Entrance examinations for science and technology

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The history of the Indian Institutes of Technology (IITs) and the current state of their joint entrance examinations have an important lesson for higher education in science and technology. The IITs were originally created to produce a skilled workforce of scientists and engineers to support the economy and society of the newly independent India, and to represent 'India's urges, India's future in the making'. IIT Kharagpur, the first of the IITs, was set up in 1950. Over the next decade came four more, and together, the five IITs played a pivotal role in the growth of science and technology in the country. An IIT degree became a brand name, and IIT graduates came to enjoy high prestige among both the top employers in India and admission committees in the best universities in the world. Admission to an IIT developed into a middle-class Indian's dream. One consequence was that IITs soon had to deal with hundreds of thousands of aspiring students.

Given the prestige associated with the IIT degree, the educational goals implicit in the IIT entrance examination shape the nature of learning among high school students; at least the pragmatic and highly motivated students intent on an IIT degree tend to focus on what they perceive as essential for entrance into an IIT, and end up ignoring the rest of what school education offers. It is important, therefore, that the community of science educators and administrators keep a careful watch over these entrance examinations as one of the factors influencing the future of science education and research in the country.

There have been, in recent years, a series of voices expressing skepticism about the quality of IIT graduates as well as IIT entrants. Most recent, perhaps, is Sugata Srinivasaraju's article in *Outlook India* which reports Tata Steel's managing director, B. Muthuraman, himself an IIT alumnus, announcing that TISCO is 'not likely to recruit' IIT graduates any longer[1]. It talks about:

> '. . . the calibre of students who make it into the IITs by subjecting themselves to the killing rigours of coaching factories in places like Kota and Hyderabad. The alumni seemed to conclude that these products of coaching factories – who now form, according to Wikipedia, 95 per cent of students at IITs – had a blinkered approach to education, did not recognize new ideas and had lost the spirit of inquiry and innovation. In short, elements that had built Brand IIT over the decades had now gone missing.'

This situation should not be surprising: some IIT professors had anticipated it long ago. In 2000, a special edition of *Infocell*, an IIT Kanpur publication, presented a fairly detailed analysis of the central flaws of the IIT Joint Entrance Examination (JEE). Among the problems that Vijay Gupta's cover story identifies are[2]:

> '. . . teaching and coaching (as is practised by the JEE coaching schools) are two different kinds of things. Even the best of coaching does not attempt to clarify concepts. It does not inculcate the spirit of inquiry. It does not train persons in starting from the first principles. Instead, it relies on pattern recognition. Do enough problems so that when you see a problem in the exam, you can recall the special trick, the special integrating factor, substitution or whatever required to obtain the answer.'

> '. . . the practice of drilling has affected the general attitude of students towards the education process. It is reflected in their performance, in the narrowness of their vision and in their technological career achievements. Gone is the love for learning and the curiosity. Our students wait in the lectures for the bottom line, the formulae they can plug into or the recipe they can follow for the examination problem. Since the brighter among the school-going students are interested in preparing for JEE, the entire school education stands adversely affected. The students now spend lesser and lesser time in exploring what is not directly relevant for JEE.'

As a remedy to the problem, Gupta recommends thorough and well thought out reforms in JEE, such that the questions test candidates on their conceptual understanding and thinking abilities, and are pitched at an appropriate level. Outlined below is a set of suggestions for the implementation of this call for reforms in IIT JEE.

These ideas are not directed towards a comprehensive solution to the problems in science education in India. They do, however, address an important factor that has consequences not only for science education in IITs but also for comparable prestigious educational institutions pursuing science and/or technology, including the Indian Institute of Science, the Indian Institutes of Science Education and Research, The National Centre for Biological Sciences and the Birla Institute of Technology and Science. They will also be relevant for the proposed 'Universities for Innovation' which are expected to 'stand for humanism, for tolerance, for reason, for the adventure of ideas, and for the search for truth . . .'[3] Finally, they will also indirectly influence what high school students (and their parents) prioritize in their education.

A value system for science and technology education

Any evaluation of quality presupposes a clearly articulated value system within which the evaluation can take place. What are the attributes desirable in IIT entrants – the input to IIT? An answer to this question requires a characterization of what we expect of IIT graduates – the desired output.

The IITs expect their graduates to become highly competent mathematicians, scientists and engineers, some of them growing into world leaders in their respective fields. If so, the attributes listed under (a)–(j) below can be viewed as a reasonable profile of these graduates, and the potential to develop these attributes can then be viewed as constituting a value system for evaluating entrance quality: (a) an understanding of a body of established *knowledge*; (b) the *ability to apply* that knowledge to standard textbook problems and situations; (c) the ability to go beyond (b) to find *creative and innovative solutions* to *novel* problems and situations; (d) *independent learning*: acquiring knowledge without depending on an educational institution; (e) *critical understanding*: an understanding of the evidence/reasoning that bears on what is accepted and rejected as knowledge (a), and on controversies; (f) *critical thinking*: critically evaluating one's own and other people's beliefs, opinions, conclusions and practices; (g) *independent inquiry*: finding interesting questions and looking for answers as a foundation for research and arriving at one's own informed judgments; (h) a *rational mindset* and the capacity for reasoning; (i) *intellectual skepticism*: doubting and questioning one's own and other people's beliefs, opinions, conclusions and practices; (j) *communication* of ideas with clarity, precision and effectiveness.

The students entering the programme should have the *potential* to acquire these attributes through the education that the IITs provide.

An analysis

Which of the attributes in (a)–(j) do the JEEs test? Even a cursory glance at the question papers for 2008 and 2009 is enough to convince anyone of the following:

- The JEE questions are designed to test (a) and (b), and occasionally (c). They do not test any of the remaining attributes of the potential for science and engineering.
- Even within these, the assessment is limited to mathematics, physics and chemistry; the potential to engage with domains like biology, neuroscience, cognitive psychology, linguistics and logic, all of which are part of modern technology, is not tested.
- The questions do not probe into the multidisciplinary and transdisciplinary aspects of knowledge and thinking, crucial for innovative scientists and engineers.

Thus, the IIT JEE is designed to test the recall of isolated information that we treat as regurgitation and routinized mechanical application.

In the past, the IIT entrance exam questions used to be of the open-ended type, making it possible to identify students who are bright but nevertheless may not have given a technically correct answer, or may have left some questions unanswered. Unfortunately, given hundreds of thousands of candidates, the only feasible question format is one that lends itself to computer grading, for instance, multiple choice questions (MCQs). Unfortunately, the MCQ format has been typically used to test recall of information and mechanical application skills. Given 60 questions in a three-hour exam (three minutes per question) as in IIT JEE, the exam prioritizes speed and meticulousness, leaving no time for thinking, reflection and creativity. It thus favours fast, surface-smart students and handicaps slower ones who may however be deep thinkers and creative explorers.

Furthermore, surface smartness can result from the extensive practice that expensive coaching programmes provide. The coaching industry also results in the system unjustly favouring the affluent and the urban, and disadvantaging the poor and the rural.

A partial solution to the exam format problem would be to use what might be called 'Enhanced MCQs' (EMCQs) which combine the practical advantages of computer gradability with a reasonable degree of open-endedness, and allow for the testing of the capacity for independent thinking, reasoning and inquiry. The central characteristics of this format of MCQs are:

- increased number of options to choose from, say, 10 to 20, to increase the search space;
- allowing for the choice of two or more options, without specifying how many are required for any given question;
- allocation of full marks to a combination of two or more options, and different weights to different options; and
- penalties for the choice of inappropriate options.

Even entrance examinations that test the capacity for independent thinking, reasoning and inquiry using the EMCQ format may not do away with the coaching industry, but as Gupta points out, the nature of the industry will be forced to change from one of coaching to one of teaching. An extended sample of such questions and the rationale underlying their design are available in 'Assessing Science Talent' at http://www.iiserpune.ac.in/~mohanan/educ/assess-talent.pdf.

Recommendations

Based on the above remarks, I would like to make the following suggestions: (i) The questions should be designed in such a way that they do not lend themselves to mindless mechanical routines. (ii) The assessment should pay attention to those attributes among (a)–(j) that are testable in an entrance examination, namely, (c) and (e)–(i). (Attributes (d) and (j) are not testable in a computer gradable examination.) (iii) The format of the questions should be changed from the standard MCQs to EMCQs. (iv) The subject matter of the questions should go beyond the traditional mathematics–physics–chemistry boxes, to include other areas of modern science and other pursuits that have a bearing on the growth of engineering and technology.

As Vijay Gupta pointed out in 2000, the brighter among the school students now '. . . spend lesser and lesser time in exploring what is not directly relevant for JEE'. The solution, as sketched above, is an entrance examination system that tests those attributes that are needed for the innovative pursuit of science and technology. What is relevant for doing well in JEE would then coincide with what is ultimately valuable in science education.

Even if we adopt (i)–(iv) above, using a single entrance test for the selection of candidates is unwise. The role of the entrance test should not be the confirmation of the 'top' candidates, but an elimination of the clear cases at the bottom. The choice can then be made out of a more manageable number of applicants. The selection process subsequent to the elimination could be done in one or more stages, on the basis of a feasible and realistic combination of school grades, projects, essays and interviews. A fine-grained selection system of this kind would yield a far more reliable result, worth the additional effort.

Evaluation of the candidates' potential needs to be combined with a provision to nurture that potential. Some concrete examples to implement this suggestion can be found in 'Nurturing Science Talent' at http://www.iiserpune.ac.in/~mohanan/educ/nurture-talent.pdf. A web course that I designed to nurture the capacity for academic inquiry among undergraduate students across a wide range of subjects (Academic Knowledge and Inquiry at http://wiki.nus.edu.sg/display/aki), may give the reader a sense of how (c) and (e)–(i) can be developed among students.

1. Srinivasaraju, S., *Outook India*, April 2007; http://www.outlookindia.com/article.aspx?234521
2. Gupta, V., *Infocell*, 2000, **3**(4); http://www.iitk.ac.in/infocell/Archive/dirjuly3/cover_story.html
3. Mahadevan, G., *The Hindu*, 27 July 2010; http://www.hindu.com/edu/2010/07/27/stories/2010072750040100.htm

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Safety of systems for industry and environment: relevance and challenges

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3rd December 2009 marked the 25th anniversary of the Bhopal gas tragedy. On 3 December 1984, water tank was contaminated with methyl isocyanate at a pesticide plant in Bhopal, the capital of Madhya Pradesh, initiating a series of events that led to a catastrophic toxic release. The 40 tonnes of methyl isocyanate released from the plant killed more than 3000 people and permanently injured more than 50,000 (refs 1, 2). Ironically, in the same month December 2009, there was an accident in a prestigious chemical laboratory in Mumbai, where two young PhD students were killed as a result of explosion[3]. In December 2009, there were also newspaper reports on the contamination of water by the radioactive isotope of hydrogen, tritium which caused a high level of radiation effect to more than 50 workers of a power plant in Karnataka. This calls for revisiting the safety issues more earnestly than ever before[4].

The use of radioactive materials cannot be avoided because of their useful applications[5–7]. Radioactive ^{60}Co has many applications, for example, for sterilization of medical equipment, radiation source for medical radiotherapy, industrial radiography, and for improvement of shelf life of edible items. The recent casualty resulting from the radiation hazard due to cobalt-60 in Delhi is an eye opener[8] and calls for the necessity to take extra care on the issues of safety management particularly while handling radioactive inventories. It is shocking that the educational institution was negligent in disposing radioactive items in an auction, without following proper safety procedure which left common people to face the risk of being exposed to radiation. In spite of strict guidelines by the Atomic Energy Regulatory Board (AERB) that all radioactive materials should be disposed of in controlled conditions, there was apathy towards following the process of safety.

In addition to the accidents in the factories or laboratories, there are many miscellaneous fires reported from different parts of the country, especially in summer, either due to electrical short circuit or negligence or mishandling of fire. More recently, in July 2010, there was a report on leakage of chlorine gas from the stack of abandoned cylinders disposed off in Mumbai which caused illness to a number of people. This is a result of lack of knowledge on the effect of disposal of condemned cylinders before disposing of the abandoned cylinder. The disposal approach is so casual that the authority paid little or no attention to the remnant of chlorine gas in the cylinder. All such events were the outcome of either lapse of duty and/or lack of scientific safety culture.

The most deplorable fact about Bhopal havoc is that the events of the tragedy could have been avoided, even if a few safety precautions had been properly implemented, as believed by many experts. It is now understood that the Bhopal accident was associated with many technological and managerial shortcomings that caused initiation and escalation of the toxic release[1,2].

In India probably as yet there has not been any proper assessment of negligence and status of safety vis-à-vis corresponding loss due to disaster. However, response to hazards, its consequence and the probability of accident can provide a qualitative measure of the risk associated with a process operation[6]. The fire disaster not only creates immediate havoc but in larger perspective it remains mostly unnoticed that the root cause of such fire hazards finally contributes carbon footprint[10] to the atmosphere. It is therefore necessary that the carbon footprint, i.e. the total set of emitted green house gases (GHG) caused by a fire accident should be estimated to make an appropriate strategy for implementation of safety measure. The heat energy generated from any fire hazard is a waste since it cannot be used for obvious reason that there is no mechanism to utilize it from an accidental fire. On an average 1 kg of rice husk yields about 0.5–1 kWh of electricity[11]; this figure gives a rough estimate of energy released due to fire.

In the past, forest fires were more frequently noticed in Indonesia and Australia and the effect of such forest fire was so intense that even the neighbouring countries such as Singapore, Malaysia