Collaborative Undergraduate Biology Research: Re-Structuring Undergraduate Biology Education in India

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This work is an effort to convert undergraduate college laboratories into contemporary, open-ended interactive, inquiry-driven and collaborative research laboratories and hence bridge the gap between practice and theory of biology.

The programme Collaborative Undergraduate Biology Education (CUBE), as the name suggests, is an invitation to young researchers at the undergraduate level into the nature of scientific inquiry through its essential component of collaboration. Our aim is to design 'functional learning ecologies' by means of simple model systems to facilitate collaborative undergraduate research in the frontiers of biology.

"Education should not be something we do to our students: It must be something we do in collaboration with our students" (Brewer & Smith, 2011).

Introduction

The rapidly advancing frontiers of biology research and the changing nature of biology resulting from it, have called for some serious action to be taken to transform the nature of biology education. The undergraduates need to be prepared for the challenges posed by the changing ways we think about and engage in biological research, while opportunities for investigating questions, which otherwise could never be addressed, are becoming possible due to emerging technologies (Luck, 2009). There is a strong need to first accept and subsequently ensure that the biology we teach authentically reflects the biology we do. The 21st century biology undergraduate needs to engage in authentic biology research and integrate the research experiences and skills acquired into understanding, solving and making informed decisions on complex problems related to biology and those encountered in their daily lives (Brewer & Smith, 2011).

The 21st century biology requires that undergraduates learn to integrate concepts across levels of organization and complexity and that they synthesize and analyze information that connects conceptual domains (*ibid*). Teachers, educators, researchers and curriculum planners need to view teaching from an approach that captures the spirit of the nature of scientific practice and to look for concepts that communicate to each other because it would make more sense to communicate the generalities and encourage students to discover their applications through well-designed laboratory exercises (Bialek & Botstein, 2004).

The challenge, however, is to keep the undergraduate classroom current and dynamic without making it overwhelming; to excite undergraduates with the current cutting-edge discoveries and at the same time finding the right balance between the depth of coverage required for conceptual understanding and the factual knowledge needed for the same. This may need a restructuring of the current undergraduate biology syllabus in many ways. One of the productive ways to strike this balance is to revamp the undergraduate biology by integrating research with teaching; making undergraduate research a meaning-making experience (Jenkins et al., 2007).

A growing body of literature has found a link between student research and lasting learning (Bender, et al., 2009, Petrella & Jung, 2008). In a survey (Lopatto, 2007) of more than 2000 undergraduates at 66 universities (Survey of Undergraduate Research Experiences [SURE], students described the research experience as having lead to considerable gains in their "understanding of the research process," "readiness for more demanding research," "understanding how scientists work on problems," "learning lab techniques," "tolerance for obstacles," and various other research areas. The gains persisted even 9 months later when the same students were surveyed, suggesting long-lasting benefits of research experiences (Lopatto, 2007, Hunter et al., 2007, Laursen et al., 2010).

In order to inspire and further solidify the interest of undergraduate biology students in making career choices in biology they should be given an opportunity to experience the allure of the research scholarship. Their participation in such pursuit will improve not only their ability to understand how biologists conduct research but will also prepare them to evaluate scientific claims in their day-to-day lives. This rightly falls under the mandate of “The Vision and Change: Call for Action” report, which discusses the need to develop *biological literacy* to prepare the coming generation of biology scientists, educators, and informed citizens (Brewer & Smith, 2011).

Hands-on research cultivates scientific thinking, giving students authentic research experiences including designing experiments, interpreting unexpected outcomes, coping with experimental failures, considering alternative methodology, testing new techniques and many more (*ibid*). These experiences go beyond the *apprenticeship model*[1] and such outcomes can never be expected to be a part of any regular college laboratory.

The undergraduate biology research environment thus forms a rich learning ecology with student-centric features. The typical features of such an ecology is that it is open-ended, interactive, inquiry-driven, cooperative, collaborative, and context-bound. Without any doubt, the research experience will have high levels of student–student and student–faculty interactions, ready connections of the subject matter to topics of student interest and relevance, learning that reflects aspects of scientific inquiry and most importantly learning progressions designed from the efforts of an ongoing students feedback to the teacher as well as their peers (Wood, 2009, Laursen et al., 2010).

Linking teaching and research will help to bring the processes of research into teaching and can support students in the development of a variety of specific as well as general skills. It can also benefit institutions to build a research profile and thus encourage networking with other institutions and research groups. Further a community of biology educators/researchers will be built, who are willing to integrate evidence-based practice into their teaching. Platforms like an online portal will provide an overview of the pedagogic practices and the reasons for adopting a particular practice (Jenkins et al., 2007). It is very important that the *mutually synergistic communities* of biology teachers/educators and biology researchers work together in order to meet the common goal of student-centered learning.

Indian Undergraduate Scenario

Undergraduate biology research is conspicuous by its absence in colleges and universities, in India. This results in the unfortunate event of what is being taught in the class room reflecting little of what actually happens in the contemporary research field. Overall, in a world propelled by knowledge and knowledge economy, there is this curious case of science becoming less and less attractive an option for the burgeoning number of youth in the country. This, surely, calls for our immediate attention. The biology graduates are entering universities with only a traditional descriptive model of the subject and are unaware of the need and importance of research in connecting theory in biology to its practice. Moreover, biology graduates are often seen changing streams as they are not motivated and find themselves inadequate to pursue career in research.

Diagnosis: An alternate Social Network Model

Conventional social scientific studies “assume that it is the attributes of *individual* actors whether they are friendly or unfriendly, smart or dumb”, lazy or industrious etc. that matter. On the other hand, “social network analysis produces an alternate view, where the attributes of individuals at a given time are less important than their *relationships and ties* with other actors within the network” (Global, 2010). Hence, rather than treating individuals (persons, institutions, etc.) as discrete units of analysis, it focuses on how the structure of ties affects individuals and their relationships (Watts & Strogatz, 1998). See fig 1. below. (Figure not visible, please provide correct format)

One characteristic feature that stands out in India, in the sphere of science in general, is the absence of any conscious collaborative approach as a means for strengthening the scientific pursuit. Institutional mechanisms for this are lacking. Hence, we witness several scientific bodies working largely in isolation or with almost non-existent functional networking among them. The absence is all the more pronounced in research collaborations between undergraduate colleges and research institutes in India, unlike in the west.

1 This model is taken as a contrast to the CUBE initiative and is explained as one that assumes a passive transfer of skills in a traditional, closed and individualistic laboratory investigation.

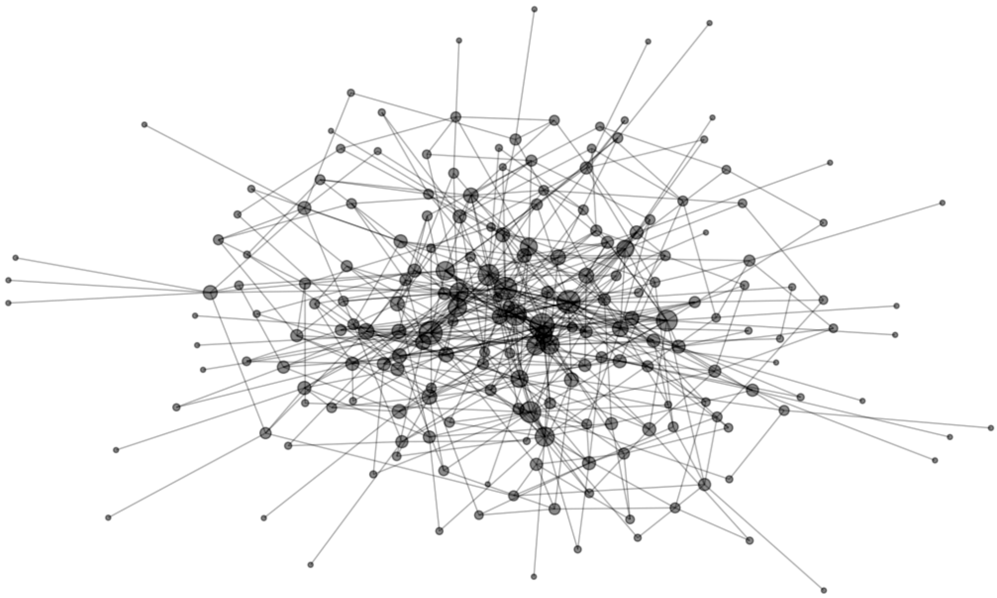

Figure 1: Topology generated using Parallel Global Multiobjective Optimizer (PaGMO1.1.4)[2]

An example of a network inspired by the Small-world Network Theory. The bigger nodes are the members with high connectivity. They link the many different smaller nodes through functional networking; allowing for large amount of mobilization. So even when most nodes are not neighbors of one another, they can be reached from every other node by a small number of hops or steps. The model belongs to a class of scale-free networks and incorporates two important general concepts of growth (number of nodes in the network increasing over time) and preferential attachment (greater connectivity ensures greater receptivity for new links). The model therefore, explains the empowerment of individual nodes by offering opportunities to alter the structure of their ties and relationships.

Remedy: Establishing Functional Linkages between Colleges & Research Centres through Collaborative Undergraduate Research

Our suggested remedy in this proposal is to restructure the relations between the large number of existing bodies by actively facilitating the formation of functional networking among them. We, therefore, propose a scheme that is aimed at empowering existing teachers of more than 26,000 colleges and 504 universities in the country, enabling them to functionally network among themselves and with research scientists, through a large number of collaborative undergraduate research programs, using among others, the state-of-the-art social networking technology. (Examples of such collaborative research are not uncommon in the US, like the HHMI initiative, University of St. Thomas, Minnesota, and are largely recommended by all recent review reports like the *Bio 2010* by NRC).

This scheme offers the means to empower teachers of colleges who are the mainstay of the undergraduate science in India; they are, currently, a demoralised set of individuals, largely isolated from the mainstream practice of scientific research and more importantly, from the active research-network. As undergraduate teachers and students are made part of the process of creation of knowledge though a collaborative approach, this program envisages that in the near future, the practice in the classroom truly reflects what goes on in scientific laboratories and the research field, in general. The idea is to offer avenues and possibilities to alter the scenario by bringing about a change in the nature of ties and relations of an incipient network of institutions and individuals.

Networking such a large number of colleges/universities and research institutes, as India has, may look formidable, though if one can develop approximately 500 hubs (about one each in a district), these will act to facilitate the process and thus networking such a large number of teachers and researchers will become feasible.

2 Author: Luke O'Connor (http://pagmo.sourceforge.net)

Each hub needs to cater to and work on a reasonably smaller number of nodes (e.g. about 40 colleges, in this case). It will become sustainable once these links are activated through collaborative research projects. "No node in such a network is meaningful on its own right, but only by virtue of the links the node has with the neighboring nodes." (Nagarjuna & Kharatmal, 2011). Further, it does not escape us that this functional network, by natural extension will involve not only the sprawling education system but can eventually promote Citizen Science Programs, too.

The network model in action: The CUBE Summer 2012 Initiative

We give below one such narrative; a working model that offers a plausible alternative that according to us, will bring about a paradigm shift in Science Education in India:

The Collaborative Undergraduate Biology Education (CUBE) Summer 2012 is a pilot study for Collaborative Undergraduate Biology (CUB) Research initiative to create a network of research and resource centres, throughout the country, catering to undergraduate biology research. These centres are essentially college laboratories that are expected to act as resources for bringing in undergraduate colleges in India under the tenet of inquiry science, process-approach towards science, discovery learning and collaborative research. We present here a phase-wise description of this ongoing CUBE program:

Phase I: The first phase was a 5 week hands-on research program during the summer vacation started in an academic institution on April 23, 2012 with three participating colleges situated in a metropolitan city of India. The program continued in the institution campus till May 30, 2012. A total of 19 students participated in the program and had either appeared for their first year, second year, third year of the 3 year bachelor's or the second year Masters examinations in the area of biological sciences.

Phase II: The next phase of the CUBE continues further by the 3 colleges networking with their neighborhood colleges to establish an undergraduate research, starting with the continuous maintenance of the Simple Model Systems[3] developed in Phase I. Thus each participant college in phase I not only establishes an undergraduate biology research lab using the simple model systems that they worked with in the CUBE summer 2012 program but also conducts workshops for 4 neighborhood colleges each, for helping them establish similar labs in these colleges. The functionality of this newly established link is ensured by the research projects that each college from phase I will carry out with the neighboring colleges. Thus what we expect to have at the end of October 2012 is a functional network of [1 (academic institute for CUBE Summer 2012) + 3 (phase I colleges) + 12 (neighborhood colleges)] 16 colleges from one of the metropolitan cities + another 4 colleges[4] (each from other major cities in India); a total of 20 undergraduate college hubs.

Phase III: In the subsequent phase, each of the 20 colleges from phase II will network 5 more colleges each; again by first helping them to establish simple model systems based biology research and further collaborating with them on research projects. Thus, with a multiplicity factor of 5 at level III, we expect to form a functional network of around 100 undergraduate colleges in India by the Summer of 2013.

Phase IV: A similar cascade effect even with a multiplicity factor of as low as 2, is expected to network around 200 colleges by October 2013.

Phase V: A network of around 400 colleges (multiplicity factor of 2) is expected by Summer 2014.

3 A detail narrative of the CUB Research (Phase-I) using Simple Model Systems Approach is available in digital format at http://beta.metastudio.org/gstudio/resources/documents/show/1318/ as a supplementary file and a summary scheme of the same is depicted as FIgure 2 on the subsequent page.

4 The colleges networked by means of workshops like CURE (Collaborative Undergraduate Research & Education) initiative. For details of the CURE initiative, see www.metastudio.org.

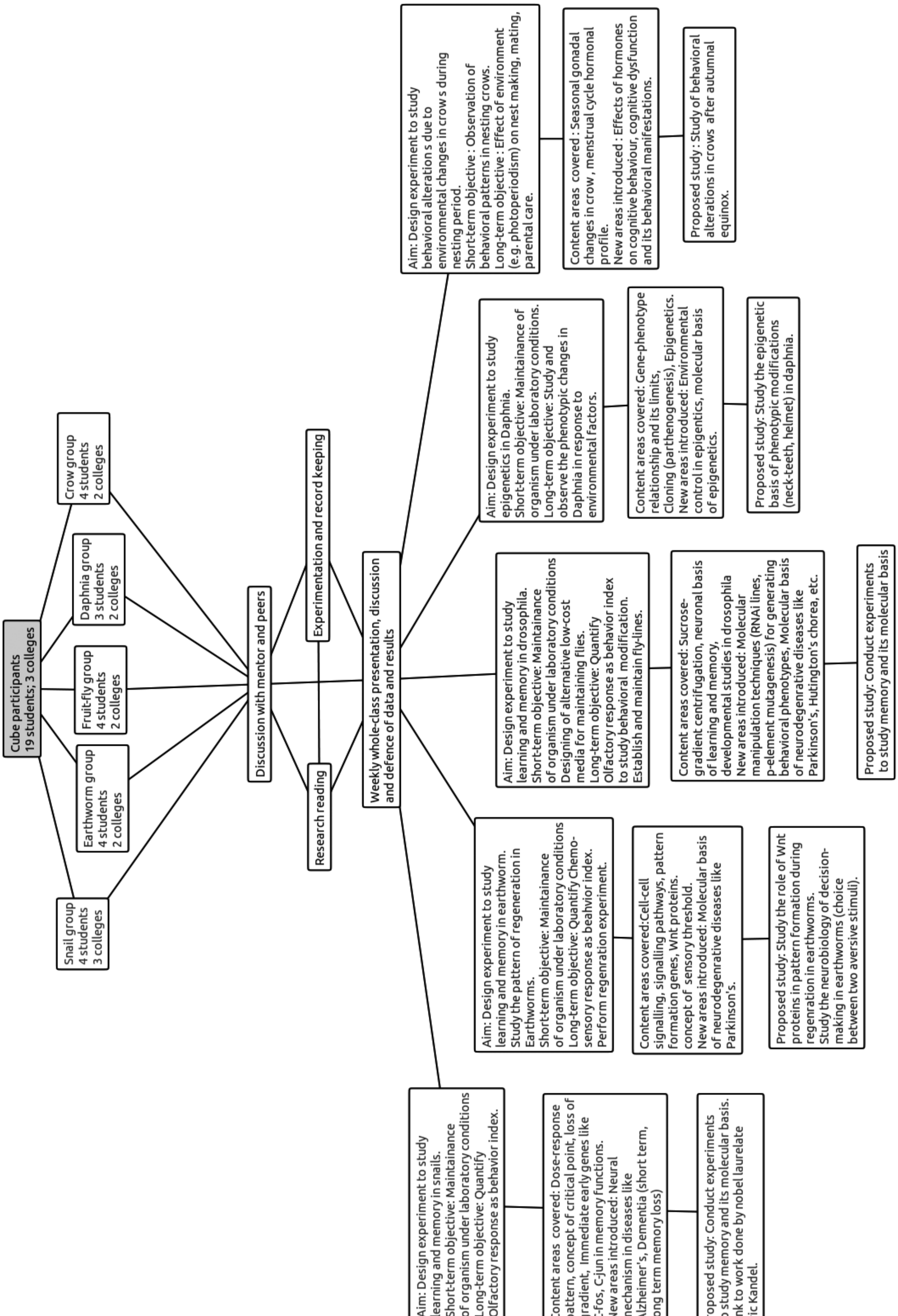

Figure 2: Summary scheme of the CUBE summer 2012 programme using Simple Model System Based Research

Discussion and Conclusions

In the following section we present a glimpse of who has benefited from the CUBE program, in what ways and how that provides an impetus to the cascade phenomena that has already started showing its effect by means of students setting up undergraduate research program in their respective colleges. We had in our mind certain expected themes of the outcomes at the start of the project and the discussion is centered around those themes:

***a. What does it mean to be a graduate*?**

The spirit of 'graduateness', a term defined in the higher education policy documents of the United Kingdom, is the state of preparedness of the student to appreciate the extent of their subject, that is the student should not only know the background of the subject but should also possess the skills to appraise and interpret new information or discoveries. This will give them a sense of ownership of the subject and the comfort and confidence to make a transition from being a passive observer to becoming an active participant (Entwistle et al., 2002, MCcune & Hounsell, 2005).

There is a great deal of scaffolding that is required to smoothen the entry of students from high school science to college science. The shift in focus from gaining experiences about the already known world to a world full of possibilities is not at all an easy one. If the students are not convinced early enough of the possibilities and challenges of research in college science then fewer numbers will feel the necessity to undertake science as a career option (Brewer & Smith, 2011).

Some student responses to a free-wheeling questionnaire at the end of the CUBE summer 2012 program justify the claim:

> "The CUBE summer program has changed my objective and motivation and my way of thinking and questioning on any subject. Before joining the CUBE programme I never questioned my subject (i.e. why am I doing this? what is my interest in it?). These things have now started coming in my mind and it has made me more motivated for my subject."

> ".....I had no idea of what real biology is. I was just doing biology for the sake of scoring marks."

> ".....what I have acquired through the discussions about science is, my attitude towards science has been changed. It has motivated me to go deep into any concepts that I never thought."

b. What tangible outcomes has the CUBE been able to provide?

Skill development is inevitable in the course of any engagement with research project. Thus whether or not these skills have been deliberately sought, any student completing a research project will have acquired a valuable set of life-enhancing experiences.

When the students were asked to contrast the CUBE laboratory sessions with the regular college practicals, the students expressed that the CUBE projects giving them a lot of scope to discuss possible variations to an experiment and try it multiple times. They regarded this interesting because it gave them the real sense of experimentation and the importance of multiple trials for establishing the reliability of the results. They wrote that such a practice gave them confidence in their data.

c. Is a programme like CUBE accessible to all students and colleges?

The concept of research and research labs is one that invests a lot in the laboratory equipments and materials but we have, by the use of very simple model systems, proved that what is required is the sophistication in the mind of the researcher rather than the sophistication in instruments for engaging in good research. This is particularly important to establish in a developing country like India where most of the colleges would hesitate to even try out such practices because of the limit on capital involvement in conducting research.

Some student responses have been very interesting in this regard:

> "....before coming to this programme, we had a notion that complex biology research requires a lot of sophisticated machines, techniques, etc. We never thought that simple organisms could give insight into very deep research areas. After this programme, we have realised that research doesn't necessarily require fancy equipments and that relevant questions can do the trick."

> "After joining the CUBE programme I came to know that research can be done by anyone by using some sophisticated ideas and some good observation."

> "I use to think that research means having a very big lab, doing reactions and having very hi-fi stuff, but I have learned that many complex things can be studied using simple systems."

d. What does the CUBE offer students who do not want to pursue sciences at higher studies?

We content that a minimum scientific literacy (akin to the concept of *biological literacy*) is not only desirable but also essential for becoming an autonomous and informed individual of the society. There is certainly a value in having experienced the knowledge about science; the how's and why's of science. An understanding of the methods of scientific inquiry, the relationship between claimed knowledge and presented data, an appreciation of the culture of science and of the close interactions between science and society are important for making informed decisions in everyday lives.

e. Were the students having fun and enjoying it?

Having a sense of ownership of the learning process, being motivated for it and deriving fun out of such learning represents a radical shift that takes place in the learning style for most students during their involvement in a research project. The project belongs to them and they are the active performers in its progress. This sort of personalised learning converts enthusiasm into productivity which in turn feeds into their feeling of self-worth. Many students find this independence empowering and motivating. They respond positively to the acquired responsibility for their own learning. These valuable aspects of a research experience contribute to the student’s personal, professional and scientific maturity (Luck, 2009).

A general increase in the feeling of competence and self-worth can be seen in the student responses to the differences between the CUBE research programme and the college laboratory courses.

> “....the feeling of self-worth is more as we put in our ideas and experiment them in contrast to college practicals where we do the same work as others and everybody follows the lab manual.”

> “....we are asked to come up with our own ideas and it makes us feel worth.”

> “There is no pressure for correct answers and we make mistakes and find right answers.”

> “....confidence in explaining the work done to others has increased a lot as the experiments and concepts were developed by us through discussions.”

f. Do teachers need to be active researchers?

There has been a lot of debate on the link between teaching and research in higher education in recent years (Sears & Wood, 2005, Jenkins et al., 2007). Engaging (developing, guiding) in undergraduate research projects can be a straightforward way of integrating teaching and research. Moreover, if student research projects are viewed as part of one’s teaching, it can help reduce the burden of the course considerably.

Student research differs from other kind of research in its purpose: it is part of learning, the emphasis is on process rather than outcome. So in spite of the uncertainty of the outcome of the project *per se,* any research project can be considered as a success if the student emerges from it with an understanding of what science is and how it works. (Petrella & Jung, 2008).

These changing ways of learning call upon a revision in the traditional methods of assessment and evaluation to incorporate student's scientific thinking through open-ended problem-solving abilities. Further, students working in collaboration will start to understand how research is a collaborative effort and will develop teamwork skills. They will also help each other to achieve greater breadth and depth of understanding.

Results from the Phase I CUBE initiative are already visible. We will discuss them in brief here: Each of the three participating colleges have already established research labs in their colleges, using simple model system-based approach. One of the colleges (suburban) has already established a network with two more neighboring college and is helping them to establish their own lab with simple model systems. Participants from phase I have also initiated the process of entering into collaboration, with other interested participants from different colleges, on various research projects. These research projects will be supervised by the teacher-mentors of respective colleges. More short-term workshops to introduce CUB research in undergraduate colleges are in the pipeline at three centers in a metropolitan city and three other major cities of India.

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