invisible meridians in the human body is the basis of acupuncture. In class, students experienced “needling” and noted that it was both painless and generated sensations along pathways in the body. Finally, the students spent a session making an herbal formulation that looks somewhat crude in comparison with modern medications. They took away a jar of it that can be used as an effective first aid remedy for the treatment of burns, wounds, and allergy.

### Research Projects

The course was centered around problem-based learning, which is embodied in the three research projects that were carried out during the semester. The three projects increased in difficulty and complexity and were modeled after published works. The first was assigned and was the same for all teams. The second and third ones were chosen by each team from a list provided in class or were generated by a team. The same topic was developed in projects two and three. All of them required research using primary sources and discussions with experts, development of tables and figures, bibliographies, and writing of a report (Lynd-Balta, 2006). The three assignments were:

**Project 1.** The writing of a news article on TCM for a newsweekly such as *Newsweek*. The objective was to present the philosophy and principles of TCM and how they are used on human patients. The relevance (or lack thereof) of TCM to modern Western medicine needed to be presented. The article is directed to a general audience with a limited knowledge of science and medicine, and ignorant of TCM, its principles, and therapeutic approaches. The article had to be self-contained, use a lay person’s vocabulary, and be both readable and relevant to the concerns of an average reader. Although the theme was the same for all five teams, the challenge was to make TCM interesting, comprehensible, and relevant with imaginative use of graphics.

**Project 2.** A review paper for a medical journal that gave a critical evaluation of a TCM approach to a particular medical condition or disease. Each team selected a specific subject

(e.g., acupuncture and its use in pain management; treatment of hepatitis with various TCM herbal formulations). The review was directed toward medical researchers and clinicians who were assumed to have a critical view of TCM. This assignment required the presentation of scientific evidence and proof of clinical efficacy and a comparison with the current best practices in Western medicine.

**Project 3.** A chapter in a book on the changing nature of health care in the United States. The objective was to examine how legal, social, and economic characteristics of the U.S. health care system affect the use of TCM. The audience consisted of policy makers and medical and health care administrators. Some of the subjects were regulatory drug approval of formulations consisting of mixtures of different herbs, the patenting of formulations or devices that have been in the TCM literature for centuries, insurance reimbursement for TCM procedures, and therapeutic formulations. One hot topic was integrative medicine that combines the use of Chinese and Western medicine. The teams were urged to consider the proof of concept presented in their project 2.

### Oral Presentations

The oral presentations were an integral part of the preceding research projects. Each student presented one of the three team projects in an appropriate simulated format (e.g., a talk at a university club or to a community group, a presentation at a biomedical conference, a seminar to a government policy group or industry organization). Each presentation lasted 30 min including 10 min for questions and comments. The students learned that while the content of a written report and a briefing may be the same, the approach and skills required are markedly different.

### Role Play

We introduced role play into our Biotechnology in Asia seminar with excellent results. The role-play component was extensively reworked and expanded in successive offerings of the TCM course. Its purpose was for the students to use the TCM knowledge learned in the course in a set of five scenarios. Each scenario was an abbreviated and simplified description of a real-life situation, and it was fully scripted including the background and role of each player. There were two teams of four players each, one of them reflecting

**Table 1.** Principal course elements

Component	Objective	Skills
Class demonstrations	Exposure to key TCM practices	Being open to new health techniques, assessing quality of experience
Research projects	Gain an understanding of TCM theory and practice and its potential role in U.S. health care	Interdisciplinary & cross-cultural research using primary sources, writing different types of documents for different audiences
Oral presentations	Presentation of research reports	Oral communication skills addressing different audiences, handling Q&A
Role play	Handling situations from different disciplinary & cultural scenarios	Coping with different disciplinary values, scientific criteria and cultural values, comparing with real outcomes

the priorities and values from the TCM side, the other looking at it from the U.S. perspective. The other students and the instructors formed the audience.

There were three elements in the role play:

- Team preparation of its strategy and arguments;
- Playing out the scenario;
- Class discussion of the scenario that has been acted out and comparison with the outcome in the real situation. Online commentaries about the scenario considering some of the broader implications were also used in the course.

Table 2 summarizes the five scenarios that were used in the course. All of them were interdisciplinary and reflected fundamental differences in how different societies look at health, wellness, disease, and cure. The first three scenarios dealt with the nature of scientific knowledge and proof. The first one was an academic situation that examined the credibility of TCM and the arguments for and against its introduction into the medical curriculum. The second addressed how to evaluate and integrate traditional Chinese knowledge with modern biology and clinical practice. For the Chinese, efficacy is more important than understanding the basic science whereas in the United States basic knowledge is necessary before clinical applications can take place. The third brought into sharp conflict the synergistic properties of a Chinese formulation composed of multiple ingredients versus the clearly defined activity of a pure chemical drug (i.e., the “silver bullet”). The fourth was one in which a Chinese conglomerate wished to use modern technology to develop novel forms of TCM for its own Chinese market while its U.S. subsidiary (which had the technology) would prefer to develop prescription drugs for the U.S. market. In the latter case, this raised the major challenge of meeting all

of the regulatory standards of the U.S. Food and Drug Administration. Finally, the last scenario looked at the value that a society places on innovation and the commercial monopoly that a patent provides for a novel drug in the United States. Central to this was the question of how knowledge of a medicinal formulation that has been in the public domain in China for centuries can meet the standards of novelty for patenting in the United States. Without a patent, U.S. firms and financial institutions would be unwilling to invest in such a product.

The role-play process enabled each student team to participate directly in two scenarios. They not only got to use their knowledge in life-like situations but may also have had to adopt positions and act in a manner that went against their own personal views. The comparison of each role play with the outcome in the real situation was invaluable in two ways. The students recognized how the issues they were learning were applicable to real life, and how their problem-solving abilities compared with those of actual professionals (mostly somewhat deficient, but on occasion better). In either case, it required mastery of information from multiple fields.

### Teaching Tools

The course had one general textbook, Ted J. Kaptchuk’s “The Web That Has No Weaver.” However, by necessity the research materials for each team were pretty well customized based on their selected topics. A librarian who was a member of the teaching team assisted the teams in identifying appropriate documents and books. The course had a website that was used to post information on references and as a communication link between students, instructors, and practitioners. It was vital in the follow-up discussion after role playing and in the evaluation process.

**Table 2.** Role plays

Scenario	Objective	Differing positions
Meeting of curriculum committee at major U.S. medical school	Consideration of proposal to add a TCM course to curriculum	<ol style="list-style-type: none"> <li>1. Group led by dept. chair that has developed a TCM course proposal</li> <li>2. Dean and members of curriculum comm. with traditional educational views</li> </ol>
Collaboration between biomed research groups at a Chinese and a U.S. university	Validation of TCM by Western methods	<ol style="list-style-type: none"> <li>1. Chinese group draws on existing TCM knowledge</li> <li>2. U.S. group focuses on modern biological theory and technology</li> </ol>
Licensing agreement between U.S. pharma co. & Chinese biotech co.	Evaluation of Chinese research data and determination on its use to develop a modern drug	<ol style="list-style-type: none"> <li>1. Chinese focus on a mixed formulation of several herbs</li> <li>2. U.S. desire to purify a single chemical</li> </ol>
Strategy plans for a U.S. biotech company fully owned by a Chinese conglomerate	Introduction of novel TCM products into the marketplace U.S. vs. Asian market	<ol style="list-style-type: none"> <li>1. U.S. subsidiary wants to develop FDA-approved drugs based on TCM</li> <li>2. Chinese group wants to modernize the TCM products for sale in China and Asia</li> </ol>
Submission of a TCM formulation for a U.S. patent	Application for a TCM formulation that has been in the Chinese pharmacopeia for many decades	<ol style="list-style-type: none"> <li>1. TCM company bases novelty on novel properties of formulation</li> <li>2. Patent office and attorneys argue that this is prior knowledge</li> </ol>

The honors students were academically accomplished, and the course was designed to provide them with a significant challenge. The grades in this course were based on a combination of team tasks, which included three research projects and two role plays, and an individual oral presentation. In addition, students were evaluated for their participation both in class and online.

## COURSE EVALUATION

Our evaluation of a science-based course that brought together both science and nonscience disciplines and introduced different philosophical, cultural, and social values was based on three questions:

1. Did the students acquire an understanding of the criteria for proof as it relates to basic science and to clinical efficacy? And how did such standards apply to a different system such as TCM?
2. Did students recognize the ways in which cultural and social values, economics, and government policy affect health and medicine?
3. Did the educational platform used in this course promote active learning? And which elements were most effective in meeting that objective?

Most of the evaluation was carried out in the latter two semesters because the course was still going through its trial phase during the first semester. The evaluation was divided into several parts.

The first examined active learning as it related to the three team research projects and oral presentations and the role playing. Each successive team project required increasing amounts of research and higher levels of understanding and integration of knowledge.

Assignment #1 required a good understanding of the philosophy and principles of TCM and compared them with those of Western medicine. There was a strong reliance on colloquial language and graphic materials.

Assignment #2 examined from the perspective of modern Western science the scientific evidence in support of TCM for the treatment of a specific medical problem. Each team selected its own topic. This project required the use of scientific evidence and clinical proof to validate the medical use of TCM for this indication. The report required a familiarity with scientific concepts and terminology.

Assignment #3 built on assignment #2 but went beyond scientific and clinical evidence to look at the legal, economic, and social framework in the United States that TCM would have to face in a specific application (e.g., the use of medicinal foods is dramatically different from the prescription of herbal formulations as drugs).

In a standard course, students would be expected to improve their performance as the semester progresses. In the case of the TCM course, the students had little knowledge of content and of the assigned tasks and the difficulty of the tasks increased during the semester. If learning did not occur, we would expect the performance to go down. Table 3 showed that in semester 2, the averages for the three team projects went from 90.8% to 92.5% to 89.6% in the final one. In semester 3, the averages went from 92.8% to 81.8% to 91.7%. In both cases, the students were able to maintain the

quality of their work in the face of higher requirements though in semester 3 there was a significant drop-off between assignments #1 and #2. The oral presentations gave each student the opportunity to articulate the major conclusions of his/her team projects. Almost all of the students were able to do this at a good or excellent level. Performance in the research projects and accompanying presentations gave a clear indication that the students had mastered the basic scientific, interdisciplinary, and cross-cultural concepts of the course.

Role play complemented the research projects in that each team participated in two separate scenarios that were based on real-life situations. Such efforts required the processing of the research and writing that had been done and applying them to problem scenarios. In each scenario, there were different possible outcomes that required convincing the opposing side and negotiating working agreements. The role plays were evaluated *qualitatively* on the basis of the work in the scenarios and the follow-up discussions in class and online. Students were rated as average, good, or excellent (see Table 3). In semester 2, eight students were excellent, six good, and seven average. The results were better in semester 3 where the corresponding numbers were 10, nine, and three. In both cases, more than half of the students performed above average, which was remarkable given the complex nature of the role plays. This provided evidence that the students had sufficient understanding of the material and were able to use it operationally in complex work situations.

At the end of the course, the students completed an evaluation form, and the last class session was used for a focus group run by staff from the university's Center for Teaching Excellence. In the questionnaire, students were asked to evaluate their knowledge of a set of topics relating to TCM and Western medicine before and after the course. The topics were: history, philosophy, theory, homeostasis, diagnosis, infectious diseases, "silver bullet," acute diseases, chronic diseases, acupuncture, herbal formulations, food and exercise, FDA regulation, and patents. On average, the students felt that their initial knowledge of Western medicine (as regards these topics) was around 60% and increased to 80% during the course. In the case of TCM, their initial knowledge was <10% and rose to approximately 95% after the course. Though the students generally found the course difficult and demanding, their course grades would indicate that they had risen to the challenge. A peer-review tool was used to determine the contribution of each student to the team projects and was then used to convert team grades into individual grades. The peer-review also pro-

**Table 3.** Class grades

	Assignment #1	Assignment #2	Assignment #3	Class part
Semester 2	90.80%	92.50%	89.60%	Excellent: 8 Good: 6 Average: 7
Semester 3	93.80%	81.80%	91.70%	Excellent: 10 Good: 9 Average: 3

vided information on the interactions between team members. In semester 2, 17 of them received an A and three of them received a B. In semester 3, 20 of them earned an A and two of them got a B.

The student questionnaires, the focus group, and voluntary comments provided a strong endorsement of our course design. All of the students indicated that their purpose in taking the course was to gain an understanding of the theory and practice of TCM. All of them felt that the course had met those expectations in defining TCM as an integral, holistic system for human health. A fourth also gained a deeper understanding of Western medicine and of the multiple elements that define a health care system. A similar number commented on the potential and challenges of integrative medicine where the use of Western medicine and TCM are combined (e.g., surgery combined with acupuncture for pain management). Close to a third of the students indicated that they now took a much more serious view of the health care system in the United States and how it impacts their own personal health. About the same number felt that they were now much more open to complementary systems of medicine and, in particular, were receptive to TCM's ideas of maintaining health and being treated with TCM.

Finally, it is important to understand how the overall course strategy and its component parts worked to achieve the outcome described above. The student evaluations and focus group indicated that the most effective elements were:

- The participation of TCM practitioners and the opportunity for students to have hands-on experience with key TCM practices (e.g., acupuncture, Tai Chi, herbal preparations). There was a widely held view that the lecture on Asian art was catalytic in defining the impact of culture on intellectual activity.
- The team projects that were directed toward integrating different disciplinary material to understand TCM.
- Role plays in which student teams were able to participate in real-life scenarios that emphasized the advantages and challenges of TCM as compared with Western medicine.

Criticism of the course was directed at the lectures and to some degree at the work in teams. It is clear that the more active-learning components were more appealing to the students, but it must also be recognized that the lectures by the two key instructors represented the essential glue that bound the disparate elements (Klionsky, 2004). The team approach was an essential method in that it enabled the students to handle a large work burden and exposed them to the necessity of working with peers that differ in their aca-

demically, racial, and cultural backgrounds (which was deemed important in the peer-review).

## CONCLUSION

Our objective with the TCM course was to create a science-based course that was culturally diverse and introduced nonscience majors to scientific concepts and methods of proof while making STEM majors sensitive to the issues that link science and society. The topic of health and medicine is ideal for this purpose and touches the personal lives of the students and those who are closest to them.

Philosophically, the course did not present TCM in opposition to modern Western medicine but as a complementary approach to it. Table 4 shows some of the principal differences between these two schools of medical thought. Western medicine identifies functions in relation to body structures or tissues, defines disease as malfunctions or infections of such structures, and uses invasive methods to eliminate the causes of the disease. The ideal is to find a "silver bullet" that will specifically remove the cause of the disease or its symptoms. The efficacy of the treatment or drug should be rapid and applicable to a large population of patients; it has generally been most successful for acute illnesses. The medical team comprises generalists, specialists, and laboratory technicians, each of whom examines the patient from his/her perspective. TCM perceives the body as a whole where health is defined as a balance between its many components and functions. Disease occurs when this balance is disrupted and treatment requires the restoration of this balance. Prevention through the use of specialized foods, Tai Chi, and acupuncture is critical, and treatment is by definition gradual because it requires bringing the body back into balance. The patient is seen as an individual (not a patient group), and wellness or therapy is customized. The basic relationship is that between the doctor and the patient because the former has to be familiar with the lifestyle and events of the patient's life. These two systems of thought reflect differences in history, culture, and society. The students, as well as the current generation of biomedical experts, are challenged by some of the central issues. For example, how does one deal with the contradiction of having acupuncture being effective as an anesthetic procedure while being totally ignorant of its mechanism of action? Is it reasonable to adopt integrative medicine and combine TCM and Western medicine, e.g., using chemotherapy to treat cancer and using a TCM formulation to suppress nausea and discomfort and promote appetite? Several quotes from students serve to emphasize what they have gotten from the course:

**Table 4.** Two different medical worlds

	Western medicine	TCM
Human body	Structure & function cells, tissues, organs	Holistic entity
Objective	Treatment of disease & affected system	Maintaining or restoring homeostasis; prevention
Treatment	Fast. Most effective on acute diseases	Gradual. Directed toward chronic conditions
Patient	Considered as a group	Customized treatment
Doctor	Interaction of generalist, specialists & lab techs	Relationship between doctor and patient

On culture: "Through the means of an extensive research project, class role-plays, and guest presentations, I expanded my learning experience beyond discussing facts to indulging myself in a culture other than my own."

On mixed teams: "My diverse group was an advantage and an eye-opening experience. My Chinese group member in particular had a different interpretation on everything, which truly convinced me that different cultures create different attitudes and bases of thought."

On the global workplace. "I feel as though the course came along at just the right time. . . . Its lessons were able to stay with me throughout my college career and gave me the tools I need to successfully work in any environment."

The course has been taught for three semesters, and it has met with significant success. It is not unusual to have students earn good grades and yet feel that they have acquired little new knowledge. Here there was a convergence of good academic performance and a sense of satisfaction about having mastered the basics of TCM and drawing contrasts with our system of Western medicine. The course design and its active-learning platform using multiple techniques was an effective working model for other global STEM courses such as those in the EAST program.

It should be evident that this course required a great deal of work and resources from both faculty and collaborators, and it had targeted a small group of excellent and highly motivated students. Much remains to be done in adapting this model so that it can be applied to other courses, in particular those with a large and diverse student body. This challenge is, however, one that must be met by our colleges and universities in preparing a globally competitive work force as recommended by two recent major reports (National Science Board, 2003; National Academy of Sciences, National Academy of Engineering and Institute of Medicine, 2005).

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