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Flexner 3.0—Democratization of Medical Knowledge for the 21st Century: Teaching Medical Science Using K-12 General Pathology as a Gateway Course

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Abstract

A medical school general pathology course has been reformatted into a K-12 general pathology course. This new course has been implemented at a series of 7 to 12 grade levels and the student outcomes compared. Typically, topics covered mirrored those in a medical school general pathology course serving as an introduction to the mechanisms of diseases. Assessment of student performance was based on their score on a multiple-choice final examination modeled after an examination given to medical students. Two Tucson area schools, in a charter school network, participated in the study. Statistical analysis of examination performances showed that there were no significant differences as a function of school ($F = 0.258$, $P = .6128$), with students at school A having an average test scores of 87.03 (standard deviation = 8.99) and school B 86.00 (standard deviation = 8.18; $F = 0.258$, $P = .6128$). Analysis of variance was also conducted on the test scores as a function of gender and class grade. There were no significant differences as a function of gender ($F = 0.608$, $P = .4382$), with females having an average score of 87.18 (standard deviation = 7.24) and males 85.61 (standard deviation = 9.85). There were also no significant differences as a function of grade level ($F = 0.627$, $P = .6003$), with 7th graders having an average of 85.10 (standard deviation = 8.90), 8th graders 86.00 (standard deviation = 9.95), 9th graders 89.67 (standard deviation = 5.52), and 12th graders 86.90 (standard deviation = 7.52). The results demonstrated that middle and upper school students performed equally well in K-12 general pathology. Student course evaluations showed that the course met the student's expectations. One class voted K-12 general pathology their "elective course-of-the-year."

Keywords

Flexner Report, health literacy, Interprofessional Education and Collaborative Practice, medical science, K-12 schools, medical education, pathology coursework, STEM curriculum, whole slide images

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Introduction

For the past century, college and K-12 students have had limited access to medical school science coursework, such as pathophysiology, pathology, pharmacology, and clinical microbiology.[1-7] The 1910 Flexner Report recommended that medical science be "upper-level coursework" allocated to the final years of college or graduate school, thereby stifling considerations of teaching medical science at lower levels of education. Now, this century-long de facto prohibition to the widespread availability of medical science coursework for premedical college and nonmedical college, as well as to K-12 students, is finally breaking down (Figure 1).[7-19] Two immediate questions for medical science and other science educators are "can a gateway medical science course such as general pathology be successfully taught to K-12 students?" and "does general pathology content constitute an appropriate gateway medical science course for nonmedical students?" The general pathology coursework that served as an image-rich gateway course for the introduction of mechanisms of diseases for medical students throughout the 20th century is now a candidate to fill this gateway medical science course role.[20,21]

In order to explore this possibility, a medical school general pathology course was adjusted to serve as a stand-alone K-12 "mechanisms of diseases" gateway medical science course.[22] This adjustment was accomplished by adding essential human anatomy and normal histology elements at the front end of the course and by truncating some of the medical school content to adjust for the number of hours for classroom instruction in a single trimester, elective course (Figure 1).

Between 2008 and 2014, this innovative K-12 general pathology course was successfully completed by 117 of the 122 K-12 students including the 73 students in this study. This article reports on the performances of 73 grade 7 to 12 students who took the course as a regular school year, 1 semester elective course, at one of 2 schools in the BASIS Schools, Inc, charter school network.[23] BASIS charter schools were selected both because of their availability in Tucson and, more importantly, because of the known consistency of their classroom environments and the high levels of motivation for innovation among their teachers.[23]

The objective of this study was to peg the K-12 general pathology course to appropriate grade levels. Student ages ranged from 12 to 18 years.

Materials and Methods

Pilot Cohort

This K-12 pathology course was initially developed and piloted with 39 summer fellowship students drawn from 25 Arizona high schools and middle schools and 3 out-of-state high schools, who took the K-12 general pathology course as a component of our University of Arizona Department of Pathology's 6-week long Sir William Osler Summer Fellowship Program (established initially in Chicago, Illinois, in 1978), and, in parallel, as a regular school year elective course for 10 Phoenix Union Bioscience High School students. Thirty-five of the 39 summer program students, and all 10 of the Phoenix Union Bioscience High School regular school year students, achieved passing grades. Both the summer programs and the initial regular year program utilized the state-of-the art videoconferencing facilities at our Phoenix-based T-Health Institute, a division of the Arizona Telemedicine Program (ATP).[24-27] The Phoenix Union Bioscience High School campus was immediately adjacent to the College of Medicine, Phoenix Campus, and within a short walking distance of the T-Health Institute (Appendix A).

Origins of K-12 General Pathology

The single K-12 general pathology course used in this study was adapted from The University of Arizona's College of Medicine, Tucson's former second-year general pathology course (Both the College of Medicine, Tucson, and the College of Medicine, Phoenix, now use organ-based integrated curriculums). Classroom time constraints limited the number of topics that could be included in the K-12 general pathology course. A single K-12 general pathology course was used for all grade levels reported in this article. Lectures and associated PowerPoint presentations were essentially the same across all grades, although there were minor tweaks in the K-12 curriculum as the pathology faculty members teaching the K-12 general pathology course fine-tuned their lectures from year to year, as they do for medical school courses.

The K-12 general pathology course was designed as a flexible gateway course serving diverse purposes including K-12 biology education, Science, Technology, Engineering, Math (STEM) curriculum, as an introduction to mechanisms of diseases for future health industry workers, and as a resource for enriching population literacy programs by adding a medical science component (Figure 2). The University of Arizona's two separately accredited Colleges of Medicine provided a rich learning environment for these K-12 students.

Participating Schools

Seventy-three students from 2 schools in the BASIS Schools, Inc, charter school network, BASIS Oro Valley (school A, BASIS OV) and BASIS Tucson North (school B, BASIS TN), both within 15 miles of the University of Arizona College of Medicine, Tucson, enrolled in these classes.[23] BASIS schools are nationally highly ranked public charter schools, based on the results of a 2015 US News and World Report analysis of more than 29,000 public high schools.[28] Student participation rate in, and performance on, Advanced Placement and International Baccalaureate tests were primary factors used to rank the schools.

BASIS students who enrolled took K-12 general pathology as a single trimester elective. The classes met 5 days a week for a 12-week trimester. The numbers of students who participated at each grade level are shown in Table 1. Classroom teaching

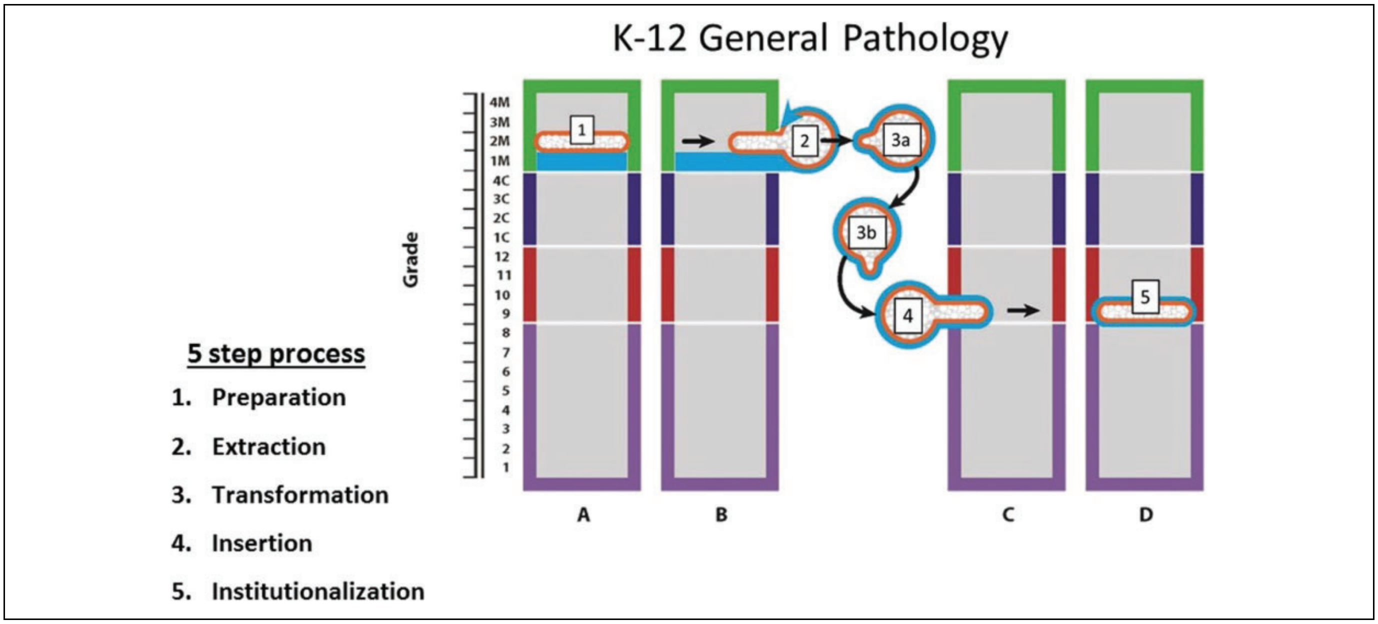

Figure 1. "Flexner frameworks" for medical education.[2] Here, medical school general pathology coursework is shown in a common curricular framework used in the United States today, in the location of a second-year medical school course (2M; Flexner framework A). Scale on the left represents the progression of grade levels. Flexner framework "A", grades 1 through 8—primary and middle school bracketed in purple; grades 9 through 12—high school, bracketed in red; 1C through 4C, college, bracketed in dark blue; and 1M through 4M, medical school, bracketed in green. In framework "A," first-year medical school coursework is shown in solid light blue. Second-year medical school general pathology shown as a collapsed ellipse with an orange capsule. Creation of K-12 general pathology is shown as a 5-step process. In framework B, medical school general pathology is being extracted and carries with it a light blue coating, representing the essential first-year anatomy and histology content. The extracted coursework is further adapted and reoriented (shown as a 2-step progression in the space between frameworks "B" and "C"; steps 3a and 3b). This is then reinserted into Flexner framework "C," shown as element "4," being inserted at the ninth grade level (see scale left, grade 9). This is then "institutionalized" in the "Flexner 3.0 framework" labeled "D", on the right, shown as element "5" in the "5-step process" (note 1).

was typically conducted on-site at a BASIS school, although some lectures and reviews were given by the faculty by videoconferencing from the College of Medicine, Tucson. Additional enrichment activities were held at the University of Arizona College of Medicine, Tucson. BASIS teachers conducted reviews and introduced supplemental materials on days that College of Medicine faculty members were not scheduled to teach.

The University of Arizona's Institutional Review Board

This study was exempt from the institutional review board approval of The University of Arizona.

Student Recruitment

Students were selected for participation by their biology teachers, based on student interest, teacher recommendations, and a personal ''letter of interest'' generated by the applicant, with student's parent or legal guardian permission.

Course Teachers

University of Arizona's tenured pathology professors, all of whom had extensive prior experience teaching pathology coursework to both medical and graduate students, taught the classes at the 2 BASIS schools. BASIS school K-12 science teachers administered the multiple-choice question examination. Deidentified lists of student's examination scores were forwarded to the course director at the College of Medicine, Tucson, for further analysis.

Course on Mechanisms of Diseases

Topics in the K-12 general pathology course included mechanisms of cell injury, adaptation, repair, and cell death; circulatory disorders; acute and chronic inflammation; immunopathology; hereditary diseases; and neoplasia and idiopathic disorders.[20,21] These topics were covered in a series of 45-minute lectures, supported by PowerPoint slides. Problem-based learning took place during hands-on gross organ demonstrations, whole slide imaging laboratories, simulation laboratory exercises, and a series of ''disease-of-the-week'' presentations. Students reviewed essential human anatomy and histology at the beginning of the course.

Illustrated Medical Word List and Disease Glossary

Two customized visual learning tools were developed in-house. These were used to ''jump start'' the students into

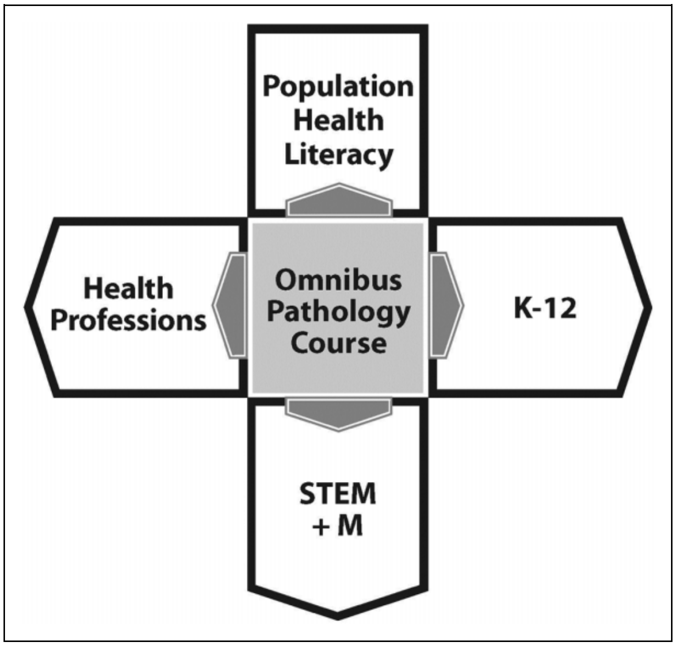

Figure 2. Because the K-12 general pathology course can be inserted into a standard K-12 curriculum at various grade levels, and serve as a gateway medical science course for multiple curricular tracks, it is referred to here as the "Omnibus Pathology Course," reflecting its general applicability. Here, the Omnibus Pathology Course is shown, within the 3 pentagons (ie, 3-o′clock, 6-o′clock, and 9-o′clock) as a gateway course for K-12 medical science, for a STEM curriculum (with the addition of an extra "M" [ie, STEMM] standing for "medical science"), for entry to a broad array of health professions education tracks, and, in the square (top), as an enhancer for population health literacy in general.

thinking about diseases upon commencement of the courses. The "Illustrated Medical Word Package" consisted of 100 essential words that were subsequently encountered in didactic presentations and problem-solving exercises. These essential words were presented initially in the classroom as a PowerPoint presentation and then as handouts and online resources materials. A second resource package, also developed in-house, was "The Illustrated Medical Diseases" package that illustrated aspects of 50 diseases (Figure 3). The students completed 3 hours of drills on these images. Visual learning was emphasized by showing, and working with, these same images repetitively throughout the course. These images served as frames of reference for classroom discussions, reviews, gross organ laboratories, and other problem-solving exercises.

Course Enhancements

In order to enhance student learning and experience, students at all grade levels participated in the same 4 enrichment activities (described below). These activities were usually completed within the time constraints of the course's regularly scheduled meeting time, unless travel to the College of Medicine was required.

Medical Library and Online Search Strategies

College of Medicine librarians gave tutorials to the students on advanced computer search techniques and strategies. The students, in turn, used these search strategies to research their specific assigned disease topics and to develop their end-of-course oral presentations and companion poster presentations. The students were encouraged to become familiar with online media and information resources related to the topics they study as well as breaking news relevant to the course and their assigned disease topics.

Medical Simulation Laboratory

A second enrichment activity was a 1-hour session in the Arizona Simulation Technology and Education Center simulation laboratory where the students gained hands-on experience in passing an endotracheal tube and in cardiac resuscitation on a sophisticated life-like patient simulator. Students also gained hands-on experience using an abdominal laparoscopic surgical simulator (Figure 4D and E).

Gross Organ Demonstrations

The third activity involved a 1-hour session in the University Medical Center morgue, led by a staff pathologist and pathology residents. The students handled and examined organs and described lesions in preserved formalin-fixed autopsy specimens (Figure 4B). Formalin-fixed organs were also taken into the classrooms at the BASIS schools for student exercises.

"Adopt-a-Disease" Oral and Poster Presentations

Finally, there were the Adopt-a-Disease oral and poster presentations. Students, in groups of 3 or 4, were assigned a disease (eg, diabetes mellitus, chronic obstructive pulmonary disease, drug-resistant tuberculosis, Crohn disease, lung cancer, etc) and completed a 2-part assignment focused on that disease: (1) gave a 20-minute oral multimedia presentation to faculty members, peers, and family members at an evening event at the College of Medicine and (2) created a scientific poster describing their assigned disease topic. The oral presentations followed a set format including information on etiology, pathogenesis, pathology, therapy, and disease outcomes. In the hour prior to the oral presentations, student groups stood next to their posters, which were displayed on the hall walls outside the lecture hall and answered questions about their projects from course faculty, students, and guests (Figure 5). Posters were subsequently displayed on the hallway walls at their schools. In addition, each student group searched online for a representative video, available on YouTube, of a patient or caregiver discussing the student group's assigned disease. Students showed this 3- to 5-minute YouTube video to the audience at the end of their oral presentation. The students then commented on what they imagined it was like to have their "adopted" disease, followed by questions and

Table 1. Final Examination Scores and Student Course Evaluations.

Grades K-12	K-12 Biology Course	No. of Students	Examination Score (Range)	Student Course Evaluations*	Tucson Area BASIS School
7	Biology 2	20	85 (63-100)	4.70/4.70	School B
8	Biology 3	23	86 (55-93)	4.70/4.65	School A
9	Honors Biology	9	90 (78-100)	5.00/4.67	School A
12	"Capstone" (post-AP)	20	87 (70-98)	4.50/4.56	School B

Abbreviation: AP, Advanced Placement.

* Left number represents the mean student "overall course rating," and the right number represents the mean student rating for "personal expectations met," with 1 being "poor" and 5 being "excellent." As all students took a comparable final examination, the cohorts of students were collapsed into the 4 grade levels[7-9,12] for the analyses. One student did not pass the final examination and was not included in the analyses, thus n = 72.

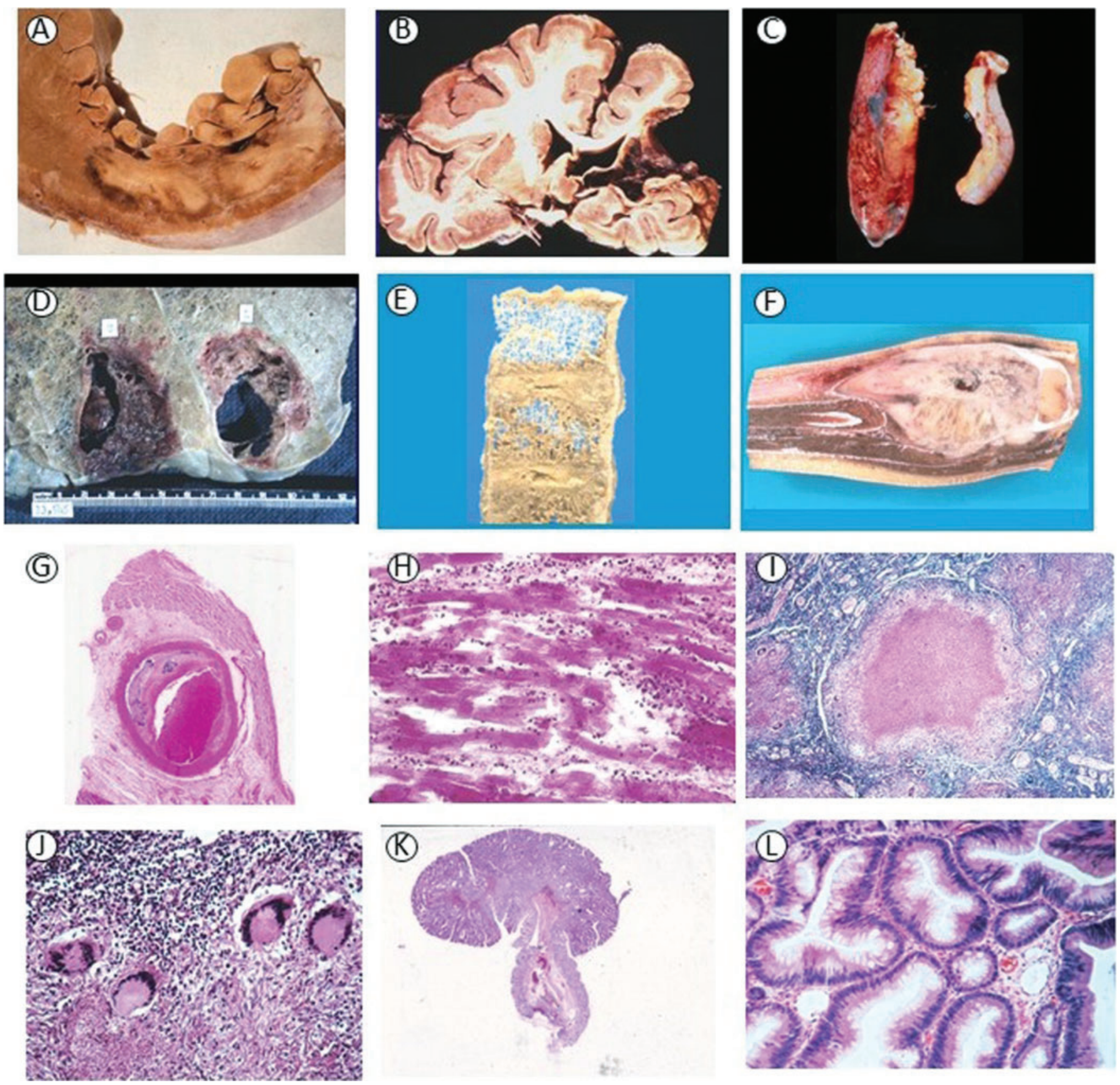

Figure 3. Representative medical images from the "K-12 Pathology Illustrated Glossary." A to F, Gross pathology images. A, Myocardial infarction. B, Brain-old stroke. C, Appendices (acute appendicitis, left; normal appendix, right). D, Lung, *Staphylococcus aureus* abscesses. E, Spine, osteoporosis. F, Femur, osteosarcoma. G to L, light microscopy. G, Heart, coronary artery thrombosis. H, Heart, acute myocardial infarct. I, Lymph node, caseous necrosis, tuberculosis. J, Lymph node, Langhans giant cells, tuberculosis. K, Colonic polyp, low magnification. L, Benign colonic polyp, higher magnification.

Figure 4. A, Whole slide imaging (WSI) by upper school (11th and 12th grade) summer course students. These WSI cases were optional for regular school year students. The students are viewing WSI of colon adenocarcinoma, seen on the video monitor and on their laptop computers. B, A mixed class of 10th, 11th, and 12th grader students in the University Medical Center morgue examining formalin-fixed organs. C, Upper school (9th through 12th grade) students in the T-Health Amphitheater in Phoenix, using the "Push-to-Talk" feature to queue up to answer Jeopardy-type questions. D, Student in the medical simulation laboratory, performing a successful endotracheal intubation exercise. Following 4 unsuccessful intubation attempts, this 11th grade student has succeeded in passing the endotracheal tube into the mannequin's trachea. E, Seventh grade BASIS student in the Simulation Laboratory experiences the performance of laparoscopic suturing. F, College of Medicine, Tucson, K-12 general pathology course completions picture for a mixed class of seventh and eighth grade students.

answers. For some diseases (eg, breast cancer), students found many relevant testimonials on the Web. Occasionally, students substituted a video of their own making if a member of their family, or a friend, happened to have the disease that their student group had been assigned to research.

Final Examination

Questions for the final multiple choice examinations given to all students in the study were drawn from the same pool of medical school general pathology course examination questions. The final examination was given to the students in the final week of their course. All students took a comparable examination.

Student Satisfaction Surveys

The students filled out course evaluations following the completion of the final examination. Two measures of course satisfaction were rated: "overall course rating" and "personal expectations met," with 1 being "poor" and 5 being "excellent."

Statistical Analysis

Several analysis of variance (ANOVA) tests were conducted using test scores as the dependent variable and grade, gender, school, and semester taken as independent variables in a series of 1-way ANOVAs. As all students took a comparable final

Figure 5. "Adopt-a-Disease" evening student presentations at the University of Arizona College of Medicine, Tucson. A, One seventh grader and 2 eighth grade students giving, as a team, 20-minute oral presentations on lupus erythematosus. Areas covered include etiology, pathogenesis, pathology, therapy, outcomes, public health implications, and the presentation of a YouTube testimonial from a patient with the assigned disease. B, Audience for the oral presentations include students, teachers, and family members. C, Poster presentations along the walls of the corridor outside the auditorium. D, Twelfth grade students' poster presentation to parents on chronic myelogenous leukemia.

examination, the cohorts of students were collapsed into the 4 grade levels[7-9,12] for the analyses.

T-Health Amphitheater

The K-12 general pathology course pilot programs were carried out, in part, in the T-Health Amphitheater at the Institute for Advanced Telemedicine and Telehealth (T-Health Institute) in downtown on the new Phoenix Biomedical Science Campus. The T-Health Institute is the Phoenix division of the state-wide ATP. It's a major hub on the 160-site statewide broadband telecommunications network operated 24/7 by ATP engineers. K-12 general pathology was the initial course offering at the T-Health Institute, for high school students. This reflected, in part, the strong commitment of The University of Arizona to K-12 science education and STEM curriculum (Appendix A).

Results

Excluding the pilot cohort of 39 students, 72 of the 73 students passed their final examination. Some mixed classes included both the 7th grade and 8th grade students, whereas others had both the 8th grade and 9th grade students, with the 12th grade students in a class of their own. There was no statistically significant difference ($P < .001$) in examination scores for students in the 7th grade, 8th grade, 9th grade, or 12th grade. This suggests that neither the prior completion of Honors Biology nor Advanced Placement Biology affected the examination scores. This near uniformity in performance across different K-12 grade levels is important in that it affirms the hypothesis that the K-12 general pathology course is essentially an independent variable and can be successfully adapted and inserted into curriculum at many different grade levels (at least as early as the 7th grade) as coursework outside the tight control of health-care profession schools.

Several ANOVA tests were conducted on the final examination score as a function of gender, semester, grade, and school (Table 1). There were no significant differences as a function of school ($F = 0.258$, $P = .6128$), with BASIS OV students having an average of 87 $\pm$ 9 and BASIS TN students having an average score of 86 $\pm$ 8. There were no significant differences as a function of class grade level ($F = 0.627$, $P = .6003$), with 7th grade students having an average score of 85

± 9, 8th grade students 86 ± 10, 9th grade students 90 ± 6, and 12th grade students 87 ± 8. There were no significant differences as a function of the trimester in which the course was taken ($F = 1.360$, $P = .2625$). The overall average was 87 ± 8, with the first trimester at 85 ± 9, second trimester 84 ± 10, and third trimester 89 ± 8. There were no significant differences as a function of gender ($F = 0.608$, $P = .4382$), with females having an average of 87 ± 7 and males an average of 86 ± 10.

In the open question part of the student satisfaction surveys, the students commented that the simulation laboratory exercises, the trip to the morgue to study gross organs, and their Adopt-a-Disease exercise were of especially high value.

Discussion

Throughout the 20th century, recommendations of the legacy 1910 Flexner Report[1-5] that medical science be taught as "upper-level" coursework in medical schools were universally implemented in the United States. Abraham Flexner, an organizational genius, consigned premedical coursework in biology, inorganic chemistry and organic chemistry, and physics to undergraduate colleges.[2,5] By 1930, the medical profession had created its own reality around the Flexner Framework for medical education (Figure 1). For the remainder of the 20th century, critical aspects of medical science coursework were reserved for medical students. This may have had a negative long-term impact on health literacy in the general population in the United States.[28-36] Even today, pathology is not taught at many US nursing and pharmacy schools. Excluding pathology from nursing and pharmacy curricula is myopic and limits the scope of the content of Interprofessional Education and Collaborative Practice (IPECP) exercises downstream.[37-42]

Today, calls for redesign of undergraduate premedical education are resonating among thought leaders.[6-19] With a goal of initiating the process of recalibration of medical science education in the United States, we have instituted an approach that adapts medical school pathology coursework for K-12 middle schools and high schools with encouraging results (Table 1).

An obvious benefit of repositioning medical science coursework earlier in the US education process is that it significantly broadens the student base potentially exposed to critical medical knowledge and critical thinking about diseases that may affect them personally in their own lifetimes. Furthermore, students who have taken medical science prior to entering the health professions, such as medicine, nursing, pharmacy, public health, and the allied health professions, could come to their professional schools well-schooled in the fundamentals of medical science for the first time. Subsequently, when enrolled in their terminal degree programs, interprofessional education subjects could be expanded beyond the constraints imposed today by gaps in the essential medical science educations of especially nurses, pharmacists, and public health workers (Weinstein et al, unpublished data, 2015). Today's IPECP educational topics for medical, nursing, and pharmacy students learning together are limited in their scope and can be restricted to safety and quality of service issues in some settings.[38-41] This could be remedied by the reconciliation of arbitrary differences in the curriculums of the various health professions education tracks. However, this can be a sensitive issue, especially for nursing and pharmacy school deans. One approach might be to institute a common K-12 general pathology course as a gateway course for students tracking into any of the health professions, as supported by the results of this study. Even if those students receiving early education in medical science do not enter into a health profession, they will still have gained important knowledge about the nature and root causes of diseases, in general, and thus be potentially more aware of, and proactive in, their personal health and well-being. Higher levels of health literacy would be a societal benefit as well.[43]

This article describes a disruptive innovation in education, namely, the repositioning of traditional medical school general pathology coursework on mechanisms of diseases from second-year medical school to middle school and high school (Figure 1). Using medical college general pathology coursework as the starting point for creating a multiple-use gateway K-12 medical science course is not simply a marriage of convenience for pathology faculty members involved in the program. General pathology coursework, as taught in US medical schools throughout much of the 20th century, interweaves 3 critical threads: (1) medical practice and health-care providers' perceptions of many diseases are highly visual in nature and well served by the use of visual learning within the context of an image-rich curriculum; (2) understanding mechanisms of diseases is critical to linking science and medical practice; and (3) meaningful use of health literacy by patients requires some knowledge of medical science, however rudimentary, in order to provide context for patients participating in the management of their health. We need to reset the conditions for public education in order to match the circumstances of the 21st century population literacy to the certainty of the 21st century life.[36,42-44] The very medical science subjects that were initially bypassed for inclusion in general studies curriculums offered to college students and K-12 students by the 20th century health education curriculum planners are finally moving center stage for inclusion in the general US education system, at nearly every level in the secondary school education spectrum, and above.

The K-12 general pathology course is intentionally made flexible and can be adapted for additional purposes and venues including using it as a college-credit gateway course for an innovative biomedical science STEM curriculum (eg, STEMM; Figure 2). Furthermore, by adding 10 to 20, 1 to 2 hours, whole slide image laboratories, in which students visualize digital histopathology of iconic diseases and discuss structure–function relationships within diseased tissues and organs, the K-12 general pathology course might be upgraded into a college-level, Advanced Placement medical science course.

Finally, K-12 general pathology can fill yet another role, recently identified elsewhere, in our high school/early entry colleges.[8,44] The early entry college movement is expanding in the United States. This may be the forerunner of a significant movement away from the 20th century framework in which primary and secondary school students spend 13 years in environments spanning kindergarten through 12th grade.[8,44] There are growing concerns over the redundancy of the content in the 11th and 12th grade curriculum with college student coursework. Enhanced K-12 general pathology could be used as a scientific entry point for students entering many different college options or could serve as the gateway for lifelong learning about health care regardless of a students' formal education plans. Exposing students to medical science curriculum in the latter half of the K-12 portion of their education may also result in increased student interest in professional health careers. This could be critically important as shortages in the supply of doctors, nurses, pharmacists, and other health professions are currently on the rise.

The idea of retrofitting an entire population with medical science knowledge sounds onerous. On the other hand, repositioning medical science education earlier in our schools could improve health literacy for a far larger segment of the general population. If understanding the content of medical science is no more challenging than understanding other biological sciences, such as environmental science, it may make sense to introduce medical science in middle school, when a student's language mastery skills are near their peak.[8,44] The education-independent nature of this innovative general pathology course allows for greater flexibility to make it available to a broad range of students of various ages. As students learn the material, they will have increased potential to understand health conditions and to help guide themselves and others to more informed health-care decisions.

Appendix A

The T-Health Amphitheater as a Multimodality "e-Classroom-of-the-Future" and Multipurpose Center for Innovation

The T-Health Amphitheater (conceived by Dr Weinstein) provided the Phoenix site used for the pilot program to develop and test the K-12 general pathology course as a regular school year high school course.[24-27] Figure A1 reflects the high level of interest, and strong level of support, by The University of Arizona's president, and state and national leaders, for activities that were to take place in the international award-winning T-Health Amphitheater, and at the Arizona Telemedicine Program (ATP) headquarters in Tucson, the T-Health Institutes' parent organization. (Figure A1 A and B). A later university president participated in Dr Weinstein's ATP's Tucson activities in Interprofessional Education and Collaborative Practice (IPECP) innovation with enthusiasm as well (Figure A1 C). The T-Health Amphitheater provided an excellent venue in which to develop and test the regular school year version of the K-12 general pathology course (Figure A2). The Arizona Rural Telemedicine Network, a 160-site, 70 community broadband telecommunications network, operated by ATP engineers, is now available for statewide dissemination of the K-12 general pathology curriculum (Figure A3). The University of Arizona has celebrated these accomplishments (Figure A4 A). Currently, The University of Arizona's T-Health Amphitheater is used by over 40 independent Arizona and national organizations for their local, regional, and national videoconferencing events (Figure A4 B). The T-Health Amphitheater has become a destination site for visitors to the Phoenix Biomedical Science Campus in downtown Phoenix. The ATP regards such highly visible activities as providing an important platform for their "disruptive innovations" in education, such as the K-12 general pathology course described in this article.

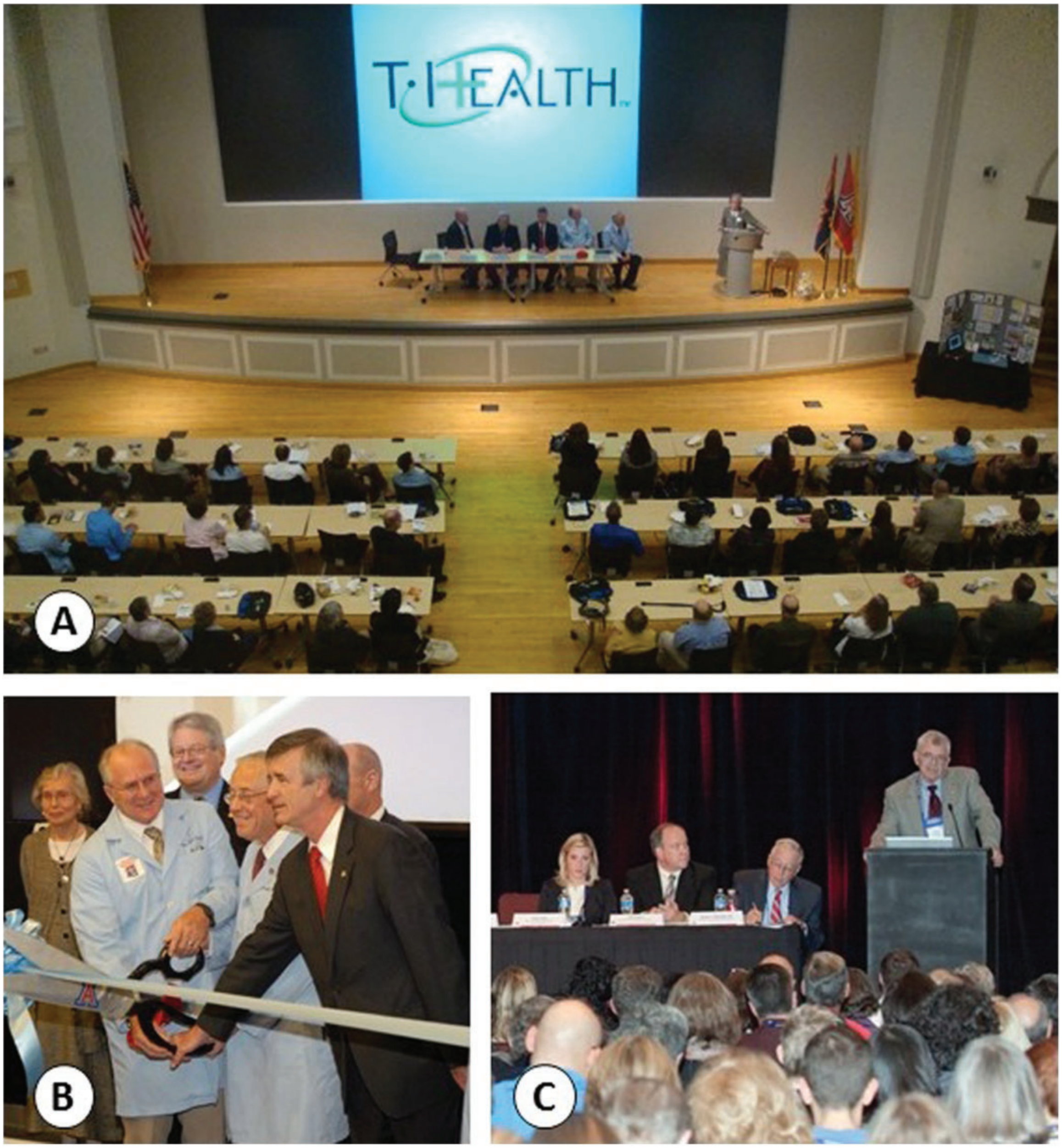

Figure A1. University president's support of the T-Health Institute, the Arizona Telemedicine Program and the Department of Pathology programs in education innovation and reform. A, Dedication of the T-Health Institute, Phoenix, Arizona, the education innovation division of the Arizona Telemedicine Program, codesigned by Dr Weinstein, a former chair of the Department of Pathology, October 23, 2009. A total of over 200 attendees at the T-Health Amphitheater dedication, in the Virginia Piper Auditorium, on the Phoenix Biomedical Campus, in downtown Phoenix. B, 2009—Ribbon Cutting Ceremony for the dedication in the T-Health Amphitheater, Phoenix. Left to right: Madeline Schmitt, RN, PhD, National Leader in Interprofessional Education and Collaborative Practice (IPECP); Robert "Bob" Burns, Arizona State Senate President and Cofounder of the Arizona Telemedicine Program (ATP) with Dr Weinstein; Jon Linkous, Executive Director, American Telemedicine Association; Ronald S. Weinstein, MD, Professor of Pathology (Chair 1990-2007) and Director, ATP; and The University of Arizona President, Robert Shelton, PhD. C, 2011—Opening Ceremony of another major event, the "Collaborating Across Borders III" conference, in Tucson. Hosted by Dr Weinstein, this meeting was the largest meeting in the world, to date, on IPECP. There were 700 attendees from 11 countries. President Shelton's successor, President Gene Sanders, PhD, was at the podium. Dr Weinstein was seated to his right, next to Rick Myers, the President of the State of Arizona Board of Regents and a representative from the local US Congresswoman's office (Representative Gabrielle Gifford, D-AZ).

Figure A2. Video wall in the Arizona Telemedicine Program's T-Health Amphitheater in downtown Phoenix, Arizona. This was created by Dr. Ronald S. Weinstein and his team of computer specialists. His ATP staff programmers, and outside contractors, worked on the customized computer software packages for the video wall implementation for nearly five years. Dr. Weinstein managed the project from Tucson. The T-Health Amphitheater ("e-Classroom-of-the-Future") received the first place 21st Century Achievement Award, education facility category, in the International ComputerWorld Honors program, in 2008. Six 80-inch video screens, comprising a 7 foot $\times$ 18 foot video wall. This dual-function videoconferencing facility was designed as a "command and control" center for Interprofessional Education and Collaborative Practice (IPECP) distributed training and as content aggregator and dissemination center for an envisioned statewide K-12 student medical science education program. Video wall; upper left, 8 off-campus faculty member participating in the video conferenced classroom session; lower left, off-site Tucson participants in the video conference; upper right, "stacks" of off-campus students participating in the video conference, each "stack can accommodate up to 50 students, waiting in a queue to move to the front of the stack, by voice activation. Individual stacks could be constituted of 7th grade, 8th grade, 9th grade, and 12th grade students respectively; lower right, Phoenix participants in the video conference (they could be members of the lay public auditing a student session); upper middle, patient being worked up at a rural clinic in the Arizona Telemedicine Network; lower middle, chest X-ray of a patient (simulation).

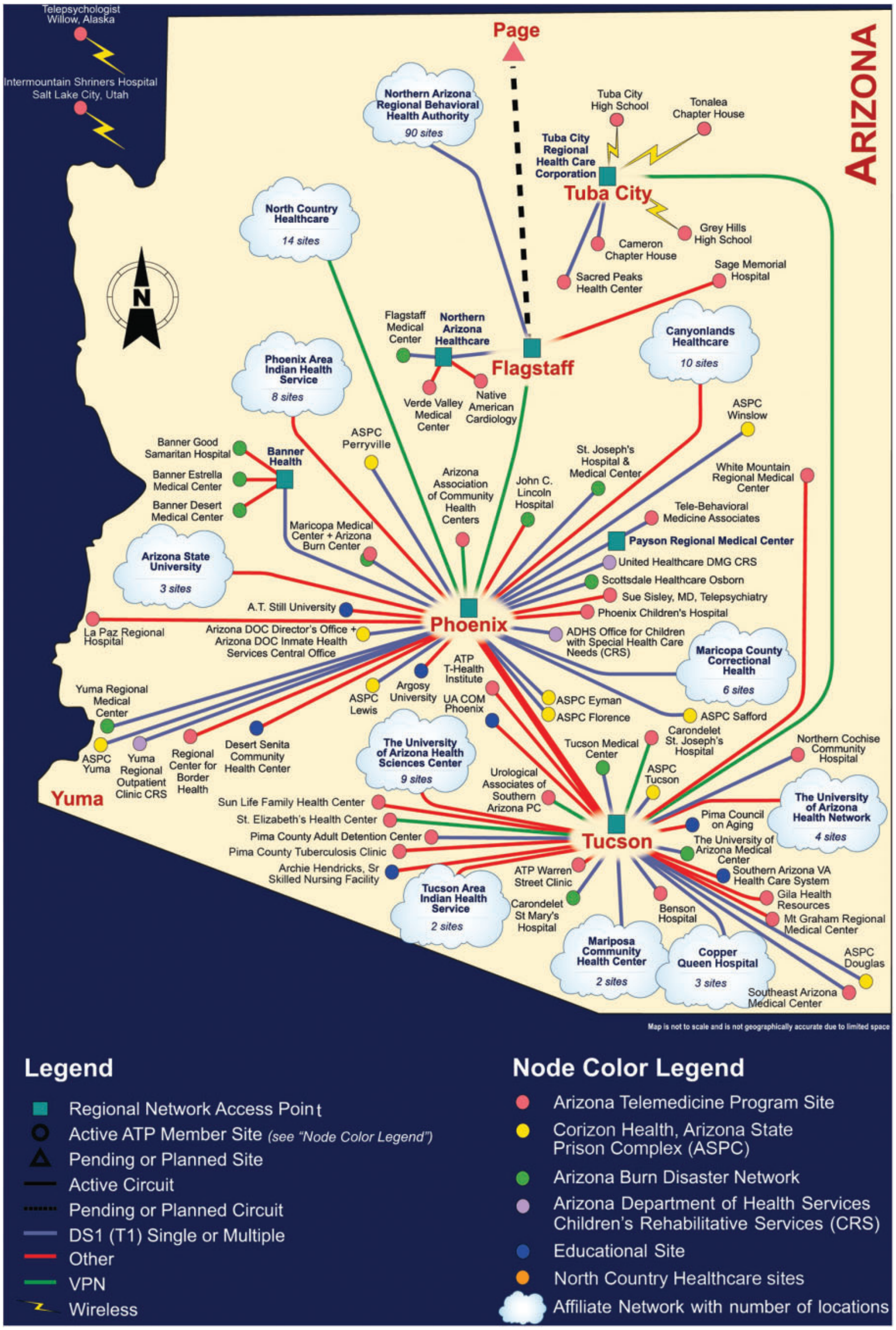

Figure A3. Arizona Telemedicine Program (ATP) broadband, 160-site, telecommunications network, designed and managed by the ATP engineers, since 1998. This network supports both telemedicine services and diverse education, and research, programs. The network will be used for a statewide K-12 general pathology (mechanisms of diseases). Students from 31 high schools and middle schools have already participated in the K-12 general pathology courses sponsored by ATP/T-Health Institute. In addition, over 15 000 hours of College of Medicine CME (Continuing Medical Education) training have gone out over the network.

Figure A4. A. Dr Weinstein (left) being honored at The University of Arizona "2012 Innovator-of-the-Year" Luncheon. The University of Arizona's Technology Transfer Office presented Dr Weinstein with a sculptured glass award trophy (being held) and a US$10 000 monetary award. Dr Weinstein is shown with his long-time collaborator, Arizona State Senate President Burns, R-District 9, (right) at the Innovation Award event in Tucson. Dr Weinstein has had a career-long interest in innovation, dating back to 1964 when, as a Tufts medical student at the Massachusetts General Hospital in Boston, he successfully upgraded an electron microscopy tool enabling the molecular imaging of intramembrane proteins. He continued on as a ground-breaking innovator for the next half century. Dr Weinstein and Senator Burns cofounded the Arizona Telemedicine Program, in 1996, and the T-Health Institute, in 2003. Internationally, working with the US Army Yuma Proving Ground, in Yuma, Arizona, Dr Weinstein and Senator Burns helped establish the Panama Telemedicine and Telehealth Program, in the Republic of Panama, as well as numerous other telemedicine programs at home, around Arizona (Figure A3).[45] The US Army helped plan and fund the build out of the international award-winning T-Health Amphitheater in Phoenix. Dr. Weinstein is a serial entrepreneur who co-founded, with his sister Beth Newburger, one of the first successful IBM PC-based educational software companies, OWLCAT, Inc., in 1982. In 1984, OWLCAT, Inc., was acquired by Digital Research, Inc., the seventh most rapidly growing start-up company in the United States at the time. In 1985, in Chicago, Dr Weinstein was the inventor of robotic telepathology and introduced the word "telepathology" into the English language. He patented and commercialized telepathology. To date, telepathology systems have been implemented in over 30 countries. Dr. Weinstein has been referred to as the "father of telepathology." In Arizona, working with faculty and a graduate student at the University of Arizona College of Optical Sciences, Dr Weinstein was coinventor of the array microscope, a breakthrough optics technology.[46] He cofounded DMetrix, Inc, an Arizona company that established the industry standard for ultrarapid digital scanning of histopathology slides and helped commercialize its ground-breaking DX-40 slide scanner, and next founded UltraClinics, Inc, a company that, in collaboration with College of Medicine faculty, pioneered the concept of bundling of telemammography, telepathology, and tele-oncology same-day breast-care services for women.[47,48] DMetrix, Inc, received several bioindustry "start-up company-of-the-year" awards and national innovation awards and was runner up to General Electric in the International Wall Street Journal Innovation Award competition. DMetrix, Inc, has been granted 29 US patents.[49] B, Arizona Governor Jan Brewer (seated) signing important telemedicine legislation at the Arizona Telemedicine Program's T-Health Amphitheater, in Phoenix. Standing, left to right: Senator Bob Burns, State Senator Gail Griffin (R-District 25), Dr Weinstein, Stuart D. Flynn, MD, Dean, University of Arizona College of Medicine, Phoenix, and Steve Goldschmid, MD, Dean, University of Arizona College of Medicine, Tucson. These activities contributed to the world-class reputation of the Arizona Telemedicine Program, and its T-Health Institute, as leaders in innovation and helped set the stage for the creation of the innovations in K-12 medical science education described in this article.[50,51]

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Note

1. In this article, for purposes of consistency, the commonly used abbreviated designation for Flexner's initial book on medical school curriculum,[1] the so-called "1910 Flexner Report," is modernized to "Flexner 1.0." A mixed bag of proposals and ideas for modernizing the recommendations in Flexner Report 1.0 leading up to, or stemming from, the 100-year commemorations of 1910 Flexner Report, in 2010, are referred to here, collectively, as "Flexner 2.0" documents.[2,6,9,17,19] Most of these thought leaders assumed that medical science would remain under the authority of the medical profession into the foreseeable future. We disagree. In this article, we refer to our K-12 general pathology gateway course (also called "Omnibus Pathology Course" due to its universal applicability; Figure 2) as an introductory course for a future "Flexner 3.0" curriculum. As envisioned, that curriculum would also provide follow-on courses on a broad range of medical science subjects, as well as complementary courses and experiences linked to other academic fields. Implicit in the Flexner 3.0 concept is that medical science education and medical knowledge will be liberated and flow naturally throughout society. We are hopeful that the recent reorientation of the US National Academies of Sciences, with its creation of a new US National Academy of Medicine, could trigger national efforts to democratize medical knowledge throughout our schools and along other information highways.[8,43] The strikingly low levels of health literacy in the United States are unacceptable if patients are expected to fully participate in their own health care, as proposed by public policy thought leaders here and abroad.[29,34,36]

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