Adv Physiol Educ 38: 210–215, 2014;
doi:10.1152/advan.00143.2013.

Inspiring careers in STEM and healthcare fields through medical simulation embedded in high school science education

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Submitted 17 December 2013; accepted in final form 20 May 2014

Berk LJ, Muret-Wagstaff SL, Goyal R, Joyal JA, Gordon JA, Faux R, Oriol NE. Inspiring careers in STEM and healthcare fields through medical simulation embedded in high school science education. *Adv Physiol Educ* 38: 210–215, 2014; doi:10.1152/advan.00143.2013.—The most effective ways to promote learning and inspire careers related to science, technology, engineering, and mathematics (STEM) remain elusive. To address this gap, we reviewed the literature and designed and implemented a high-fidelity, medical simulation-based Harvard Medical School MEDscience course, which was integrated into high school science classes through collaboration between medical school and K–12 faculty. The design was based largely on the literature on concepts and mechanisms of self-efficacy. A structured telephone survey was conducted with 30 program alumni from the inaugural school who were no longer in high school. Near-term effects, enduring effects, contextual considerations, and diffusion and dissemination were queried. Students reported high incoming attitudes toward STEM education and careers, and these attitudes showed before versus after gains ($P < .05$). Students in this modest sample overwhelmingly attributed elevated and enduring levels of impact on their interest and confidence in pursuing a science or healthcare-related career to the program. Additionally, 63% subsequently took additional science or health courses, 73% participated in a job or educational experience that was science related during high school, and 97% went on to college. Four of every five program graduates cited a health-related college major, and 83% offered their strongest recommendation of the program to others. Further study and evaluation of simulation-based experiences that capitalize on informal, naturalistic learning and promote self-efficacy are warranted.

medical simulation; science education; health care; science, technology, engineering, and mathematics

SOBERING ACCOUNTS OF CHALLENGES faced by the United States (U.S.) to remain competitive in science, technology, engineering, and mathematics (STEM) fields have stimulated numerous attempts in the past decade to bolster the numbers of students who aspire to and attain higher education degrees and careers in these fields. Based on National Academy of Sciences recommendations, efforts have ranged from actions in K–12 education, research, and higher education to economic policy (13,14). For example, the National Science Foundation has funded dozens of partnerships between K–12 teachers and universities to "inspire and motivate the next generation" in STEM education and recently expanded these grants to include computing science explicitly (15); researchers are analyzing determinants of STEM teacher turnover (10), searching for barriers to STEM courses for U.S. students (8), and addressing the persistent underrepresentation of ethnic minorities and women in STEM (20), and the White House sponsors an Educate to Innovate initiative that engages business leaders in investing in STEM education and recruits role models to increase the participation of underrepresented groups (23). Nonetheless, the most effective ways to promote learning and inspire careers related to STEM remain elusive (18).

In this Personal View, we offer our perspective on this challenge. In 2008, through a partnership between a high school and a medical school, we collaborated to address this problem by designing and launching MEDscience, a unique educational program that integrates participation in hands-on, medical case problem-solving scenarios using mannequin simulators within a 13-wk high school science course. The curriculum, which combines both classroom didactics and closely related simulation scenarios, incorporates a weekly simulation session that is cofacilitated by a Massachusetts-certified high school science teacher and a clinician, as previously described (16). Small groups of students manage a "patient" (mannequin) with a simulated condition such as an asthma attack that is linked to the concurrent high school didactic content, engage in a debriefing after each session with science and clinical faculty members, and complete written reflections. Since its launch in 2008, the program has been adapted and expanded to additional high school, college, and graduate school programs.

Our rationale in designing and implementing the program is centered on an intent to promote self-efficacy, or the belief in one's ability to succeed in a specific situation, through the students' hands-on solution of the "patient's" problem, potentially contributing to persistence in pursuing a science or health career. The curriculum also takes advantage of informal, naturalistic learning (6) in tandem with didactic teaching. Simulated experiences are affectively compelling and cognitively and socially engaging. This sociocultural approach brings students into action with others, communicating and coordinating efforts while participating increasingly in a culturally valued, real-world event. Both observation and side-by-side joint par-

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ticipation are included. Rogoff (17) views such engagement as "a process of becoming, rather than acquisition."

To inform future comprehensive assessment and refinement of this unique project, we sought to follow up with students who had participated in the program at the inaugural high school to gather insights into sustained program effects from the students' perspectives and elucidate possible mechanisms by which these outcomes occur. With approval of the Institutional Review Board of Harvard Medical School, we conducted a pilot cross-sectional telephone survey of alumni of the Harvard Medical School MEDscience program to explore important categories of influence on STEM and healthcare attitudes and career choices of this unique, simulation-based educational curriculum embedding naturalistic learning into formal high school science courses.

We assembled a convenience sample of former students who were over the age of 18 yr, took the Harvard Medical School's MEDscience course between 2008 and 2012 in the original high school that adopted MEDscience, and no longer were in high school. A team of physicians, high school science teachers, and graduate students in the health sciences designed a 15-min telephone questionnaire with both open- and closed-answer questions based on a literature review and prior student narrative reports. In closed-answer questions, participants were asked to rate various perceptions on a scale from *1* to *5*. The instrument was pilot tested with graduates of nonparticipating high schools and refined. Two trained interviewers conducted telephone surveys using the instrument.

The survey comprises four major exploratory domains, with the first domain exploring the near-term effects of participation. A series of retrospective pretest questions refer to changes in expectations expressive of attitudes toward healthcare careers as recalled before participation and then again subsequent to participation. Scores were summed into an individual composite score, and group means and distributions were calculated. The second domain was reserved for the enduring effects of participation, which refer to attitudes and actions taken after graduation from high school. These items were summed into single before versus after individual composite scores, and the group distribution was compared with the expected distribution. The third domain gathered information on various contextual considerations that may have influenced the respondents' overall experience. The fourth domain queried diffusion and dissemination of the program. For the third and fourth domains, response frequencies were calculated.

Three attempts were made to reach each eligible student for whom contact information was available. Contacted students were asked to provide verbal informed consent at the time of contact and before the telephone survey was conducted. The educational intervention was as previously described (16). Statistical analyses consisted of paired *t*-tests to assess differences between groups, the Kolmogorov-Smirnov nonparametric test to compare observed with expected probability distributions, and frequency counts to characterize qualitative data. Data were compiled in Excel 2010 (version 14.0.7106.5003, Microsoft, Redmond, WA), and statistical analyses were conducted using R software (version 3.0.1, www.r-project.org).

From the time that MEDscience began in 2008 until 2012, 155 students participated at the inaugural high school. Among these, contact information was available for 68 students, of whom 22 students were currently in high school and thus were not eligible for the study. Of the remaining 46 students, 14 students were unable to be contacted on 3 attempts, 2 students declined, and 30 students consented and completed the telephone survey (65%). The sample consisted of 24 female respondents and 6 male respondents with average age of 19 yr. No differences in age or sex were found between responders and nonresponders. The reliability value for the instrument was calculated at 0.85 (Cronbach α) and 0.98 (Guttman λ 6), both good results. There was no construct validity testing of the instrument as the number of respondents was too small.

Near-Term Effects

With respect to changes in expectations expressive of attitudes toward health careers immediately before and after the MEDscience course, students retrospectively reported high incoming attitudes, with these attitudes then increasing over the course (from means of 7.78–8.87 of a maximum of 10). A paired-samples *t*-test showed a significant before versus after gain ($P < 0.05$), with a moderate effect size of 0.49 (Cohen's *d*; Table 1). A density plot of the distributions (Fig. 1) showed shifts from the pretest to posttest curves. Overall gains (calculated by subtracting pretest from posttest values) showed a fairly even distribution, with some students gaining more and others less, and most students roughly in the middle.

Enduring Effects

Table 2 shows mean values for the four survey items regarding enduring attitudinal effects of participation, further shown in Fig. 2. A finding of significance for these items means that there was a less than expected variation around the mean values. Results for all four items were significant, a clear indication that the mean values are not only very high on the *1–5* scale but also that they are broadly shared. This indicates that students in this sample attribute elevated levels of impact

Table 1. *Before versus after expectations for science/health education and career*

Item	Average Score
1. I want you to think back to when you were in high school. In terms of BEFORE you took the science course with Stan the mannequin, had you EVER thought that science or health courses in high school WOULD be an important part of your education: please answer on a *1–5* scale, with *1* being you did not consider it important and *5* being you thought it was very important.	3.97
2. Now I want you think about AFTER you took our course; on a scale of *1–5*, did you think that taking science or health courses in high school had now become a more important priority for you?	4.43
3. BEFORE you took our science course, did you think that you would like to eventually find work in a science- or health-related job? Please give an answer, again from *1* to *5*, where *1* is little or no desire to eventually work in science or health and *5* is the most desire to do so.	3.82
4. AFTER you took the course, and on a scale of *1–5*, did you have an increased interest in a science- or health-related job somewhere down the road?	4.43*

*Significant at $P < 0.05$ (by Wilcoxon test).

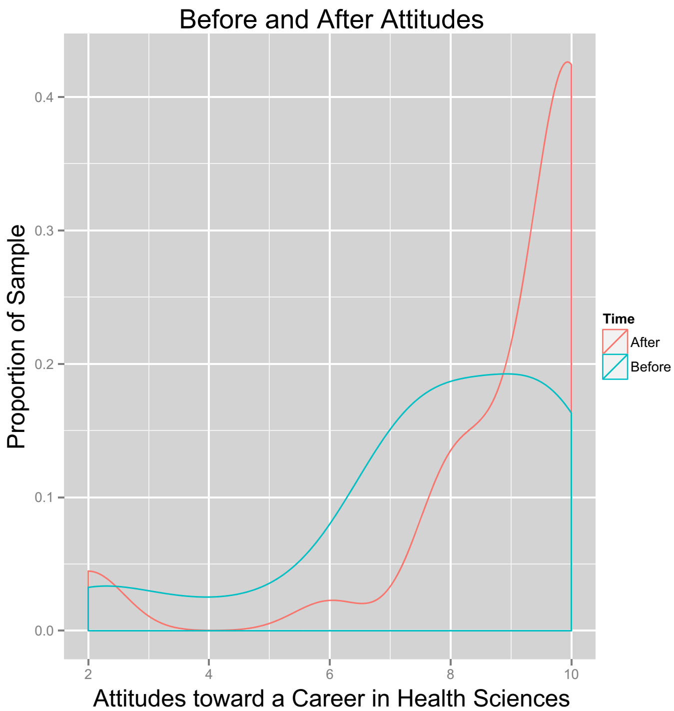

Fig. 1. Attitudes before versus after the program. Composite mean scores indicating attitudes toward science- and health-related education and careers on 10 survey items were averaged for 30 students, showing positive initial attitudes and significant gains after the MEDscience program. $P < 0.05$ by a paired-samples *t*-test.

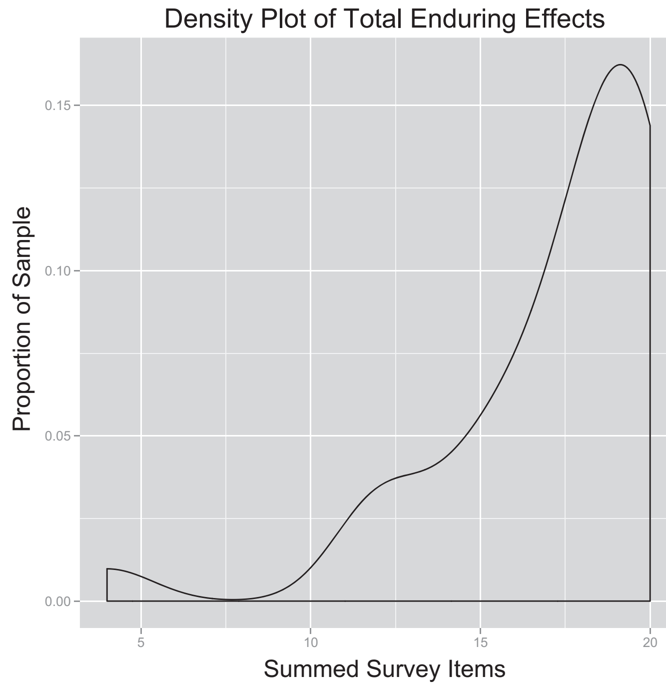

Fig. 2. Density plot of enduring attitudinal effects. Composite scores express the sum of four five-scale items (maximum: 20) relating to the lasting effects of participation in the MEDscience project. The distribution was found to be significant ($P < 0.05$ by single-sample *t*-test, mean: 17.17, SD: 3.56, t = 26.389), indicating that the respondents were strongly united in their attributions of value. This finding supports the inference that the MEDscience program was consistently effective across the sample.

on their interest and confidence in pursuing a science- or healthcare-related career to the program.

Contextual Considerations

In response to a series of open-ended questions about attitudes and experiences related to the pursuit of a career in science or healthcare, 63% of respondents reported that they took additional science or health courses during high school as a result of their experience in the MEDscience course, most typically anatomy and physiology. Additionally, 73% reported participating in a job or an educational experience that was science or health related during high school. All respondents reported graduating from high school, and 29 of 30 respondents (97%) reported going on to college. Table 3 shows the very high levels of intention to continue.

Results for survey items regarding effects of the participants' social milieu on the decision to continue, or not, in a science- or healthcare-related field showed less variability than expected ($P < 0.05$ by Kolmogorov-Smirnov test) in sources of encouragement from family, friends, and teachers, with a significant if moderate relation between external encouragement and attitudes (Pearson 0.58, $P < 0.05$). Inhibiting factors such as discouragement from others or personal situations were scored relatively low on the *1–5* scale (mean scores: 1.07–2.47), indicating that these potential problems were not generally thought to be very important by this group overall.

Diffusion and Dissemination

When asked how strongly they would recommend participation in the project, respondents' mean answers were 4.79 (significant at $P < 0.05$ by Kolmogorov-Smirnov test), with 83% responding "5." This strong level of endorsement was further indicated in response to a question about what respondents would say to another student (prompt: If you were in the role of an advisor to a high school student interested in a

Table 2. *Enduring attitudinal effects of participation*

Item	Average Score
1. [Do] you still have a continued desire or intention to pursue some type of science- or healthcare-related education, and can you rank this desire or intention on a scale of *1–5*?	4.25*
2. Do you feel that your participation in the science course with Stan the mannequin during high school affected your interest in pursuing a science- or healthcare-related career on a scale of *1–5*in terms of effect?	4.23*
3. Did participation in the course give you the confidence that you had the abilities necessary to pursue a science or healthcare-related career, on a scale of *1–5*?	4.37*
4. Did the unique way in which our course was taught, using medical scenarios and a robotic mannequin, give you MORE interest to pursue a science- or healthcare-related career, on a scale of *1–5*?	4.32*

*Significant at $P < 0.05$ (by Kolmogorov-Smirnov test).

Table 3. *After high school experiences and intentions*

Item	Findings
1. After high school, did you take a job, or have job training, in a science- or health-related field (this might include EMT training, health assistant course, hospital or clinic work, etc.)?	13% said yes
2. AFTER high school, on a scale of *1–5*, did you still have a desire to pursue a job or education, in the future, related to science or health?	4.33*
3. AFTER high school, did you go on to college or some other secondary education?	97% said yes
4. What type of secondary education did you do or are currently doing?	100% reported college
5. What is, or was, your major in college?	80% cited health-related majors
6. Did you graduate (or do you intend to graduate) from college?	100% said yes
7. During college, on a scale of *1–5*, what was your level of interest to some day have a job in a science- or health-related field?	4.28*
8. What type of job in science or health would you consider for yourself?	10 said medicine; 5 said nursing
9. Did you ever work in a science- or healthcare-related job (this might include working in a doctor's office, as an EMT, as a laboratory technician, etc.)?	30% reported as having done this
10. [If yes to the previous question] What jobs?	Laboratories and hospitals were typically cited
11. Are you currently enrolled, or have you completed, a healthcare-related program of study?	33% said they were

EMT, emergency medical technician. *Significant at $P < 0.05$ (by Kolmogorov-Smirnov test).

science or healthcare career, what advice would you give them?). Respondents emphasized the value of experiences that are the same or congruent with the MEDscience program, as shown below in this sample:

- "Find internships and other experiences in the real world to get better insight."
- "Work hard in science classes especially chemistry."
- "Get an idea of all the medical jobs there are."
- "Take this course. They open your eyes to a world of careers."
- "[Note] requirements for medical schools before college."
- "Be involved in more extracurricular activities, take more advanced placement classes."
- "Make sure to get involved in volunteer work in the field, take lots of options, keep options open [while] you're still in high school."

The overall tone of the responses is one of remarkable enthusiasm for a career in healthcare, an explicit indication of the enduring effects of the MEDscience program.

In this preliminary, exploratory assessment of the impact on career-related attitudes and choices of a unique, simulation-based program embedded in a high school science class, alumni from the first 5 yr of the project whom we were able to contact reported strong and enduring effects. In the near term, these graduates reported that favorable attitudes increased significantly between the start and followup of the course. Students attributed high levels of impact on their interest, actions, and confidence in pursuing a science- or healthcare-related career to the program. Students also reported positive yet moderate levels of encouragement from family, friends, and teachers. While it is not possible to disentangle such effects in this small sample, reported before versus after program attitudinal gains favor the influence of program effects. Students strongly endorsed the MEDscience program and demonstrated promising actions toward a career in science and healthcare fields after the program, such as election of additional science courses, participation in related experiences, and nearly uniform intention to complete college with a majority in health-related majors.

While we interpret these results from our preliminary survey with caution, quantitative and narrative responses of students in this small, retrospective sample suggest that the chosen categories and lines of questioning are appropriate for a larger, prospective study and consistent with our initial intent to promote not only knowledge gains but also self-efficacy regarding STEM and healthcare education and careers. An informal group learning approach using a culturally valued activity such as management of a patient/mannequin with a simulated, rapidly emerging medical problem may be advantageous in promoting a student's perceived self-efficacy in solving science problems and functioning successfully in a health career role. Among the four factors that Bandura (3, 4) identifies as influencing self-efficacy, the experience of mastery is most prominent, and the experience of mastery is a key component of performance in simulation. Observing peers during joint activity and interpreting one's physiological response to the situation as normal also influences self-efficacy positively (3, 4), and these experiences are integral to the MEDscience program. Others (22, 24) have shown a positive effect of various active learning strategies on self-efficacy and on the retention of students in STEM disciplines in college students.

In addition, a growing number of simulation studies in healthcare point to increases in self-efficacy after medical simulation sessions. For example, residents show increased self-efficacy after simulation in disclosing a medical error to a standardized patient (19), and multidisciplinary teams show improved self-efficacy after crew resource management-based operating room team training with simulation (12). In randomized controlled trials comparing simulation-based training with traditional educational techniques, residents in obstetrics and gynecology show favorable increases in self-efficacy after simulation in laparoscopic procedural techniques compared with nonsimulation trained peers (2), and simulator-trained nurses show greater self-efficacy in communication skills compared with case-based trained nurses (9).

Consistent with our results, recent research suggests that self-efficacy beliefs, in turn, shape students' aspirations and career trajectories. For example, Bandura et al.'s prospective, longitudinal path analysis of 11 to 15 year olds showed that children's academic and career efficacy predicted career choices designated a year later. Importantly, Bandura et al. (5) emphasized that self-efficacy influences not only preferences but also motivation, persistence, and determination to "stick it out" through challenging times in a career pathway. In contrast, academic achievement failed to add predictive value in the 2001 Bandura et al. study (5). Similarly, in a U.S. national sample of eighth graders, a student's expectation that she or he would have a career in science was a stronger predictor of later achieving a science or engineering degree than was their eighth grade mathematics achievement score (21).

Specific to STEM educational choices and careers, others have shown that self-efficacy regarding research skills predicts undergraduate student aspirations for research careers (1) and that self-efficacy beliefs enable "the perseverance and resiliency required to overcome a variety of academic and career obstacles" for women who have selected and excel at careers in mathematics, science, and technology (25).

As with any exploratory study, our findings are limited by sample size, potential selection bias, and retrospective approach. Nonetheless, these initial findings are consistent with previous studies of active, informal learning and self-efficacy and provide evidence for further focusing and evaluating the impact of a unique, simulation-based science education innovation. Such a program could only be realized through a strong collaborative relationship between a K–12 school system and a medical school (7, 11) and careful alignment and integration of the simulation experiences with each aspect of the overall high school science curriculum. These critical relationships also deserve further study in advancing STEM and healthcare education and careers, as does the impact of other out-of-school experiences noted by our participants and congruent with informal learning theory.

In summary, we collaboratively designed a novel medical simulation component embedded in a high school science course collectively called MEDscience in an attempt to promote not only learning in the traditional sense but also self-efficacy among students related to STEM and healthcare attitudes and career choices. An exploratory survey of a sample of 30 students who participated in the program at the inaugural high school suggests that categories of influence related to self-efficacy are appropriate and promising for future program design and prospective analysis. Based on our promising initial data and an integration of the related medical and educational literature, we recommend the study and use of blended simulation and classroom science learning for high school students to promote self-efficacy, which may, in turn, drive STEM education choices and career success. Capitalizing on these novel educational opportunities may provide a unique new approach to breaking through the persistent challenge of inspiring and enabling STEM-based learning and careers.

ACKNOWLEDGMENTS

The authors thank the students and collaborating teachers and administrators who made the project possible.

GRANTS

This work was supported by the Gilbert Program in Medical Simulation at Harvard Medical School, The Boston Foundation, Nellie Mae Education Foundation, Red Sox Foundation, and Jane B. Cook Charitable Trust.

DISCLOSURES

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

AUTHOR CONTRIBUTIONS

Author contributions: L.J.B., J.A.J., J.A.G., R.F., and N.E.O. conception and design of research; L.J.B., R.G., and N.E.O. performed experiments; L.J.B., S.L.M.-W., R.G., J.A.J., J.A.G., R.F., and N.E.O. approved final version of manuscript; S.L.M.-W. and R.F. analyzed data; S.L.M.-W., R.F., and N.E.O. interpreted results of experiments; S.L.M.-W. and R.G. drafted manuscript; S.L.M.-W., J.A.J., J.A.G., and N.E.O. edited and revised manuscript; R.F. prepared figures.

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