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Using immersive healthcare simulation for physiology education: initial experience in high school, college, and graduate school curricula

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Oriol NE, Hayden EM, Joyal-Mowschenson J, Muret-Wagstaff S, Faux R, Gordon JA. Using immersive healthcare simulation for physiology education: initial experience in high school, college, and graduate school curricula. *Adv Physiol Educ* 35: 252–259, 2011; doi:10.1152/advan.00043.2011.—In the natural world, learning emerges from the joy of play, experimentation, and inquiry as part of everyday life. However, this kind of informal learning is often difficult to integrate within structured educational curricula. This report describes an educational program that embeds naturalistic learning into formal high school, college, and graduate school science class work. Our experience is based on work with hundreds of high school, college, and graduate students enrolled in traditional science classes in which mannequin simulators were used to teach physiological principles. Specific case scenarios were integrated into the curriculum as problem-solving exercises chosen to accentuate the basic science objectives of the course. This report also highlights the historic and theoretical basis for the use of mannequin simulators as an important physiology education tool and outlines how the authors' experience in healthcare education has been effectively translated to nonclinical student populations. Particular areas of focus include critical-thinking and problem-solving behaviors and student reflections on the impact of the teaching approach.

mannequin simulation; technology-enhanced education

> *The rapt attention and engagement observed in informal learning environments may be not only a prerequisite or proxy for learning, but may also be an end in itself insofar as this fulfills the educational goal of exposing students to novel ideas and experiences and fosters post graduation commitments.*
>
> Lee Shulman (14)

WHILE INFORMAL LEARNING is prevalent and powerful across the human lifespan, the use of naturalistic processes to bolster formal science education is relatively limited. A Committee on Learning Science in Informal Environments convened recently by the National Research Council studied informal nonclassroom learning experiences such as field trips to museums or zoos. They concluded that such experiences are "rich with real-world phenomena…where people can pursue and develop science interests, engage in science inquiry, and reflect on their experience through sense-making conversations" and support informal environments for science learning (3).

Building on calls to better understand the impact of both informal and formal learning in the design of educational environments by Bransford et al. (1), we created an experiential education platform in which high school, college, and graduate students were asked to manage complex simulated medical case scenarios.

Patient Simulation: From Heathcare Education to Science Education

Simulation with patient simulators for medical education. Robot mannequins currently used in medical education have realistically simulated heart sounds, pulses, breath sounds, chest rise, pupil changes, and other bodily functions (4). They can be programmed or controlled to represent human physiology, both normal and abnormal, with reasonable accuracy (5). A standard hospital vital signs monitor is at the head of the bed of the mannequin and, in real time, continuously displays the mannequin's blood pressure, heart rate, respiratory rate, and oxygen saturation. These mannequins are able to talk and have a conversation with the participants, with a simulation specialist projecting his or her voice through a microphone connected wirelessly to a speaker in the mannequin's head. The instructor, hidden behind a curtain or one-way mirror, directs the case by speaking as the patient, offering a realistic clinical history and symptoms (such as lightheadedness when the patient's blood pressure is too low), and controlling the physiological parameters.

Simulation cases are written based on the specific goals and objectives of a course. The objectives are then matched with an appropriate clinical scenario. For example, to teach about the autonomic nervous system, a case on cocaine toxicity could be used. A typical simulation session would begin with orienting the students to the mannequin and the simulation environment. A case would last 10–30 min in length. At the end of each case, a content expert (who had been observing) would lead the trainees in a group discussion to debrief the case, reflecting on their responses to the scenario while covering the clinical content, behaviors of the participants, and the logic, judgment, and all-important learning dimensions of the scenario. The core skills of critical thinking, problem solving, situational analysis, data collection, and generating and testing hypotheses are the principal skills that the students must bring to bear to achieve their goal of helping the patient.

With the expanded commercial availability of patient simulators, medical schools, nursing schools, allied health professional schools, and hospitals have incorporated the routine use of simulation as an educational tool to enhance clinical education and provide a safe environment in which to practice.

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Educators reason that trainees could benefit from practicing skills and managing cases using mannequins as patients embedded in a simulated medical environment, a context similar to the one in which the knowledge and skills are eventually going to be used.

Participating in the care of simulated patients has been shown to be a powerful experience, evoking emotional engagement and engendering clinical learning that previously could only be obtained through real-time clinical care (6). In a previous work (8), we described the use of mannequin simulators to bring the typical medical school paper case "to life," allowing the cases and clinically relevant basic science concepts to emerge as they would in clinical practice.

Building on the experience of using simulation for clinical students, in 2001, we began bringing novice (preclinical) medical students to the simulation laboratory and established the concept of using the clinical encounter as an authentic problem-solving experience, asking them to rely on practical knowledge, basic logic, and situational analysis, even in the absence of any prior clinical knowledge or training (9). These students also found the experience to be uniquely powerful. According to one college student:

> A truly hands-on experience, working with Stan [the mannequin simulator] is as close to the real thing as one can get. When he talks, breaths, and his vital signs change, he elicits the fear and anxiety that would come with working on a live patient for the first time. For instance, I felt my own heart race as I struggled with colleagues to relieve Stan's tension pneumothorax and stabilize his blood pressure. At that moment, he was just as animate as you and I, and this is what makes this educational experience so special. Stan brings together all of the more or less traditional methods of instruction; that is books, lectures, smart screens, etc., but in a way that is meaningful and truly stimulating.

Simulation with patient simulators for basic science education. Adapting the patient simulator to be an educational tool for nonclinicians developed from a 1-wk summer immersion program we piloted in 2005 (7). This experimental curriculum was designed to expose young students to the problems and complexity of clinical medicine using mannequin simulators as patients in a realistic medical environment. From observing these students work through the problems they encountered and reading their daily journal reflections, it was clear to us that this experience was indeed "fostering biomedical literacy" and, broadly speaking, an interest in science and scientific inquiry. This learning also engendered the self-confidence that allowed the participants to imagine themselves pursuing the education necessary to follow such a career path. According to one high school student:

> Best of all, I brought away from this course an experience and a profound enthusiasm and desire to practice medicine. I had never felt the adrenaline rush and the satisfaction of solving an intellectual puzzle which diagnosis entails. I love this way of thinking. I love the connection of people and facts. This experience was unparalleled by my volunteering experience or course work. This program gave a unique opportunity to understand the practice of medicine from an interactive experience. It taught me so much about teamwork and patient care and communication, and it will be invaluable in my career path.

Using simulation for these nonclinical students demonstrated that attempting to help a "person" in distress, when no expert was available to take over, was a powerful "authentic problem" from which learning emerges. This learning strongly resembles the "intent participation" or "learning by observing and pitching in" that occurs in the natural environment, as described by Paradise and Rogoff (13), where learning happens when real problems are encountered, analyzed, and acted upon, producing outcomes that validate or refute the analysis and actions. This type of learning is not directed by a teacher but rather emerges from the experience itself. More comments from nonclinical students include the following:

> I'm hungry for more cases. Each case is, as someone described, a puzzle, and you have all the pieces. You just have to assemble them. The tricky part is that you have to gather the pieces up yourself.
>
> This kind of basic science, and its manifestations in cases, really makes you excited to learn it, learn it well, to remember, and practice it.
>
> We learned from our own mistakes and uncertainties; therefore we were able to generate our own lessons that we took away and really remembered.

Conducting Effective Clinical Simulation for Nonclinicians

Components of simulation-enabled physiology education for the nonclinician. Building on the observed and reported impact of the original week-long immersion program, we created three different formal physiology education programs for high school, college, and graduate students using clinical scenarios with simulated patients in a simulated medical environment. There are common elements in all levels of simulation-enabled physiology programs, which are detailed as follows.

THE SESSIONS WITH THE PATIENT SIMULATOR ARE INTEGRATED INTO A FORMAL CREDIT-BEARING COURSE ON PHYSIOLOGY. The courses have a predetermined set of learning objectives that are presented in classroom didactic sessions. The didactic sessions may be lectures, small-group tutorials, or seminars, but the content topics are presented in a sequential manner, and the case scenarios for the simulation sessions are designed to be relevant to the ongoing classroom discussion. For example, if the classroom topic is respiratory physiology, the case scenario may be asthma or pneumonia. The objectives of the didactics session would include understanding the exchange of carbon dioxide and oxygen during normal lung ventilation. Then, during the simulated pneumonia case, the respiratory gas exchange would be disturbed, as revealed by a low oxygen saturation, and there would be an abnormal chest X-ray and abnormal breath sounds due to the lungs being full with infected fluid and secretions. These abnormal findings would lead the student to consider of the impact of fluid in the lungs on respiratory gas exchange.

THE STUDENTS MANAGE THE CASES AS A TEAM. Ideally, there should be 6–8 students/team. Regardless of the classroom structure, the simulation sessions are carried out in small groups of 12–16 students. Usually (time permitting), two similar but contrasting cases are presented, and the group of 12–16 students is divided into 2 teams, with the first team managing the first case while the other team observes; the teams then switch roles. Contrasting cases, for example, could be anterior myocardial infarction paired with inferior myocardial infarction or asthma paired with pneumonia. (Note: the high school course uses only one case at a time due to time constraints.)

THERE IS ALWAYS A CLINICIAN EXPERT AND AN INSTRUCTOR FROM THE PHYSIOLOGY COURSE PRESENT. The clinician expert is necessary to know how the physiological parameters of the mannequin should be manipulated given the student's actions. The classroom expert is necessary to guide the discussion of the physiological objectives of the course. A clinician with an advanced scientific background can serve both roles, although two complementary faculty members working together provide substantial programmatic benefit, and is essential for the high school program.

THE STUDENTS MANAGE THE CASES WITHOUT ANY INSTRUCTION FROM EXPERTS. The cases play out in as realistic a manner as reasonable. A clinician expert is behind the scenes, being the voice for the patient, directing the mannequin's physiological responses, and observing the students as they struggle to figure out what is wrong and decide what to do. The clinician is counseled not to intervene by giving answers or assuming responsibility from the students but rather to ask questions that may help propel or expand the student's own analysis. This approach is similar to the scaffolding process observed in informal learning environments, in which the expert sensitively and contingently collaborates with the novice and provides just enough intervention to enable the learner to accomplish the task at hand (10).

For instance, if the students seem stuck on a narrow focus, the clinician may "join" the class as a "consultant" by calling overhead and asking the students questions about the patient that the students may have forgotten to ask of the patient. For example, if a female patient is complaining of abdominal pain, the students may have focused on appendicitis, and the clinician may come in and ask the students leading questions in an attempt to encourage them to broaden their thinking about what else might cause abdominal pain (such as in the inquiry "when was her last menstrual period?").

THE STUDENTS ARE NOT EXPECTED TO KNOW OR NECESSARILY LEARN CLINICAL MEDICINE. Instead, they are encouraged to think about mechanisms behind the clinical observations or therapeutic ideas. They are told that they are not constrained by reality as this is not meant to teach them clinical medicine but rather critical thinking and problem solving. We do not expect the students to know the specific drug names or mechanisms; however, we do ask them to brainstorm about what mechanism they might want in terms of treatment. For example, when they encounter a patient whose heart is beating too fast, they may ask to give a drug that turns off the sympathetic nervous system. However, one of the courses is a physiology and pharmacology course, and these students are expected to know specific mechanisms as well as the actual names of medications.

AFTER THE CASE HAS CONCLUDED, THE CLINICIAN EXPERT WORKING WITH THE CLASSROOM TEACHER OR TEACHING ASSISTANT DEBRIEFS THE CASE. The debriefing begins with the clinician expert asking the students to reflect on what happened, what they learned, and what questions they have about the case. The classroom teacher then leads a discussion based on what the students actually did as evidence of their knowledge and integrates the material that emerged from the case with the objectives and topics of the ongoing didactic curriculum, using examples from the case to amplify the objectives of the course. In the discussion of anterior myocardial infarction and inferior myocardial infarction, for example, the teacher would compare and contrast the two entities to highlight key anatomic and physiological differences between the two clinical presentations. These differences are notable even though the essential pathology is the same in both cases: injury to the the heart muscle. For example, an anteriorly located myocardial infarction typically impairs the pumping strength of the left ventricle supporting systemic circulation; severe injury causes low blood pressure accompanied by a compensatory increase in heart rate to maintain cardiac output. However, with an inferior infarction that affects the right ventricle, the blood pressure may also be low due to cardiac muscle injury, but the heart rate may not increase in response to low cardiac output; rather, such patients can develop a slow heart rate because key elements of the heart's electrical conduction system are anchored on the (injured) right side of the heart. Consequently, the initial treatment of both conditions, even though both are considered "heart attacks," may be notably different.

THE INSTRUCTIONAL APPROACH IS UNIQUE. As mentioned above, the clinician expert and the classroom teacher do not intervene while the students are "caring for" their patient. There are four other common facets of the instructional approach in simulation for nonclinicians.

First, we redefine the clinical encounter in terms of scientific method. In the beginning of most clinical encounters, the clinician asks the patient "What brings you in today?" The answer to that question is called the "chief complaint" and establishes the preliminary identification of the problem to be solved. The job of the clinician is then to collect information to diagnose the problem and determine treatment. With our nonclinical students, we give them a structure and vocabulary with which to approach the problem. We tell them to treat the chief complaint of the patient like any problem they might encounter in real life: collect data, consider the possible explanations (develop hypotheses known in the clinical world as a differential diagnosis), analyze the data to decide which explanations are potentially valid, collect more data to narrow down the list of possible explanations, and then decide on a solution (treatment) and try it with the anticipation that their chosen solution may confirm or refute their initial hypothesis (diagnosis). We also point out to the students that they have access to two types of data: *1*) information that the patient tells you and *2*) data that they observe for themselves, such as the results of a physical exam or laboratory results that they can obtain. We encourage them to approach every clinical encounter with an organized approach lest they overlook a major clue because they jump to an early conclusion without following the entire data gathering and eliminating process.

Second, we explicitly encourage the students to use all the prior knowledge that they may have. This knowledge may be gleaned from personal experience, health issues of relatives, prior science classes, or even pop culture–whatever they can summon up to help them solve the problem and save the patient. We frame the approach to the cases as follows: "What would you do if your friend came to you with this complaint? What would you be thinking about? What questions would you ask?"

Third, we tell students that as a group they are to solve the case. Students are encouraged to use the collective knowledge of the group, learn to listen to their colleagues since none of them knows the answer, and to use every possible resource to solve the problem.

Finally, we tell students to be creative; they are not constrained by the limits of medicine. This allows the students to envision solutions that have yet to be invented and helps them respect the limits of current knowledge. We often find ourselves saying "Your idea is a great idea; it just has not been invented yet."

These seven common elements and four instructional approaches are consistent for all levels of nonclinical students. However, the specific curricular details varied for each of the three programs developed.

Examples of Simulation-Based Physiology Education Programs for Nonclinicians: High School, College, and Graduate School

Since 2005, we have developed three simulation-enabled physiology programs for nonclinicians: a full semester-long curriculum for high school students, a series of cases incorporated into a formal physiology and pharmacology course for beginning PhD or advanced undergraduate students, and a short immersive stand-alone course ("nano-course") for graduate students in the life sciences. These three programs were all initiated at the Gilbert Program in Medical Simulation at Harvard Medical School and are based on the common elements and instructional approaches described above.

High school simulation-enabled, semester-long, science curriculum. DESCRIPTION. A description of the a full semester-long curriculum for high school students is shown in Table 1.

ORIGINS. The vision behind developing this semester-long simulation-based high school science course emerged out of the success of the Harvard Summer Premedical Institute piloted in June 2005, a 1-wk-long simulation-based immersion program for high school and college students (7). During the pilot year of the Harvard Summer Premedical Institute, students were asked to keep a diary of each day's experience. In these open-ended journals, students spontaneously highlighted the personal and intellectual growth they experienced as inspired by the events of the day. We collected the journals at the end of the week. The freely reported comments reflected a level of insight and growth beyond what we had imagined after such a short exposure. The following is one such comment from a high school student:

> The best thing I received from this week is an appreciation for the uncertainty of medicine. Science is above all about the process, the investigation, the exploration. This [experience] did not offer answers or resolutions; rather it presented problems and posed questions to broaden the scope of our idea of medicine, science and patient care.

The power of these students' words and the depth of their insights inspired us to create the semester-long course that is now offered in three different Massachusetts schools. This course has been offered continuously since 2008 at Brookline High School, since 2009 at Madison Park High School, and since 2010 at Watertown High School. The original Havard Summer Premedical Institute continues to be offered as a demonstration site for our teacher-training program, allowing us to support expansion of the semester-long programs into new schools.

CURRICULUM NARRATIVE. Each of the participating high schools has a rigorous curriculum with clear objectives of what the students should know and be able to do as a result of their learning. The curriculum is divided into eight body system modules. Each module relates to the specific medical case that the students will solve during their weekly visits to the simulation center. Cases are chosen to illustrate the role of basic and clinical biomedical science in modern healthcare. Students are exposed to concepts from physics, biology, and chemistry, and they are taught, through personal experience, the principles of teamwork, problem solving, and communication.

STUDENTS. Each school offers the course to students at different stages of their education. At Brookline High School, it is an elective course with no prerequisites and is mostly taken by sophomores and juniors. Madison Park High School offers the course to vocational technical students in the 11th grade in the nursing assistance program. Watertown High School offers the course as an elective anatomy and physiology course for 11th and 12th graders. Students are not selected but are chosen at random and represent all types of learners, matching the range of people with whom these students will work, side by side, when they enter the real world. The student bodies in these three schools reflect the cultural diversity of the public school populations of these urban communities, with a high proportion of underrepresented minorities and socioeconomically disadvantaged students. Class sizes vary between 12 and 24 students/school.

OBJECTIVES. The principal objectives for the simulation sessions are problem solving, critical thinking, and communication. The classroom didactics are primarily designed to present the Massachusetts Comprehensive Assessment System-determined human biology content and to give the students some background to prepare them for managing the simulations. Massachusetts Comprehensive Assessment System objectives are also specifically incorporated into the content of the case scenarios and are further highlighted during the debriefing sessions at the end of the simulation cases.

Specific objectives were established in accordance with the school's standard procedure for credit-bearing courses, and each of the courses is listed in their school's course catalog. Specific objectives for Brookline High School (2) are as follows:

1. Students will envision themselves as college educated healthcare providers.

2. Students' weekly reflections will demonstrate critical thinking and observations about what they have learned and experienced.

Table 1. *Description of the high school simulation-enabled, semester-long, science curriculum*

	Description
Title	Harvard Medical School Bioscience Program for High School
Participating schools	Brookline High School, Madison Park High School, and Watertown High School
Students	Grades 10 through 12
Prerequisites	None
Faculty	Massachuesetts-certified high school science teacher and a clinician
Schedule	Daily 75- to 90-minute classes, 13-wk course; offered twice a year during fall and spring semesters
Curriculum	Once a week simulation sessions as a framework for an organ system curriculum

3. Students will gain confidence in their ability to apply pedagogy to real-time situations.

4. Student engagement will remain high, as evidenced by 100% participation.

5. Students will see the connection between the classroom and clinical settings.

6. Students will demonstrate growth in critical-thinking, problem-solving, oral and written communication skills and teamwork.

SAMPLE CASE. To help students ground the process of managing a patient within their own experience, the initial case presented is a severe asthma attack, a clinical condition that someone in the group is likely to have experienced. However, students are required to think through all the possible causes of difficulty in breathing and not jump to a known conclusion. As students debrief the features of the case, other basic science concepts are brought out, such as an understanding of sound waves as part of the explanation of wheezing and in comparison to the sound of a wind instrument or the physics of electromagnetic radiation and why bone is white and air is black on a chest X-ray.

FACULTY. The didactic school-based component of the course is taught at each school by a Massachusetts-certified science teacher who is selected from among the school's regular teaching faculty members. The volunteer clinician teachers have included an anesthesiologist, an emergency physician, a retired pediatrician/oncologist, and a critical care nurse. Because the objectives of the course include both basic science content and problem solving, the specific clinical discipline and length of clinical experience needed by the clinician teachers is not relevant. What is important is an understanding of the foundations of intent participation-based learning, as described by Paradise and Rogoff (13) but adapted for a hands-on, group, problem-solving exercise in a classroom setting, the simulation room. The Gilbert Program in Medical Simulation provides faculty development for this unique pedagogical style. Faculty members (of the newly added schools) are invited to participate in the annual summer immersion program, where intent participation as a valuable learning system is modeled, observed, and discussed.

STUDENT ASSESSMENT. Assessment of the students' progress is based on several factors: attendance, pretesting, and posttesting, as well as the demonstrable acquisition of state-mandated competencies. Students are also required to write weekly reflections describing their experiences and providing evidence of growth of their knowledge, skills, and attitudes toward learning. At the completion of the course, students are required to do a PowerPoint presentation demonstrating knowledge gained and reflecting on their acquisition of skills.

In a preliminary assessment of the impact of this program, an independent educational evaluation consultant, Davis Square Research Associates, conducted an online survey of a convenience sample of participating students ($n = 23$) from an inner city vocational/technical high school (67% free or reduced lunch) and another school from a more suburban neighboring community (13% free or reduced lunch). Using a retrospective pretest model and modified Likert scales, the 34-item survey explored student attitudes toward the content of the simulation course, the students' sense of self-efficacy regarding healthcare, and the students' attitudes toward the future place of healthcare in their academic work and beyond. The survey also explored knowledge gained, including how the body works, how to make judgments based on what a patient says, and how to connect different medical data to form a hypothesis. There were statistically significant attitudinal gains (by paired-samples t-tests), with an effect size of 0.65 (robust) and knowledge gains with a very large effect size of 0.82. Both the attitudinal and knowledge gains were normally distributed (by Kolmogorov-Smirnov tests), meaning that some students benefited more than others. However, there were no significant differences (by ANOVA) attributable to the specific high school for either domain. While this preliminary survey was conducted for the purposes of programmatic evaluation, it suggests that the course works equally as well in schools serving very different student populations. This study was determined to be Institutional Review Board exempt by the Human Studies Committee of Harvard Medical School.

STUDENT REFLECTIONS. Students are required to write weekly reflection papers, approximately one page in length, on what they are learning. The following quote is a short excerpt from one reflection paper by a sophomore at Brookline High School:

> Our case was with a woman who had done cocaine. I realized I love the analytical and critical thinking we do at Harvard. It's a challenge every week and every week I learn something new about how our body works. I especially like this way of learning because I can learn a concept and then see how it directly affects the body, for example, taking cocaine increases cellular activity, thus giving a person a fever and very high heart rate. I can really see, hands on, the cause and effect of different conditions and medications on the body by observing the robot. I also realized that we all get very into it when we are working on a case. It feels pretty real to me in the heat of the moment. When the patient (the robot…) is screaming in pain or has a sky rocketing blood pressure, the pressure feels real. No one wants to kill the patient. Everyone wants to solve the case, figure out what's wrong, and make the patient healthy again. I think it's pretty spectacular that a robot can make me want to do this. It just feels so real, it's funny. I like it.

College and graduate student simulation-enabled enrichment sessions. DESCRIPTION. A description of the college and graduate student enrichment sessions is shown in Table 2.

ORIGINS. This course began in 2006 as a new course to train PhD candidate graduate students in human biology and the pathophysiology of disease. The course was to be grounded on an analysis of relevant clinical cases to bring a clinical context to the studies, and, as a pilot, one topic was presented through

Table 2. *Description of the college and graduate student simulation-enabled enrichment sessions*

	Description
Course title	Principles of Human Disease: Physiology and Pharmacology (BCMP 235/MCB 235)
School	Division of Medical Sciences of Harvard Medical School
Students	Graduate students or college seniors
Prerequisites	Genetics, molecular biology, and cell biology
Faculty	A regular course faculty member and a clinician/simulation specialist
Schedule	90-min sessions, 3 times/week (Monday, Wednesday, and Friday), 13-wk course; fall semester only
Curriculum	Three simulation sessions incorporated into a preexisting course

a session with the patient simulator. In 2007, the course was expanded to include pharmacology, two additional simulation sessions were incorporated, and the class size was expanded from 18 to 50 students.

CURRICULUM NARRATIVE. The course is a semester-long (13 wk) course that meets three times a week for 90-min sessions. Each week focuses on one system and includes overview lectures, small-group discussions of clinical cases, and either live patient interviews (five sessions) or simulation cases (three sessions). The three 2-h simulation sessions are scheduled to coincide with the specific topics of the autonomic nervous system, cardiovascular pathophysiology, and respiratory pathophysiology. During each session, the simulation cases are presented as pairs of contrasting cases, with half the group managing the first case and the other half managing the second case, and the two cases are then compared and contrasted during a unified debriefing. These sessions are meant to highlight specific diseases and key mechanisms of drugs used to treat the diseases.

STUDENTS. The course is an elective course for graduate students who have had a thorough grounding in genetics, molecular biology, and cell biology or are advanced Harvard College undergraduates who have completed introductory courses in biochemistry, chemistry, and cell biology. The class size is 5 tutorial groups of 6–10 students each.

OBJECTIVES. The primary focus of this course is the integration of principles of human physiology, pathophysiology, and pharmacology. The primary learning objectives (12) are as follows:

1. To understand key mechanisms of human organ function and disease from the molecular to cellular, organ, and systems levels.

2. To understand key mechanisms of drugs used to treat the diseases under study.

This course uses case-based teaching, including real patient interviews and the simulation, to bring the science to life and to ground the scientific content in real-life clinical experience.

SAMPLE CASE. To illustrate cardiac physiology, pathophysiology, and mechanisms of treatment, the cases of anterior and inferior myocardial infarctions are presented sequentially during one session followed by a debriefing session that compares and contrasts the two different clinical pictures and the logic and mechanisms of the different therapeutic maneuvers they each require.

STUDENT ASSESSMENT. The simulation sessions have been very well received by the students, as reflected in the increasing popularity of the course and the year-end student evaluations. Note that students are not asked to reflect on the course other than to provide short evaluations at the end of the entire semester. Typical comments include the following:

> The simulator sessions were also really helpful for putting our knowledge to practice.

> The use of technology and interaction with the class was great. Also, the simulator sessions and lectures with real patients were a unique experience that I have not seen in any other grad class.

Graduate student simulation-enabled stand-alone immersion course. DESCRIPTION. A description of the graduate student immersion course (nano-course) is shown in Table 3.

Table 3. *Description of the graduate student simulation-enabled stand-alone immersion course*

	Description
Course title	Medicine 101: Bioscience to Bedside
School	Division of Medical Sciences of Harvard Medical School
Students	Graduate students (all years)
Prerequisites	None
Faculty	A clinician and a physician scientist
Schedule	3-h sessions, 2 times/wk (Tuesday and Thursday); offered twice a year during fall and spring semesters
Curriculum	Simulation sessions are the core of this immersive stand-alone course, which is presented with content-specific didactics that model the intersection between bioscience and clinical medicine.

ORIGINS. Nano-courses are short, credit-bearing immersion courses developed to address immediate curricular needs as well as to complement the traditional bioscience curriculum. The Medicine 101: From Bioscience to Bedside course was specifically created to give graduate students in the life sciences an opportunity to see the relevance of basic science research on the practice of everyday clinical medicine.

CURRICULUM NARRATIVE. On the first day, students learn the basics of the interplay between the autonomic nervous system and vital signs. They are then introduced to the patient simulator and asked to manage a case in which the actions of the sympathetic nervous system are responsible for some of the clinical symptoms. On the second day, students begin with a discussion of signal transduction pathways from the initial stimulus to the autonomic nervous system to the cellular reaction. They are then again asked to manage more cases that represent severe derangement of the autonomic nervous system, each of which requires an understanding of cell-based physiology to devise treatments. The final debriefing connects the relationship of the entire signaling pathway to the clinical findings and potential therapeutic responses.

STUDENTS. The course is offered to graduate students in the life sciences. Students electing this course have ranged in research interests from basic cell biology to neuroscience, biochemistry, and crystallography. There are no prerequisites, but the majority of participants to date have been students in the second year of PhD graduate studies or higher. The class size is 12–18 students/nano-course.

OBJECTIVES. The objectives are to expose the research student to the concept that their basic research will have important implications for clinical medicine and that biomedical scientists should be able to articulate that connection. In the words of the students:

> 'Medicine 101' is valuable for PhD students in life sciences because it gives them an opportunity to look at the 'end product of biological research.'

> Seeing how doctors approach treating patients and what kind of decisions they have to make in the process should be useful when we scientists think about applications of our research to medicine [in Harvard Integrated Life Sciences (11)].

SAMPLE CASE. The two final cases are chemical toxicity: cocaine toxicity (from drug abuse) and organophosphate toxicity (from landscaping) and are presented to compare and contrast the sympathetic nervous system and the parasympathetic nervous system.

STUDENT ASSESSMENT. At the end of the course, each student is required to write and present a clinical case scenario that illustrates the clinical implications of their own research work. The important concept is to be able to draw the connection between a basic science mechanism and a clinical case. The following are examples of student feedback on the value of this course:

> To learn how basic research can connect to clinical applications in a realistic and productive way.
>
> For a different perspective on biomedical research, learned to take a step back from the molecular level into a more 'real-life' view.
>
> Having real active doctors teach the course. I wanted to learn how doctors work, how they apply the knowledge of biology chemistry etc. in their work.
>
> Immersion–plunge right into the role/situation forces you to think. The manikin and 'real-time' conversations really help make situations believable.
>
> To have a general idea of how medicine works, how basic biology is used in medicine.

DISCUSSION

In the real world, learning happens in a social context, where actions are observed and may be discussed and reflected upon. The three programs described in this report have been built to harness the power of such naturalistic learning. We presented diverse groups of learners with real problems that could only be solved through scientific understanding that was beyond their individual preexisting fount of knowledge. This required the learners to work together to analyze the situation and to think critically and creatively to solve the problem. In addition to tapping the intellectual drive to address the challenge, the problems were presented in a social context with an emotional overlay.

Regardless of the different objectives and very different levels of students, the three programs described share two key theoretical elements: *1*) the pedagogical method is built on active engagement with an "authentic problem" in a naturalistic setting and *2*) the material is presented in a teaching moment infused with the emotional valance of urgency. Neither of these is a new idea; this is how learning happens in the real world. Informal learning emerges through active participation in everyday life in the context of the social environment. This learning arises from the joy of play, the pride of perfecting one's performance, and the personal satisfaction derived from curiosity quenched through experimentation and making sense of the world and through the human emotion of empathy, caring for others.

Several other specific pedagogical elements are built into these sessions. In our simulation scenarios, the simulated patient urgently needs assistance and each learner is drawn into the group effort to help the patient. The learner is also forced to engage publicly; everyone pitches in and everyone's performance is visible to everyone else. Even inaction is a visible performance. Such emotional valance helps imprint the lessons. The lessons are then articulated through formal debriefing sessions that, like intent participation learning, rest on conversation and reflection as a way to highlight the learning. Finally, incorporating traditional didactic sessions in the curricula reinforces this informal learning. This provides a seamless flow between pedagogical techniques capturing the best of both worlds: formal and informal learning.

The three programs all present similar issues of sustainability and scalability. As in any small-group, faculty-intensive educational program, success and continuation require resources. Sustaining and expanding such faculty-intensive programs will require an ongoing longitudinal evaluation of educational objectives, particularly with respect to critical-thinking skills and the ability to apply knowledge in solving real-world problems. We also need to better understand the positive motivational impact of such work on impressionable young students. This is particularly important for the youngest students, where a core objective is to introduce them to the value and promise of higher education.

With respect to scalability, the short series of simulation sessions that are part of the college and graduate level courses allow flexible scheduling that is relatively easy to accommodate and administer. However, the high school course is not as flexible. These classes meet daily, and the simulation center must accommodate students every week, which requires a significant commitment from simulation centers. However, we have found these logistic problems solvable through intensive community partnerships and resource sharing; our high school program has expanded from one school to three schools and is about to add a fourth. The course has been offered for a total of 10 semesters using 4 separate simulation centers.

Summary

In the present report, we have described promising ways to embed informal learning experiences in physiology courses for high school, college, and graduate students through a unique partnership with a medical simulation center. The objectives for the high school students include general basic science content and critical thinking. For college and early graduate students, content and an understanding of scientific mechanisms are emphasized. Advanced PhD students discover the relationship, often for the first time, between their own basic science research and clinical medicine and the excitement of making translational connections as future biomedical scientists.

We believe that naturalistic learning is underused in formal science education. Our work introduces healthcare simulation to a nonhealthcare audience, creating a novel experiential paradigm for advanced high school, college, and graduate science education. We hope that our early experience in using immersive clinical simulation among nonclinical students will help better define the role of naturalistic learning in science classrooms of the future.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

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