JOURNAL OF CHEMICAL EDUCATION

Article

pubs.acs.org/jchemeduc

Chemical Education in India: Addressing Current Challenges and Optimizing Opportunities

Mangala Sunder Krishnan,[†] R. Brakaspathy,[‡] and E. Arunan*[,§]

[†]Department of Chemistry, Indian Institute of Technology, Madras, Madras, India600036

[‡]Department of Science and Technology, Ministry of Science and Technology, New Delhi, India 110016

[§]Department of Inorganic and Physical Chemistry, Indian Institute of Science, Bangalore, Bangalore, India 560012

ABSTRACT: This article gives a brief introduction to the structure of higher education programs in chemical and general sciences in India. The lack of high-quality chemical education in India in the past is traced back to the economic and social developments of the past. Remedial measures undertaken recently to improve the overall quality of chemical education and research are indicated. For the chemical education community worldwide, opportunities in India for enhancing chemistry education quality through collaborations in technical and commercial undertakings are indicated.

KEYWORDS: *First-Year Undergraduate/General, Graduate Education/Research, Curriculum, Multimedia-Based Learning, Internet/Web-Based Learning, Public Understanding/Outreach, General Public, Administrative Issues, Standards National/State*

INTRODUCTION

This article is a follow-up to editorial comments[1] by the editor-in-chief of the *Journal of Chemical Education*, and subsequent correspondence by one of us (EA) to the editor-in-chief in which an invitation was made to provide a summary of the status of chemical education in India. When India gained independence, its first Prime Minister, Pandit Jawaharlal Nehru, proclaimed "Unity in Diversity". The diversity Pandit Nehru mentioned was perhaps related to the multitude of languages and religions, and, in general, the diversity of lifestyles within the nation. This diversity continued and expanded even as the opening of the Indian economy to the western world in the 1990s took India in a direction to become a global nation not different from any other developed nation in the world. India is ranked fifth in chemical research output in the world, and the research scenario was discussed in a recent article.[2] If one looks at the education sector in India today, it is quite easy and straightforward to conclude that education in India has a diversity and challenge that is unmatched by any other part of the world.

In secondary education, there are schools with one teacher for the whole of science teaching; there are also international boarding schools with an impressive faculty/student ratio in which students have access to some of the most modern learning tools. The spectrum of schools with varying standards of education in India is unique in the world.

In higher education, India has about 630 universities[3,4] (central, state, and privately owned) and 34000+ colleges: 20 Indian Institutes of Technology (though only five of them are 50 or more years old), Indian Institute of Science (IISc, more than 100 years old), and several state and central universities, some of which are more than 100 years old. IITs, IISc, a few central universities, and the Tata Institute of Fundamental Research (TIFR) are known to be world-class in teaching and research. In addition there are 30 National Institutes of Technology (NITs, with more than half of them recently founded and the others renamed and upgraded from regional engineering colleges (REC) established from the sixties onward) and six newly founded Indian Institutes for Science Education and Research (IISER). There are also 30 central universities. The IITs, IISc, and NITs, and the Central Universities are funded by the Government of India through the Ministry of Human Resource Development.

A large number of colleges in India are also unitary institutions, such as those that offer arts and science programs only; those that offer commerce, management, and business only; agricultural institutions; medical universities; and engineering and technology institutions. There are a number of private educational institutions which offer good to excellent chemical education. More than several hundred (among the 630 plus) universities offer chemistry education at both undergraduate and postgraduate levels. India has the second largest population of students in chemical sciences in the world, next only to China. The reader is referred to other articles in

Received: April 16, 2016
Revised: July 15, 2016

this *Journal* for a discussion on chemical education in other countries.[5−8]

Till the late 1980s, science programs in universities and colleges also attracted more motivated students who placed themselves quite high in schools since the alternatives to arts and science by way of engineering, medicine, and other professional courses were far fewer. National laboratories established through the Council of Scientific and Industrial Research, Departments of Atomic Energy and Space, had already begun attracting young Indian science students, and the quality of chemical education was moderate to high. Research funding and laboratory training were quite limited until the late eighties due to significantly low funding by the government, but that did not prevent motivated students from entering science streams. The situation changed drastically when the economy opened in the nineties and the IT sector in India began establishing itself as a strong and vibrant industry, a situation that continues to this date.

THE SHIFT OF FOCUS IN THE NINETEEN-NINETIES

Three contrasting developments in chemical/science research and education have occurred since 1990.

First, the booming IT industry led to a significant rise in revenue. It enabled the government to spend quite liberally on education and research from the 1990s onward. Investment in R&D increased from $12.9 billion in 2002 to $41.3 billion in 2012 (on the basis of purchase power parity [PPP]) (current exchange rate is about Rs. 65 per US dollar, and all subsequent numbers will be in Indian Rupees, without any correction to PPP). Advisory bodies such as Science Advisory Council (SAC)[9] and the new Science, Technology and Innovation Policy (STI Policy—2013) advocate the increase in outlay for R&D to 2% of GDP from the current 0.88%, and enunciate the steps to achieve that by way of increase in private sector investment in R&D. Scholarships, bursaries, and research funds available have increased sizably, and this has had a positive influence for research programs.

Second, the immediate downside to this has been the exodus of bright students from traditional arts and science programs to engineering and IT and the establishment of several thousand private engineering and technical institutions to provide professional education courses. The balance has thus shifted so much that science programs have often ended with a large fraction of students who were otherwise not able to get into technology programs. However, this might be short-lived, and the various enabling policies and programs of the government (vide infra) indicate that motivated students are being attracted back to science education as well as professional courses. The loss is still substantial.

Third, state universities have not been able to function as well as in the past, with reduced or no faculty hiring in the last few decades due to various political, financial, and socio-economic reasons. While it is constitutionally recognized in India that a significant extent of educational and employment opportunities must be reserved to castes and communities ignored for hundreds of years, the practice of implementing the reservation policy in both student admissions and faculty hiring has found its utmost challenge. Though the Supreme Court of India had suggested that the reservation shall not exceed 50%, some state governments have legislated even higher percentage of reservation. The numbers of qualified personnel in some categories were low, and this led to a large number of faculty positions remaining vacant for a long time and an alarming degree of neglect of education, research, and development in chemical sciences in many state universities and student apathy toward chemistry.

EFFORTS TO FURTHER CHEMICAL EDUCATION AND RESEARCH IN INDIA IN THE LAST DECADE

Funding for higher education is provided largely by the central government through the Department of Higher Education (with an annual budget of Rs. 162,100 million for 2013−2014) in the Ministry of Human Resource Development (MHRD) and also by the state governments. The private sector investment in higher chemical education is primarily through their institutions and is a small fraction of public funds. Funding for research is still largely provided (about 65%) by the central government. The major funding agencies are the Department of Science and Technology (DST), Department of Biotechnology (DBT), Council of Scientific and Industrial Research (CSIR), Department of Atomic Energy (DAE), Indian Space Research Organization (ISRO), the Ministry of Earth Sciences, and the Science and Engineering Research Board (SERB), a newly created autonomous body established through an act of parliament. The outlay for these central scientific ministries and departments increased from Rs. 4.4 billion in the fifth Five-Year Plan period (1974−1979) to Rs. 236 billion in the 10th Five-Year Plan period (2002−2007), to Rs. 475 billion in the 11th Five-Year Plan period (2007−2012), and further to Rs. 1.2 trillion in the 12th Five-Year Plan period (2012−2017). These departments support a large number of individual-centric, curiosity-driven research in contemporary areas, including chemistry. There are also a large number of collaborative funding schemes in these departments, particularly for chemistry research, carried out with scientists in the USA, Canada, UK, France, Germany, Australia, and Singapore, to name a few. While most of the funding is made available to initiate and carry on research activities in chemistry/science, the quantum and the distribution across the country for education in the last ten years also indicate the changing landscape and the participation by many as opposed to a select few in the early seventies and late eighties. The University Grants Commission (UGC) and the Ministry of Human Resource Development (MHRD) are bodies that provide both infrastructure and operational grants for running all centrally funded institutions, including salaries and retirement benefits to faculty and staff. In addition, DST has been funding infrastructure development in many higher educational institutions, as a result of which university-share for research has increased substantially. The increased contributions of Indian chemists toward research publications as a result of this support have been pointed out elsewhere.[2] The same article also contains research outputs from a few selected countries, including India (Figure 1 of ref 2).

The launching of the six new educational and research institutions by the MHRD a few years ago, known as Indian Institute for Science Education and Research (IISER), for integrating higher education and research in all of science is a definite shot-in-the-arm for well-wishers of Indian science. While IITs and IISc have been contributing to the bulk of high-quality research in chemistry and chemical engineering since they started, the bulk of the students who enter these institutions have a technology orientation. Though most IITs have a large number of Ph.D. scholars in science, capacity building in India in the current decade and an orientation to do high-quality basic science research in an integrated fashion with

DOI: 10.1021/acs.jchemed.6b00231
J. Chem. Educ. XXXX, XXX, XXX−XXX

the launch of six IISERs is almost a dream come true for science; well funded as these institutions are, there is very little doubt they will be of high quality. If given the same degree of intellectual and financial support as the IITs so far which have produced technology leaders for the world, IISERs should lead science in the coming era, in particular, chemistry and chemical research. Added to that is the starting of a four year integrated science undergraduate program in IISc and the Centre for Excellence in Basic Sciences, Mumbai, started by the Department of Atomic Energy and University of Mumbai. Governments need to be committed to such acts for decades. It is also noted that with the founding of a number of such institutes with high-caliber faculty and research facilities, bright young students will find science to be a serious and engaging career option. We believe that this will benefit basic research at the interfaces of physics/chemistry/biology.

CURRENT MEASURES TO BRING STUDENTS BACK TO CHEMICAL (AND SCIENCE) EDUCATION AND RESEARCH

Until the year 1999, only postgraduate fellowships were available for science. In that year, a program for science induction known as Kishore Vygnanik Protsahan Yojana[10] (KVPY: i.e., Budding Scientists Encouragement Scheme) was started with scholarships supporting full undergraduate and science education in recognized Universities. Another program abbreviated as INSPIRE[11] (INnovation in Science Pursuit for Inspired REsearch) was started in 2008. The latter has handed out so far about 47000 scholarships to qualified youngsters joining science programs. A number of other schemes, such as the Summer Research Fellowship Program (SRFP) through the Academies of Science in India and also by the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Bangalore, National Initiative on Undergraduate Science and Visiting Students Research Program by TIFR, Mumbai, are also addressing the existing disconnect between undergraduate (UG) education and research. Though these programs are intended for UG students, they also provide opportunities for teachers in small colleges to have research experience.

Admission to doctoral programs in science is done through a national level examination conducted by the CSIR biannually. In the examination held in June 2014, a total of 144,591 students appeared for the examination and 5326 qualified (1535 in chemistry). The INSPIRE program offers about 1000 doctoral fellowships to university toppers every year, and so far it has awarded 4418 research fellowships. The number of research fellowships offered is around 6000 per year. Approximately 30% of them are given in chemical sciences. This does not, however, include the fellowships released from projects funded to faculty throughout the country as well as the fellowships given by the Ministries such as the MHRD (which funds IISc, IITs, and NITs and their postgraduate student scholarships directly). These are analogues of research and teaching fellowships provided by US universities from university teaching and research funds. At any point in time, all of these lead to government support for about 70,000 full-time Ph.D. students.

During this period, a number of new science programs for modernizing infrastructure in universities and academic institutions were also initiated. FIST[12] (Fund for Improvement of Science and Technology infrastructure) and PURSE[12] (Promotion of University Research and Scientific Excellence) are two new programs. As a result of funding through these programs and others, there is rejuvenation of research in the university sector, as evidenced from the increase in the share of scientific publications by the Universities from 15% of all research from India in 2003 to 31% in 2010. FIST started in 2000 and has funded more than 2100 departments and colleges with a financial outlay of Rs. Nineteen billion (chemistry share is Rs. 4.6 billion, 23.8% for 662 departments). PURSE began operation in 2009, and 44 universities have been supported with the total budget of Rs. 3.3 billion.

INITIATIVES FOR MASSIVE ONLINE CHEMICAL EDUCATION AND CERTIFICATION

Massive online open education in India has been formally launched in the era of the Internet by the National Program on Technology Enhanced Learning (NPTEL)[13] in the year 2003 for technical courses. This program was drafted by the IITs with professional help and advice from Carnegie Mellon University, Pittsburgh. Somewhat fortuitously, the NPTEL announcement coincided with the announcement of Open Courseware by MIT, Cambridge.[14] The government of India fully funded the NPTEL[13] and also launched the National Mission on Education through Information and Communication Technology (NMEICT)[15] in 2009. Under these two initiatives, a large number of curriculum based courses in chemistry and chemical engineering have been made available since 2012. NPTEL received Rs. 204.7 million for the first four years (US $5.5 million in 2003), 2003−2007, and received a second grant of Rs. 960 million in the year 2009 (US $21 million) under NMEICT.

More than 50 postgraduate courses in chemistry alone are nearly complete along with about 80 courses in chemical engineering. The project covers many other disciplines. Courses contain content equivalent to 40, 1 h lectures and can be used for self-study or to supplement the university curricula.

The launches of NMEICT and National Knowledge Network (NKN) for enabling gigabit connectivity between premier academic institutions, universities, and national research laboratories have helped in content development and dissemination using ICT tools for students of arts, science, commerce, humanities, management, and allied disciplines. The contents are available freely and are open for editing/repurposing. Virtual laboratories in engineering and chemical sciences have already begun to appear through coordinated efforts of IIT Delhi with ten or more other partner institutions.[16] These are distributed currently under Creative Commons License Share-Alike and Attribution, which is the same license adopted by Wikipedia. This has created a wealth of learning that was inaccessible only a decade ago. Coupled with development tools and the launch of massive open online course (MOOC)[17] programs by premier academic institutes with government funding, the opportunities for bringing in engagement and excitement in learning science, and particularly chemistry, are bright. Pedagogical tools for learning and outcome-based learning are now being brought in by national agencies in massive teacher training programs which will help them shape the youth.

CHALLENGES AND OPPORTUNITIES

The authors propose four major stakeholder groups that will have to drive and benefit from high-quality chemical education in India, for which several programs have already been initiated

DOI: 10.1021/acs.jchemed.6b00231
J. Chem. Educ. XXXX, XXX, XXX−XXX

by the government, as mentioned above. Demographic studies predict[18] that, in the next 10−15 years, India will have nearly 25% of the under-25 population in the world. Every effort should be made to improve the quality of education in India, and even more, not doing so with a sense of urgency will be suicidal to the development of the largest democracy in the world. With a population of 18 million students already in full-time higher education (with about two million in chemistry alone) and increasing at an alarming rate, and with the gross enrollment ratio in higher education still stuttering around 20%, every group of stakeholders has enormous responsibilities and opportunities. The stakeholders are identified as follows:

- Teachers and researchers in universities and research laboratories in India and professional bodies such as the Chemical Research Society of India
- The chemical industry in India and worldwide
- Government and professional scientific bodies responsible for framing and funding policies and implementing them
- International universities, academic bodies, and professional science groups led by the ACS and RSC in the world

One or more of the groups above may have to work together to significantly raise the quality of chemical education and research output. The challenges faced by the groups are far outweighed by the opportunities created; the rest of this section describes them in relation to the stages in learning and the possible roles of stakeholders.

School Education (Secondary and Higher Secondary Levels)

Indian students who choose their higher education programs have a far more substantial influence on their choice by their parents, who almost always fund them as well. Thus, *a quality chemistry education and research program in India has to convince **parents***. It is therefore quite important to introduce paradigms and objective/purposeful learning in school education through which science is seen not as a subject of rote learning, but as a subject that is exciting and a game changer for societies through lessons on discoveries and innovations of the past and small, yet revealing, hands-on demos by the children. ICT and the Internet offer some of the most exciting prospects for excitement in learning, and in the next few years, reforming the school science education curriculum and introducing simple and effective game-based learning strategies must be carried out with utmost urgency. For school, education pedagogical methods must be rigidly followed and assessment should discourage rote memory and reproduction.

Higher Education (Graduate and Post-Graduate Levels)

College level education needs to have many more practical demonstrations and learning-to-learn/unlearn concepts with direct benefits to employment, research or innovations. Programs have to be carefully designed to cater to multiple learning outcomes. NPTEL, NMEICT and Open Educational Resources available worldwide are very useful for focusing one's needs. New educational experiences using MOOC,[17] flipped class,[19] and so on need to be integrated as part of credit transfer programs if an institution does not have the necessary core competence. In addition, direct reaching out to students from colleges through innovative projects in which their faculty may contribute sizeably needs to be considered. With the availability of Internet and cloud for free access and dissemination, open-ended problems may be stated by research teams from premier institutions as potential projects.

There is currently a significant diversity in program years (three-year UG followed by two-year PG, four-year UG and five-year combined UG-PG with exit in between or not); to take maximum advantage of these, major subjects and electives need to be offered using a flexible credit system. The choice of courses available and electives that can be taken are minimal at present across all these programs. Already many engineering institutions in India have created student exchange programs in massive scales with western nations. Extending them to chemistry and other science initiatives in India with a large number of arts and science colleges through MOOCs is another potential step to correct for the students' apathy toward science degrees and the significantly low numbers still of motivated undergraduate population in science programs. It is already well established that Indian students are the second largest contingent of students for MOOCs offered by most American institutions. Formalizing the same through interactions with government and university/academic regulatory bodies in India is a win-win situation for everyone concerned.

Systemic decay of chemistry education, due to the poor lab facilities and poor educational infrastructure of many universities, needs to be checked immediately. Most universities are state-owned, and infrastructure spending for education by state governments is poor to nil. In addition to the central government's efforts to improve chemical lab infrastructure through FIST, it is necessary to build real and virtual laboratories for improving the quality of learning the concepts through experiments. Many more laboratories need to be established. The faculty in India and abroad who are well educated in their own subjects must see this as an opportunity to innovate and enhance technical and ICT capabilities for teaching experimental chemistry to the YouTube−Twitter−Facebook−mobile generation. Many American universities and programs from ACS, NSF, and The Royal Society are grappling with this problem and have a considerable head start already. One of the authors (MSK) recalls even now the excitement that he had when he was introduced to the virtual chemistry lab known as the IrYdium Project developed by David Yaron of Carnegie Mellon University in 1999.[20] The subsequent development of OCW courses by MIT Cambridge, Open Learning Initiative of CMU,[21] Canadian and Stanford's MOOCs, and NPTEL are examples of how Indian chemical education can be excited to a new level with both internal models and external help.

Implementation of Online Learning Pedagogies

While a large number of new developments on the Internet focus on types of deliveries and access to a large repository of chemical information content, they do not automatically facilitate learning effectively: "Information is NOT instruction" (David Merrill).[22] Outcome-based learning sequences and suitable taxonomies[23] of learning need to be incorporated and a diligent and outcome-based curriculum is the need of the hour. Online curriculum development and certification using MOOCs which are now currently under experimentation in India by a number of IITs are concerned with these aspects as well. This also means a large number of chemical educational resources still need to be developed that would permit different learners with specific outcomes to meet their career expectations.

DOI: 10.1021/acs.jchemed.6b00231
J. Chem. Educ. XXXX, XXX, XXX−XXX

It is important to continuously train teachers through specific career incentives (not necessarily financial always). In India, the teacher–student ratio is far from acceptable global standards. This is currently a serious shortfall, which the online education programs need to address. MOOC programs can be proctored and certified for teacher training and with academic incentives for those who complete them. MOOCs can be designed for teachers to highlight difficult chemical concepts and innovative ways of explaining them with a large number of state-of-the-art examples from current literature. They can be offered on how to use technology for enhancing conceptual learning through animations and virtual laboratories; MOOCs can be offered by industries for students to understand chemical processes based on sound fundamentals. MOOCs are already being experimented with in several countries in the world, and in India this could fill in a void created by the lack of teachers with the highest degree. The paradigm shift envisaged through MOOCs in teaching–learning is more suited to training teachers and career orientations than merely creating courses for everyone, as followers of MOOC are currently attempting.

Role of Government and Government-Funded Institutions

Diverse disciplines in universities such as law, medicine, and agriculture which require strong interfaces with chemistry (ethics, environment and forensics, pre- and para-clinical subjects, and novel chemical and biochemical processes, respectively) are currently independent entities and not interdependent as they should be. The government may encourage universities to include as many diverse disciplines as possible; interdisciplinary programs will be far more effective and will be productive when core programs of the respective fields are strengthened and are offered in one and the same campus and with adequate credit transfers between them.

Interdisciplinary programs can be introduced effectively only after achieving adequate learning in core disciplines. They are often quite effective at the Master's level. Uncritical introduction of specialty subjects as undergraduate disciplines (e.g., nanotechnology, biotechnology, and information technology) needs to be carefully reviewed and scrapped wherever possible.

IITs, IISc, and other premier institutions doing chemical research must design strong outreach programs for students in the nonmetropolitan areas. They need to encourage mandatory visits by faculty and students from secondary and tertiary institutions and increase interactions to help bring about awareness and present a vibrant picture of chemistry, which is currently severely missing. The initiative by IISc to start a Talent Development Centre[24] to help train high-school teachers all over Karnataka is worth mentioning. Such initiatives all over India would be essential.

Role of Industrial and International Partners

Direct participation by the chemical industry and chemistry researchers throughout the world in curriculum design is a must for innovations to begin at colleges. International chemical companies have all set their feet firmly in India with a research focus; the opportunity to design new curricula to help build industrial research and development with laboratories within academic campuses is enormous.

Chemical industries can help in opening up parts of their research laboratories for a fee to academic activities or absorb the cost as part of their corporate-social responsibility. Poor lab facilities and lack of quality time for hands-on experience through the laboratories currently plague most academic institutions. This may be ameliorated with faculty members undergoing such training in industrial research laboratories.

Chemical industries may be encouraged to set up research laboratories within university premises and carry out long-term R&D programs in collaboration with faculty and students in the university. Such practices happen naturally in the US and other Western nations. State governments may find it difficult to support such initiatives financially and on a long-term basis. Hence, apart from providing access to facilities, significant funding from private industries would be essential. Moreover, such laboratories are also the work areas where innovation and design can be encouraged. Young and aspiring undergraduate students and research scholars may be supported through funds under corporate-social responsibility, which are also incentivized by tax schemes.

■ CONCLUSION

The Flat World was made popular again in the last ten years,[25] in an entirely different context after a space of nearly several hundred years. It was humorously referred to as well in the introductory remarks by Stephen Hawking in his popular science account.[26] This flat world now offers unparalleled opportunities for enabling Chemical Education in India to level with the best in the world. The leveling will not only raise the competitiveness among all partners but will offer innumerable opportunities to professional educational bodies such as the American Chemical Society and chemical industries worldwide to derive much larger benefits for growth and development. Some of the challenges in achieving this goal in the short term, and the opportunities for every player in the long term, have been identified in this article based on the authors' experiences. It is hoped that these challenges will be met and the opportunities utilized.

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: arunan@ipc.iisc.ernet.in.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The authors would like to thank the respective government department agencies (DST, CSIR, and MHRD) for providing help with some of the data presented here. One of us (MSK) would like to thank the Department of Inorganic and Physical Chemistry, IISc Bangalore, for the offer of a visiting professorship for the period Aug–Dec 2014, when the initial draft of this article was written. The authors thank the anonymous reviewers for some suggestions that helped the authors in revising the article to its present form.

■ REFERENCES

(1) (a) Pienta, N. J. Innocents Abroad: A *Journal's* Outreach to India. *J. Chem. Educ.* **2013**, *90* (1), 1–2. (b) Pienta, N. J. Innocents Abroad, Part II: A Glimpse at Chemical Education in India. *J. Chem. Educ.* **2015**, *92* (3), 399–400.

(2) Arunan, E.; Brakaspathy, R.; Desiraju, G. R.; Sivaram, S. Chemistry in India: Unlocking the Potential. *Angew. Chem., Int. Ed.* **2013**, *52*, 114.

(3) (a) Inclusive and Qualitative Expansion of Higher Education: 12th Five-Year Plan 2012–2017; University Grants Commission: New Delhi, 2012; http://www.ugc.ac.in/ugcpdf/740315_12FYP.pdf (accessed Jul 2016). (b) Higher Education in India at a Glance;

DOI: 10.1021/acs.jchemed.6b00231
J. Chem. Educ. XXXX, XXX, XXX–XXX

University Grants Commission: New Delhi, 2012; http://www.ugc.ac.in/ugcpdf/208844_HEglance2012.pdf (accessed Jul 2016).
(4) (a) Annual Report 2012−2013; Department of Science and Technology, Government of India: New Delhi, 2012; http://www.dst.gov.in/sites/default/files/annual-report-2012-13_0.pdf (accessed Jul 2016). (b) Annual Report 2013−2014; Department of Science and Technology, Government of India: New Delhi, 2014; http://www.dst.gov.in/sites/default/files/annual-report-2013-14_0.pdf (accessed Jul 2016).
(5) (a) Yong, W. Developments in Chemical Education in China—STS Education and Social Organic Chemistry. *J. Chem. Educ.* **1994**, *71* (6), 509−510. (b) Xianchang, Y.; Yan, X. Developments in Chemical Education in China—Reform of Instruction in Chemical Experiments in China's Middle Schools. *J. Chem. Educ.* **1994**, *71* (6), 510−511.
(6) Coppola, B. P. Selamat Datang di Indonesia: Learning about Chemistry and Chemistry Education in Indonesia. *J. Chem. Educ.* **2008**, *85* (9), 1204−1209.
(7) Tan, K. S.; Goh, N. K.; Chia, L. S. Bridging the Cognitive-Affective Gap: Teaching Chemistry while Advancing Affective Objectives. The Singapore Curricular Experience. *J. Chem. Educ.* **2006**, *83* (1), 59−63.
(8) (a) Sanger, M. J.; Brincks, E. L.; Phelps, A. J.; Pak, M. S.; Lyovkin, A. N. A Comparison of Secondary Chemistry Courses and Chemistry Teacher Preparation Programs in Iowa and Saint Petersburg, Russia. *J. Chem. Educ.* **2001**, *78* (9), 1275−1280. (b) Berdonosov, S. S.; Kuzmenko, N. E.; Kharisov, B. I. Experience of Chemical Education in Russia: How To Attract the Young Generation to Chemistry under Conditions of "Chemophobia. *J. Chem. Educ.* **1999**, *76* (8), 1086−1088.
(9) Scientific Advisory Committee to the Cabinet (SAC-C) [Apex advisory body of the Government of India in science & technology]. http://psa.gov.in/scientific-advisory-committee/scientific-advisory-committee-cabinet-sac-c (accessed Jul 2016).
(10) Kishore Vygnanik Protsahan Yojana (KVPY). http://www.kvpy.org.in (accessed Jul 2016).
(11) DST INSPIRE Programme: Report and Recommendation from Academies' Advisory Panel 2010. http://www.inspire-dst.gov.in/INSPIRE_Academy_Panel_Report_2010.pdf (accessed Jul 2016).
(12) Report of Bibliometric Study Commissioned to NISTADS by DST (reference to FIST and PURSE); Science, Technology and Innovation Policy, Ministry of Science and Technology, Government of India: 2013; http://www.dst.gov.in/sites/default/files/Salient%20Highlights%2C%20Elsevier%2C%20Scopus%20Report%20%2831.5.16%29.pdf (accessed Jul 2016).
(13) National Program on Technology Enhanced Learning (NPTEL). http://nptel.ac.in (accessed Jul 2016). Workshop on Technology Enhanced Learning (WoTEL) documents are available at this site, as are other NPTEL project documents.
(14) Massachusetts Institute of Technology Open Courseware (OCW) home page. http://ocw.mit.edu (accessed Jul 2016).
(15) The National Mission on Education through Information and Communication Technology (NMEICT), Mission Document, Department of Higher Education; Ministry of Human Resource Development, Government of India: New Delhi, 2009; http://mhrd.gov.in/sites/upload_files/mhrd/files/upload_document/MissionDocument.pdf (accessed Jul 2016). See also the Sakshat Web site: http://www.sakshat.ac.in (accessed Jul 2016).
(16) Virtual Labs. An Initiative of Ministry of Human Resource Development (MHRD) under the National Mission on Education through ICT; http://www.vlab.co.in/ (accessed Jul 2016).
(17) (a) Downes, S.; Siemens, G. http://www.mooc.ca (accessed Jul 2016). (b) *Invasion of the MOOCs: The Promise and Perils of Massive Open Online Courses*; Krause, S. D., Lowe, C., Eds.; Parlor Press: Anderson, SC, 2014. (c) http://en.wikipedia.org/wiki/Massive_open_online_course (accessed Jul 2016).
(18) Reaping India's Promised Demographic Dividend—Industry in Driving Seat. http://www.ey.com/Publication/vwLUAssets/EY-Government-and-Public-Sector-Reaping-Indias-demographic-dividend/$FILE/EY-Reaping-Indias-promised-demographic-dividend-industry-in-driving-seat.pdf (accessed Jul 2016).
(19) Ropchan, K.; Stutt, G. Flipped Classroom. http://etec.ctlt.ubc.ca/510wiki/Flipped_Classroom (accessed Jul 2016).
(20) Carnegie Mellon University, Department of Chemistry. The IrYdium Project. http://collective.chem.cmu.edu/pdf/UserGuide.pdf (accessed Jul 2016).
(21) Carnegie Mellon University. Open Learning Initiative. http://www.cmu.edu/oli (accessed Jun 2016).
(22) Merrill, M. D. Instruction Strategies That Teach. http://mdavidmerrill.com/Papers/InstructionalStrategiesThatTeach.pdf (accessed Jul 2016).
(23) Bloom, B. S.; Engelhart, M. D.; Furst, E. J.; Hill, W. H.; Krathwohl, D. R. *Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook I: Cognitive Domain*; David McKay Company: New York, 1956.
(24) Indian Institute of Science. Talent Development Centre: Kudapura, http://tdc.iisc.ernet.in/ (accessed Jul 2016).
(25) Friedman, T. L. *The World Is Flat*; Farrar, Straus and Giroux: New York, 2005.
(26) Hawking, S. *A Brief History of Time: From the Big Bang to Black Holes*; Bantam Dell Publishing Group: New York, 1988.

DOI: 10.1021/acs.jchemed.6b00231
J. Chem. Educ. XXXX, XXX, XXX−XXX