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Integrated, Multidisciplinary and TechnologyEnhanced Science Education: The Next Frontier

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Integrated, Multidisciplinary and Technology-Enhanced Science Education: The Next Frontier

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Abstract

Contemporary science education at all levels presents several critical pedagogical and social challenges to educators and learners alike. Among these challenges are the widening *Intergenerational Information Technology* (IIT) divide and the need for a comprehensive and balanced multidisciplinary training. In the past few years, it has become clear that one significant hurdle impedes the efforts to integrate information technology in the classroom – the Intergenerational IT divide. The IIT gap reflects a different growing misalignment between providers and recipients of the science and technology educational content in terms of the expected vs. supplied, needed vs. perceived and contextual vs. abstract specialized learning. The common K-12 teacher or college instructor is much less familiar with, and slower to adapt to, the new ether of communication and novel IT resources. The transfer and blending of data, research challenges and methodologies between diverse areas of science is also critical in motivating wider spectra of students, demonstrating cross-disciplinary methodological concepts and synergies, as well as for engaging students in research projects. This article discusses the problems faced by modern science educators and suggests some methods and vision for coping with the increasing IIT divide and the social need to train "complete" and broadly educated citizens.

Keywords: science education, multidisciplinary, Internet, technology, blended instruction, online resources, intergenerational IT divide, information technology, policy.

Introduction

There are many geographic, social, economic and technological challenges that K-College science educators and students regularly face (Burns, 1995). Two of the most pressing ones are the continuing expansion of the *Intergenerational Information Technology (IIT)* divide and the social demand for broad, comprehensive and balanced multidisciplinary education.

Since 2000, we have witnessed the explosion of the Internet, various web-applications and information technologies for content generation and delivery. Certain groups of the population help develop and embrace these new ITs, others just try to keep abreast with them and still others are barely hanging in, if not completely giving up on the new IT developments (Inoue, 2006). There are extremely strong age effects in how the population perceives and responds to these technological demands, changes and implications (Finegold, Mohrman, & Spreitzer, 2002). Typically, students and learners are more inclined to be engaged in development, testing and adoption of new ITs (Maag, 2006; Yaşar, Little, Tuzun, Rajasethupathy, Maliekal, & Tahar, 2006). Despite their frequent early exposure to new IT and blended educational developments, teachers and instructors seem to be much more conservative, less willing to explore, validate and/or adopt new IT instruments in their curricula (Koukel, 2006; Vannatta & Fordham, 2004), e.g., www.genyes.com, www.eschoolnews.com. This leads to an undesired gap – the *Intergenerational IT divide* – between the providers (instructors) and consumers (learners) of educational and training curricula. This effect is secondary to the normative gap representing the natural gradient in the knowledge of the two parties engaged in science education. The knowledge-gap is an important underlying cause for our educational endeavors – to bring up the next generation of citizens, well prepared to deal with future scientific, health, political, environmental or social challenges. The IIT divide is a byproduct of the fast-paced evolution of technology, which will likely widen and have detrimental effects on the ways we teach, the efficacy and apprehension of our educational endeavors.

The second considerable challenge in modern science education is the training of *complete* and *broadly* educated workforce. On the short-term, it may be economical, resourceful or appealing to train students extremely well in one narrow scientific discipline or subject. We may accomplish much specific progress, with measurable outcomes, by allocating significant resources in development of an individual-field expertise. However, the long-term results of such approach may be quite the opposite of expectations. Now-a-days, most graduate and professional schools, as well as much of the job opportunities, seek to recruit individuals that have widespread interests, training and capabilities. For example, application review panels at top medical schools currently give preferences to applicants that have a round background and affinity to social, geo-political, scientific and cultural facts and affairs; more so than to applicants that may be exceptionally strong in only one discipline or have narrowly defined curiosity. For example,

> UCSD School of Medicine admission guidelines state *A broad base of knowledge is advantageous in preparing [to be] a physician*;
>
> *Harvard Medical School is looking for people with broad interests and talents*;
>
> University of Pennsylvania School of Medicine advises applicants *to consider and think broadly of [their prior] academic and extra-curricular experiences*

This comes from the realization that a modern clinician, scientist, engineer, economist or politician needs to be able to reason, integrate knowledge and make decisions in *out-of-the-box* situations, where no single discipline or methodology is likely to solve a problem completely. In addition, abilities to effectively navigate and bridge the gaps between different science disciplines, social orders and behavioral psychologies will likely improve the prospects for our future workforce, leaders and scientists (Munshi, 2006). Lastly, the transfer and blending of data, research challenges and techniques between diverse areas of science is critical in motivating majority of students, demonstrating cross-disciplinary methodological concepts and synergies as well as for engaging students in research projects.

If technology enhanced multidisciplinary education improves student motivation and learning retention, what are some specific instances of IT instruments that may be employed by instructors? Modern information technology-driven educational tools are much more than simply collections of static lecture notes and homework assignments posted on one course-specific Internet site. Over the past five years, a number of technologies have emerged that provide dynamic, linked and interactive learning content with heterogeneous points-of-access to educational materials (Dinov, Sanchez, & Christou, 2008) These new IT resources include common web-places for course materials (e.g., Blackboard, Moodle), complete online courses (e.g., http://www.uclaextension.edu/), Wikis (e.g., http://wiki.stat.ucla.edu/socr), interactive video streams (e.g., http://duber.com/LetsTalk, http://blog.click.tv/, www.ivtweb.com/), audio-visual classrooms, real-time educational blogs (e.g., http://www.pbs.org/teachersource/learning.now), (Brescia & Miller, 2006), web-based resources for blended instruction (e.g., http://en.wikibooks.org/wiki/Blended_Learning_in_K-12), virtual office hours with instructors (e.g., http://voh.chem.ucla.edu/), collaborative learning environments (e.g., http://sakaiproject.org/), test-banks and exam-building tools (e.g., http://sourceforge.net/projects/tcexam/) and resources for monitoring and assessment of learning (e.g., http://www.opensymphony.com/webwork).

Challenges and Actions

No one can accurately predict the technological advancements or the prospective pedagogical challenges that educators will have to deal with in the next 10-30 years. This is because of the expected exponential increase in computational power and significant geopolitical, social and environmental challenges we are likely to face in this period. Yet, it is reasonable to assume that the technological progress we are likely to see will exceed an order of magnitude the advances witnessed in the past 20 years (Adomavicius, Bockstedt, Gupta, & Kauffman, 2006; Munakata, 2007; Pareek, 2006; Roberts, 2000). Such rapid increases in knowledge build up, data collection, communication and information infrastructure, for a relatively short time-span, will strain the delicate but functional balance we had reached in the 20th century in educating a broadly intelligent and skillful workforce. Two specific high-impact science educational challenges are likely to exacerbate over the next couple of decades – the *Intergenerational IT divide* between students and educators; and the dilemma of training *broadly* educated citizens at higher cost vs. the alternative of lower-cost *discipline-specific* education.

Intergenerational IT Divide

The accelerated development and utilization of the Internet, web-applications and new information technologies in all areas of social life has also impacted the field of science education. There is an interesting interplay between technology developers (visionaries and engineers) and the general public. New technologies may be designed by developers to solve general problems or may be introduced to solve some specific user needs. In either situation, age effects may sometimes have desirable taming implications or unintended forestalling repercussions (Daveri & Maliranta, 2007; Willis & Tranter, 2006). Younger learners are more willing to get involved in design, testing and broad distribution of new ITs (Bongalos, Bulaon, Celedonio, de Guzman, & Ogarte, 2006). There is evidence suggesting a correlation between the use of IT in the classroom and the level of student involvement (Cutrim, Rudge, Kits, Mitchell, & Nogueira, 2006). On the other hand, instructors appear to be more attracted to the established/accepted pedagogical techniques than to explore newly introduced IT instruments (Cartelli, 2006; Guillot & Pryor, 2007; Moore, 2006). Certainly the majority of new technologies may eventually be discarded, proven to be inefficient or be quickly replaced by even newer advancements. However, some, like the collaborative Wiki environments, are bound to make an impact on how we train the next generation of scientists and engineers. This IIT gap between the educators and students is the result of differences in perceptions of the goals of scientific training, socio-economic factors, as well as quick turn around of technological breakthroughs (Conole, 2008). Left unchecked, the IIT gap will likely expand and impact on the immediate efficacy and long-term apprehension of our current educational activities.

There are several possible strategies to slow and perhaps reverse the IIT divide and ensure that our educational efforts are balanced and effective. Some of these are discussed below.

Continuing Instructional Technology Training

One of the most powerful ways to impact the progression of the IIT divide is to involve science educators in continuing technology education training. This may be done under discipline-specific or general societal/organizational umbrellas. Most instructors and teachers already participate in various semiannual or quarterly continuing education events within their discipline. Few are deeply involved in regular technology-based refresher courses. For example, fewer that 25% of the UCLA statistics faculty attend a continuing education course each year. The experience of this author, as a recipient and deliverer of science and technology education to teachers and educators, confirms that many instructors are not familiar with the basic modern means of Internet communication (including, blogging, collaborative wiki environments, database and applet interfaces, web-services, data resources, etc.) A sustained effort is needed on the part of educators, science administrators, policy makers and the general public to facilitate and enable continuing science and technology education for instructors at all levels.

Engagement of Instructors in Science and Technology Research Projects

Instructors from elementary school to college should be involved in science and technology research projects pertinent to their level and curricula. By judging at variety of state and local science fairs, this author has been very impressed by the motivation, elaborate thinking and complexity of projects developed by K-College students who were supervised by instructors engaged in multi-disciplinary science and technology research. For instance, the annual California Science Fair serves as a forum for showcasing student research projects directed by K-12 teachers and college instructors, a venue for exchange of ideas and as an informal student project evaluation mechanism. The amazing variety and work quality of student projects presented there are evidence of the effects of engaging instructors in research projects (e.g., http://www.usc.edu/CSSF/History/2006/Alpha.html). There are various ways to learn and contribute to new or ongoing research projects conducted by higher education institutions, professional organizations, private and federally funded initiatives (e.g., www.usc.edu/CSSF, NationalGeographic.com/genographic, ed.fnal.gov/trc_new/projects/web_resources.shtml, etc.)

Institutional Commitment in IT and Blended Instruction
The interest, available infrastructure and resources provided by home institutions are essential for the engagement of teachers and instructors in contemporary science and technology education. Many institutions (e.g., schools, colleges, universities, institutes and centers) provide computational resources, audio-visual and Internet-digital infrastructure, seed grants, human resources and other forms of support to entice their instructors in technology learning and creative utilization of IT in the classroom (e.g., www.oid.UCLA.edu/AVS). Institutional commitment could be a significant barrier or a considerable asset in developing an IT blended curriculum.

Funding Agency Engagement in IT and Blended Education
There are a multitude of agencies that provide funding support for a wide spectrum of innovative educational endeavors (e.g., www.ED.gov, www.GrantsAlert.com, www.NSF.gov, www.spencer.org, www.kidsinneed.net, etc.) Federal, state and private funding initiatives aim at stimulating creative thinking and exploration of novel strategies for IT and blended education. Even though these are merit based and in some instances very competitive, few good proposals are turned down. For example, in 2006-2007, the National Science Foundation received 44,000 grants, 11,000 of which were funded (of course, not all were education related). When submitting a grant proposal, the critical components are to find a specific call for application that jibes well with the proposed idea, format the proposal according to the specific call and grant writing guidelines, and ensure that the proposal addresses a real (educational) challenge that is not already solved. Such extramural funding does enable instructors to buy out time for attending continuing education events, develop blended curricula, establish new collaborations, collect data and design research projects. All of these will have a positive effect on reducing the IIT gap.

Integration of Available Digital Resources in the Classroom
In the past several years, a large number of digital resource libraries have been cataloging, curating, evaluating and integrating most of the valuable IT resources for enhancing science education using interactive aids, electronic media and instructional materials. A list of some of these resource libraries is available online at http://SOCR.ucla.edu/htmls/SOCR_Recognitions.html. These resources provide datasets, methodological and conceptual learning materials, tools for data analysis and exploration, hands-on activities, demonstrations, tutorials and refreshers for all disciplines, topics and levels. Instructors should dedicate the time to find, test, compare and select appropriate resources for their curricula. With respect to web utilization, students are much ahead of most instructors and they can easily discover Internet resources on their own (Maag, 2006; Yaşar et al., 2006). The problem with the latter is that students may use inappropriately such resources (intentionally or unintentionally) without instructors even realizing it. For example, many instructors (including this author) are sometimes unaware that on the Internet, problem solutions, virtual tutors and blogs contain solutions to many homework assignments, which diminishes the intended value of personally completing such assignments. The reduction of the IIT gap will taper these possibilities and increase the value of personal learning efforts.

Broad vs. Narrow Spectrum Educational Training

There is a good agreement that all learners need to be generally trained first (Hernon & Schwartz, 2006; Posch & Steiner, 2006). Science oriented learners eventually should branch out and specialize in a specific discipline that they further explore and advance in. The main question is: when should the regression into a specific scientific area occur in the learner's course of training? In the past, this break point was probably in the first decade of life. More recently, the point of specialization occurred first in high-school (1960's), then in college (1980-1990's). Now-a-days, science students frequently carry multi-disciplinary research and training in graduate and post-graduate school. This ever increasing demand for multidisciplinary training reflects the steady increase in human life-span, the accumulation of general knowledge, technological advancements and the escalation of the complexity of problems addressed by researchers, clinicians and policy-makers.

The debate over the discipline bound vs. cross-discipline training is especially crucial in undergraduate and graduate college education (Holt, 2007; Mitrany & Stokols, 2005). Frequently, the two extremes are pure mathematics students (very discipline-oriented, high-level of competency, low cost training) and various humanitarian majors (broad discipline learning requirements, including many watered-down quantitative courses, somewhat higher training costs, low-level knowledge spanning many subjects). The multi-disciplinary and area-specific educational trainings are complementary, not overlapping or antagonistic. For example, brain mapping and computational neuroscience challenges may serve as driving biological projects for developing novel methods for statistical analysis (Dinov, 2005). And conversely, the introduction of new mathematical models of shape may lead to unexpected biomedical applications (Srivastava, 2005). An over commitment to any one of the two educational directives will ultimately have drastically negative effect on the entire educational system. The reason is that multi-disciplinary sciences are completely contingent upon having robust and computationally tractable theoretical properties and results needed to establish the spokes of modern scientific understanding of the physical world we live in. Multidisciplinary research efforts allow us to build bridges and establish affinities between such (sometimes independent) spokes of scientific endeavors. On the other hand, no single scientific area can model, represent and explain the complexities in any physical, biological, social, political, medical or psychological system. Solutions to all real-world problems demand multi-disciplinary thinking and cross-scientific approaches.

Some of the directions below may help us promote interdisciplinary science and protect the homeostasis between discipline-oriented and cross-discipline thrusts in science education.

Develop New and Diverse Multidisciplinary Educational Curricula

There is a real need to design new plans for multidisciplinary instruction involving two or more disciplines. The lack of available educational materials that cross between different disciplines and enable sharing of data, techniques and tools is due to scarcity of expertise to develop such instruments (Borgman, 2006). Few educators are well versed in multiple scientific fields (Bender, 2005; Freeman, 2005). Thus, collaborations and interactions between different areas are sometimes impeded by insurmountable linguistic, methodological and physiological barriers (e.g., terminology, specifications of data and methodological protocols, *a priori* assumptions). The community of science educators should strive to improve communication and overhaul the efforts to develop educational materials and transferable knowledge across multiple disciplines. Examples of such efforts involving mathematicians, engineers, biologists, statisticians and physicists are developed by the National Internet-based Science Educational Resource.

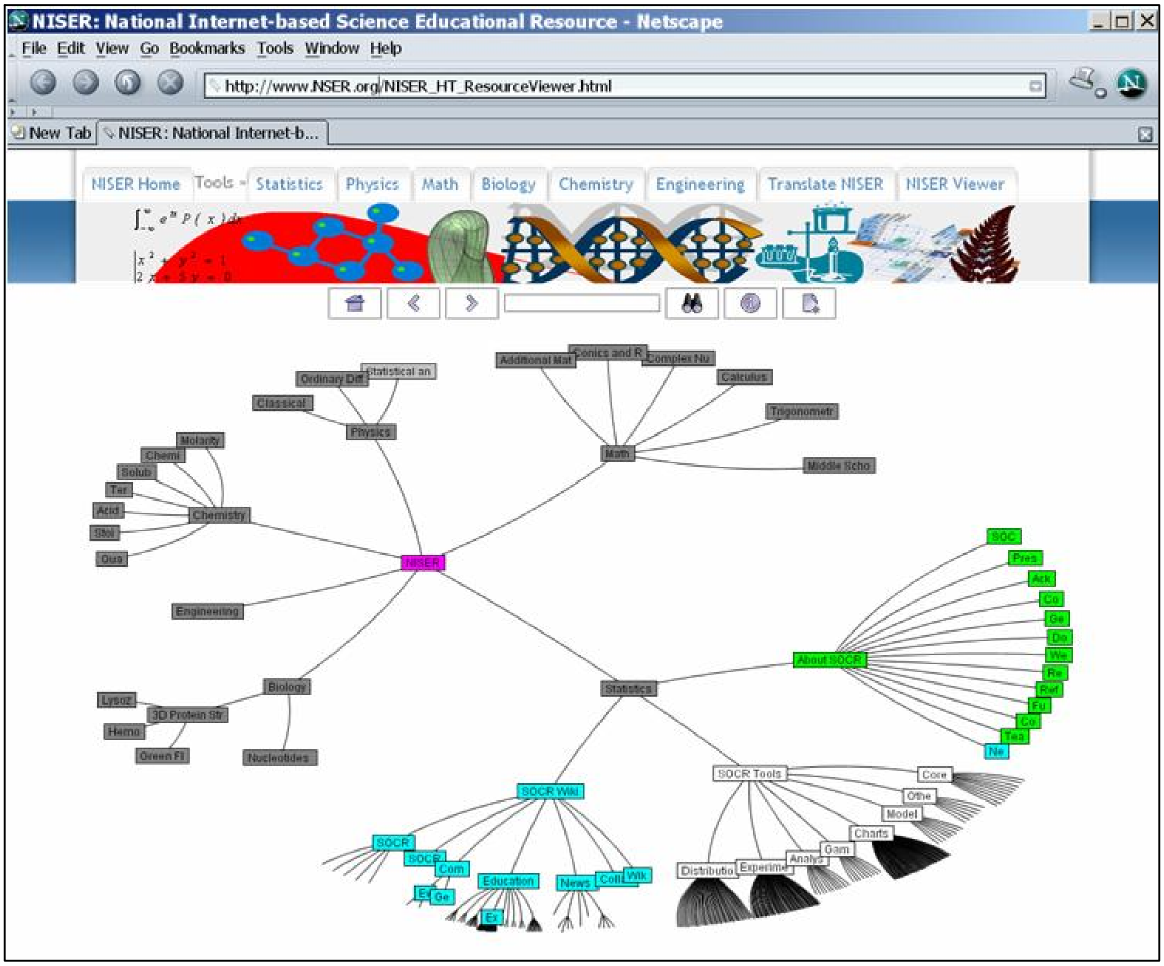
Institutional Commitment to Multidisciplinary Education

Little progress in designing, validating and disseminating multidisciplinary educational materials is practically possible before ensuring firm institutional commitments and support to these efforts. In addition to demanding scientific expertise from varieties of fields, multidisciplinary resource developments also require logistical, financial, administrative and human resource commitments that are only conceivable and implementable by larger institutional, organizational and legislative initiatives. A 2004 National Academy of Sciences report entitled *Facilitating Interdisciplinary Research* (NAS, 2004) identified barriers to interdisciplinary efforts including limited resources, the academic reward system, differences in disciplinary cultures, the pursuit of national rankings (based on traditional disciplinary categorizations), differences in policies and procedures across departments, and decentralized budget strategies that give advantages to departments over interdisciplinary programs.

The University of California, Los Angles (UCLA) is one example of an organization embracing crosscutting educational programs that serve undergraduates and graduates. UCLA includes 32 interdepartmental program majors, nearly 500 courses are offered as cross-listed in two or more departments, faculty members participate in several departments through split appointments (5.4%) or joint appointments (24.5%), and there are over 80 campus-based multidisciplinary research centers, characterized by long-term institutional commitment and robust funding.

Introduce Efficient Multidisciplinary Resource Interfaces

Even if we are successful in developing, testing and distributing a large number of interdisciplinary educational resources, a possible imperative to their utilization by instructors as classroom aids may be the efficient means of resource traversal, querying and comparisons. Such interfaces to multidisciplinary digital libraries should facilitate the community involvement in updating, ranking and management of the resource collectives. NSDL, MathDL, and NISER provide examples of such interfaces. This figure below illustrates an example of the interactive and dynamic exploration of the NISER resources. The issues of classification, organization, traversal and management of interdisciplinary materials and educational resources will become pressing with the expansion of the volume, complexities and affinities of these resources. Efficient, robust and extensible infrastructures for management, visualization and (human and machine) interaction with these resources will be vital for the success of the future interdisciplinary educational efforts.



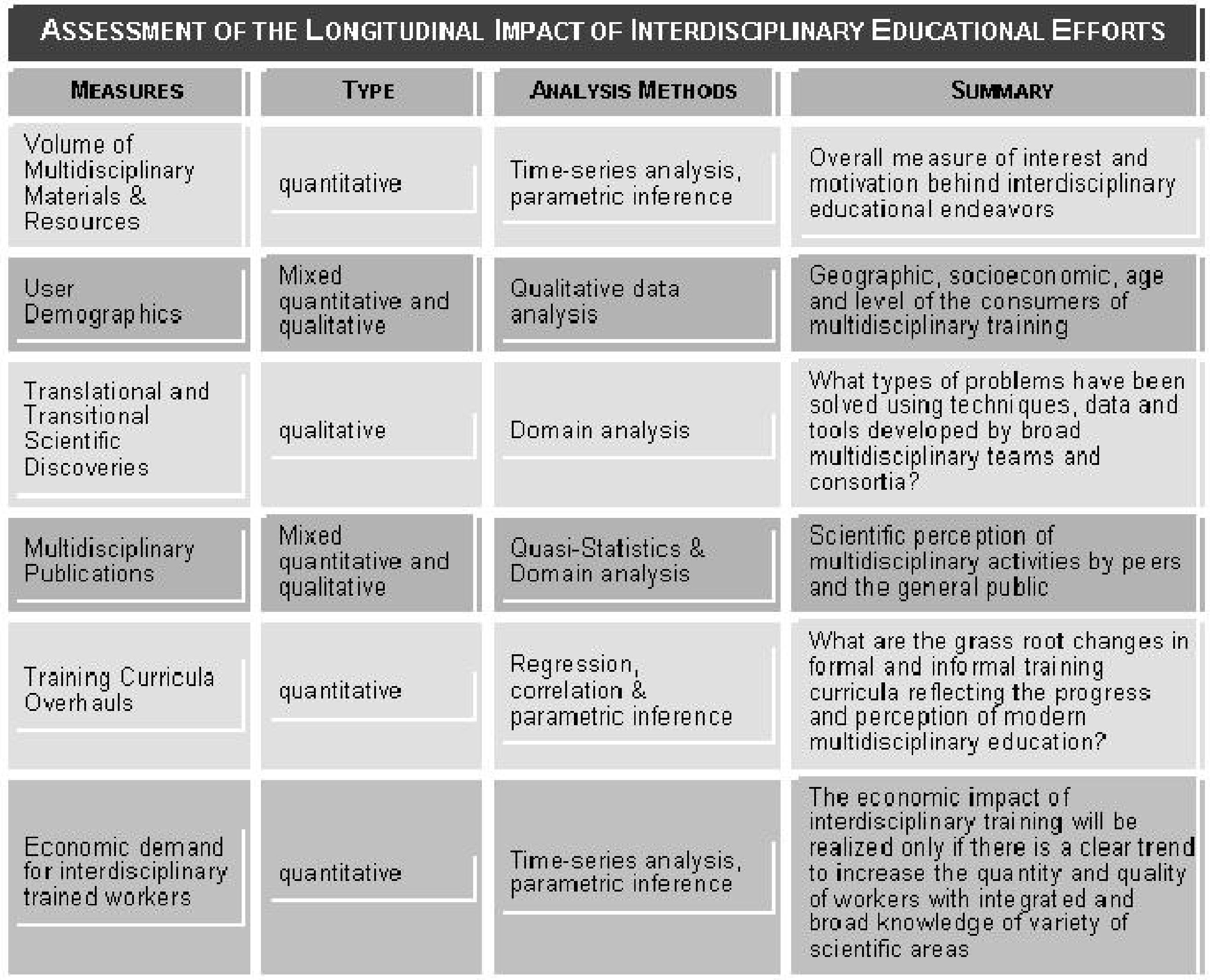
The NISER interactive graphical user interface enabling traversal, discovery and dynamic exploration of available multidiscioplinary educational resources and learning materials. (http://www.nser.org/NISER_HT_ResourceViewer.html)

Expectations of Student Participation in Multidisciplinary Programs

There are several direct implications of engaging students in multidisciplinary learning activities. Interdisciplinary training exposes students to the practical interactions of concepts and properties they have learnt in other field-specific curricula. This reinforces the meaning and applications of these concepts to study natural processes or develop models about our world. Multidisciplinary research projects also tend to rapidly and sustainably attract students' attention and serve as a powerful learning motivational tool (Joan, 2007). Learners exposed to well-designed and interactive hands-on multidisciplinary training acquire unique perspectives in understanding and dealing with complex problems (Shekar, 2007). Such training provides the glue that will hold together and perhaps stimulate the future scientific endeavors. At the same time, imminent advancement in scientific research and applications is contingent upon the availability of sufficient high-level knowledge expertise within each scientific field as well as the abilities of researchers and scientists to look across many areas, draw resources and make inference about general multi-disciplinary challenges.

Mechanisms for Assessment of Instructional effectiveness of Interdisciplinary Education

Quantitative evaluations of many educational interventions, including the efficacy of multidisciplinary training, are difficult because treatment effects may be observed as dependent or categorical measurements, they may be significantly delayed in time, be extremely non-parametric/non-linear or may be indirectly manifested (Dinov et al., 2008). Therefore, a mixture of quantitative and qualitative evidence should be used to assess the effects of interdisciplinary training, as well as the social and economic impacts of the balance between high-competency area-bound and cross-disciplinary education. The table below summarizes some of the important measures for assessment of the efficacy, perception and promise of interdisciplinary education to improve human life, health and general knowledge.



ASSESSMENT OF THE LONGITUDINAL IMPACT OF INTERDISCIPLINARY EDUCATIONAL EFFORTS

MEASURES	TYPE	ANALYSIS METHODS	SUMMARY
Volume of Multidisciplinary Materials & Resources	quantitative	Time-series analysis, parametric inference	Overall measure of interest and motivation behind interdisciplinary educational endeavors
User Demographics	Mixed quantitative and qualitative	Qualitative data analysis	Geographic, socioeconomic, age and level of the consumers of multidisciplinary training
Translational and Transitional Scientific Discoveries	qualitative	Domain analysis	What types of problems have been solved using techniques, data and tools developed by broad multidisciplinary teams and consortia?
Multidisciplinary Publications	Mixed quantitative and qualitative	Quasi-Statistics & Domain analysis	Scientific perception of multidisciplinary activities by peers and the general public
Training Curricula Overhauls	quantitative	Regression, correlation & parametric inference	What are the grass root changes in formal and informal training curricula reflecting the progress and perception of modern multidisciplinary education?
Economic demand for interdisciplinary trained workers	quantitative	Time-series analysis, parametric inference	The economic impact of interdisciplinary training will be realized only if there is a clear trend to increase the quantity and quality of workers with integrated and broad knowledge of variety of scientific areas

Multidisciplinary science education – an impact evaluation matrix.

Discussion

There will be some educational challenges in the next decade that we can foresee now and many that will only become apparent in the future. For instance, it is expected that computers and Internet usage will vary by family socioeconomic status, race and parent educational level (Norris, 2001). There are several studies that have consistently established this notion of the digital divide (DeBell, 2003). A summary of these social and geo-political effects is included in the *Computer and Internet Use by Students in 2003* report, published by the National Center for Education Statistics in September 2006, (DeBell, 2006). This report surveyed about 56,000 households and obtained information on close to 30,000 students from nursery school to 12th grade. The results indicate that students' technology usage is divided along low (87%) and high (95%) income families; Whites (93%), Asian (91%), Latinos (85%) and Blacks (86%); public (91%) or private (86%) school enrollment; high-school (89%) and college (93%) educated parents. All of these differences are statistically significant at 0.05.

In anticipation of the less obvious future challenges of education, and particularly the role of IT-enhanced and multi-disciplinary curricula, we need to debate and outline clear policies and directions for smooth transitions and timely resolutions of such unexpected conundrums. The ideas proposed in this manuscript provide a starting point for this debate on how to address prospectively two of the most pressing needs of science and technology education – the student-instructor *Intergenerational IT divide* and the dilemma of effectively training advanced discipline-bound and multidisciplinary scientists.

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