UNDERGRADUATE RESEARCH: 
FOSTERING CREATIVITY 
THROUGH PERSONALIZED 
EDUCATION

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Abstract: In this paper we argue that the true aims of education lie in producing 'creative' individuals where creativity is referred to mean motivated, passionate, skilled, adaptable and responsible. Such attitudes to learning, especially in the mathematical and physical sciences, are best produced through a strong undergraduate research program, in fact more so than traditional classroom teaching. Research experience at the undergraduate level instills a deep sense of personalized education and learning that can make the entire university experience extremely pleasurable and of lasting value.

1 INTRODUCTION

In his address to the Mathematical association of England in 1916, Alfred North Whitehead argued for the need for both a breadth and depth in education. He went on to say that[2]:

Let the main ideas which are introduced into a child’s education be few and important and let them be thrown into every combination possible. The child should make them his own and should understand their application here and now in the circumstances of his actual life. From the very beginning of his education, the child should enjoy of discovery...

These very poignant words from over a century ago still rings true and has value for the current state of undergraduate curriculum. This paper will address the importance of Whitehead’s comments to the current state of our undergraduate mathematics and physics programs. The
first natural question that we are lead to pursue is: What are the aims of undergraduate education? A first plausible answer to this question might be that education aims at:

1. Raising curiosity and an appreciation of knowledge among youth and advance the idea of lifelong learning.
2. Producing well informed citizens that uphold the ideals of the nation.
3. Providing useful skills to students so that they can be part of an effective workforce.
4. Allowing students and graduates to develop a sense of success which then provides positive reinforcement to the entire process mentioned above and allows for its continued sustenance.

These aims are relevant to all disciplines but it is worth highlighting the importance of these ideals in the mathematical sciences. Mathematics and Physics, particularly the latter, have suffered from low retention and enrollments, especially in recent years[5]. With the increasing demand for a scientifically well trained workforce, the needs to better retain and train these students is of grave importance. In these above mentioned theoretical disciplines where several years of coursework is focused on tool building and one is often disconnected from the realities of the field, the need for constant motivation cannot be overemphasized. I am sure, many of us faculty in the mathematics, especially in interacting with lower level undergraduates have come across the question Why is this useful? When am I ever going to need it outside of this class? These questions lie at the core of the nation’s science crisis and addressing them through creative adaptations in our teaching and learning environments can go a long way in redressing this situation.

At the same time we also recognize that mere retention of students is insufficient. What a good scientific and mathematics education strives for is providing the insights to spark creativity in their students which goes beyond a mere mastery of subject skills[11]. Creativity, as a desirable national trait has even been realized by politicians; the British Prime Minister, Tony Blair remarked not so long ago[1]

Our aim must be to create a nation where the creative talents of all the people are used to build a true enterprise economy for the twenty first century - where we compete on brains, not brawn.

In this rest of this paper, we argue that an official and strong undergraduate research program, which is integrated into the undergraduate math and science curriculum as a requirement, is a very significant factor
in bringing creativity to the forefront of outcomes from undergraduate education and expectations from our students. First, a proper examination of creativity, especially in the context of education is necessary.

2 CREATIVITY

The literature on creativity is vast and dates back to centuries and spans different cultures. While creativity itself has remained a somewhat elusive notion, there has been a need to understand it better to see if it inherent or can be cultivated. David Bohm[6], relates creativity to the idea of ’originality’ which he states:

...is very hard to define or specify...it will be best to hint at it...One prerequisite for originality is clearly that a person shall not be inclined to impose his preconceptions on the fact as he sees it. Rather, he must be able to learn something new, even if this means that the ideas and notions that are near and dear are overturned.

Bohm’s idea of creativity in the sciences particularly, are very reminiscent of Thomas kuhn [7] who saw true advances and understanding in science as occurring periodically as major paradigm shifts, the classical example therefore being the major shift from a Newtonian view of gravity to the Einsteinian version. As Bohm suggests, for creativity to thrive, preconceived ideas must be abandoned; one must give up the self in the subject or perhaps immerse oneself deeply in the subject that hand to such an extent that the self dissolves with the subject. A careful reading of Bohm reveals that he identifies creativity with originality, penetrating insight and new inventions but also to

...a new fundamental set of similar differences that contribute to a genuinely new order...

He goes on to say that

In the whole of human history, perhaps only a few people have achieved it [creativity]. Most of the rest of human action has been relatively mediocre, though it is interlaced with flashes of penetrating insight that help raise it above the level of mere humdrum.

Sternberg [17] also argues that while not everyone can reach the pinnacle of creativity, they can adopt a creative attitude. Much like Bohm, Sternberg along with several others also refer to the crowning achievements of humanity as creative acts such as [17] Darwin’s theory
of evolution, Linus Pauling’s valence-bond theory and Monet’s impressionist paintings to name a few.

Evidently, Bohm’s and Sternberg’s standards for creativity are rather high and measured by a need to overturn the course of human thought. While Bohm’s overall premise is very sound, we feel that the idea of creativity should allow for variations in the degree of impact. This is especially needed when discussing the idea of creativity in the context of education. For instance, an act of creation that impacts an entire civilization or society would be deemed an act of \textit{high level creativity}, while an act that overturns the perception or idea about something for oneself would be an act of \textit{low level creativity}; actions leading to a personal epiphany can still be creative, though personal. In general creativity can be then identified as falling somewhere within these extremities. Hence, no matter the degree, the impact of the creation is nevertheless a paradigm shift. In fact, within this framework, one could envision creativity as being both a physical and mental act.

As an example let me narrate my personal experience in creativity with my undergraduate research student, PM, a physics major. PM and I were, some months ago, considering the problem of experimentally verifying the results of our mathematical work on flow of viscoelastic fluids under shearing \footnote{[?].} . The experimental setup was a formidable challenge to design and build and would also been an expensive proposition. PM accomplished this seemingly difficult task by stripping a car-window assembly unit purchased from a junk yard and putting it together with the rest of the apparatus, which was also self made (see figure 1). While the details of the design cannot be discussed here it suffices to say that PM’s creativity in this matter allowed us to bypass an otherwise difficult problem. While, one cannot compare the impact of this creative act with that of Darwin, Pauling, Monet or any other it still abides at some level by all the necessary conditions to be deemed creative. The impact of this out of the box approach was felt by our laboratory and the experimental team, not an entire civilization. In the context of education, it must be realized that such creative growth must begin with small steps before it evolves into one of ground breaking magnitude. Surely Darwin, Pauling, Monet, Einstein and others first tinkered with smaller acts of creativity before producing their now recognized acts of genius. Perhaps frequent acts of lower level creativity predisposes one to higher levels of creativity.

Analyzing student creativity becomes much more meaningful through this more general definition of creativity that we propose; what we seek in our undergraduate education can therefore be itemized as
1. cultivation of a culture of creativity or adoption of a creative attitude
2. desire for lifelong pursuit of creativity and
3. progression to higher levels of creativity.

This allows for a more democratic view of creativity, where all students, not just a select few have room to grow, change and create change. The central goal of all education has after all been to foster growth and change in the student by allowing them to see things in unforeseen ways.

The literature on creativity from psychology and education scholars is event more vast. Based on the works of [12, 13, 14, ?, 17], Spendlove [11] identifies several qualities of a creative person, namely


These traits can all be seen to fit very well into one of the educational objectives that we outlined in the introductory section. Also worth mentioning in this context is Professor Paul Baker’s attempt and success in bringing the creative process to the fore of undergraduate education [3]. Using the theater as a stage for exploration, Baker asked his students to use the concepts of space, movement, color, silhouette, line, sound, rhythm, shape, and texture, collectively termed the integration of abilities to delve into their own individual creative processes. Baker points
students to the ultimate level of growth or creativity which he advocates all students to aim for:

To some few, growth is the discovery of a dynamic power of the mind. There is a long period of intense study, criticism and self-examination. Directions are not easily found; words do not come easily; the growth process is of little immediate interest to anyone else...The growth is very precious and private...It works and slaves; engulfs whole ideas; absorbs; performs surgical operations on pat formulas; laughs heartily at mediocrity and opens new worlds of insight. This mind is at home in any period, in any place where genius has produced lasting works.

The definition of creativity or ultimate growth, as Baker envisions it is not so far from what we proposed as a variation to Bohm’s view of creativity. The fascinating aspect of Baker’s thinking is that he provides a practical approach to foster creativity among all students.

3 UNDERGRADUATE RESEARCH AS PERSONALIZING EDUCATION

Now that we have some semblance of a working definition of creativity, we must examine ways to foster this attitude among our students. While Paul Baker provides a framework and setting to inculcate the creative attitude in the classroom which has been very successful, it is hard to estimate if it leads to creativity. The question of how to bring out scientific and mathematical creativity still remains. What perhaps Baker does most effectively is personalize the educational experience, at least within his course by allowing students to shape the course, within some broad outlines, as they saw fit. This is in stark contrast to the traditional classroom education method where the students participate passively in a lecture. While there is much to be said about the traditional education method. It provides a coherent framework of well tested programs to have students acquire a certain skill, it does precisely that; provide students a skill and refines their intelligence. While intelligence is an essential part of creativity but not all of it.

Based on the effective teaching methods of several university professors, Bain [4] proposed the promising syllabus which lures the student into the course, not through formal descriptions of the course content and reward systems but through personalizing the course and asking questions that would excite the students. This can go a long way and has proven to be very successful. But needless to say, it is not merely the syllabus that is to be credited but the entire philosophy of the course and
the effective delivery of that philosophy to the students. While a great teacher can inspire, motivate and instill good learning habits, the student merely experiences a projection of the teachers talent. How much of this projection remains with the student through the remaining years of education? How does one positive classroom experience affect the other classes? While most people can recall a stimulating course taken with a very gifted teacher, one rarely recalls the exact content of the course and despite this positive experience one can often also simultaneously recall a very negative classroom experience. What we are seeking is a *synthesizing experience* that brings all of the undergraduate education experience under one umbrella; unleashes self-sustaining motivation and excitement from within the student. Educators in different disciplines have felt the need to *personalize the entire education and learning process* so students find a natural connection to their life on the college campus and beyond. In the words of Ellen Langer[8]

Information that is about ourselves, about the parts of ourselves that we really care about, is the easiest to learn.

We propose that a strong research experience during the undergraduate years as the key to bringing out true creativity through a very personal connection to education and learning. While undergraduates are widely involved in research in most college campuses, their involvement is voluntary and driven by personal desire. The student can at best earn a stipend or some credits for their work. Unless, one is involved in an honors or formal research program, not all students are exposed to a rigorous research experience. The mathematical sciences such as pure and applied mathematics and theoretical branches of physics particularly suffer from this problem often due to the lack of sufficient background and prerequisite knowledge. Research then seems to be thought of as a one way street; *once you have mastered the basic material you can participate in research activities*. However, any graduate research student would confess that mastery of subject and successful research works as a feedback loop. Langer states [8]:

Studies have conformed that science is better taught through hands-on research and discovery than through memorization alone. In English, teaching for understanding means emphasizing the process of writing and exploring the literature rather than memorizing grammar rules and doing drills. Understanding is encouraged in history by turning students into junior historians.

Why then don’t we turn our mathematics students into junior mathematicians? Based on a survey of 76 students participating in a summer
research program Seymour et al. [18] identify the major benefits of a research experience. These included:

- increased interest in the discipline
- improved attitude to learning; ownership of project fosters a sense of responsibility
- better career preparation
- improved skills: ability to better collaborate, communicate, write
- critical thinking ability
- better understanding of the scientific process
- better learning skills; learning through active participation
- become part of a community.

The problem with the current hesitation with involving more mathematics and theoretical physics students in research perhaps lies in the fact that the research mentors and faculty view this as a hindrance to their own high level creative achievements. This ties into the Bohmian and perhaps a wider view of creativity being a major act of paradigm shift and preventing a possible low level creative evolution of the student. Therefore the exact nature of undergraduate research, especially in the mathematical sciences must be considered. A few possible ways of conducting an effective undergraduate research program are discussed in the following section.

There is common consensus among all scholars of creativity that the key feature of this trait is in the ability to abandon old ideas for a new one. As Sternberg puts it [?]:

...intelligence represents a thesis, creativity an antithesis...

If we then to foster creativity among our students there must be a healthy dose of questioning of the existing knowledge base that must be introduced into the college experience. One cannot overturn paradigms if one is made to blindly follow them. This attitude can best be inculcated through the research experience where every mathematical and scientific law is a hypothesis to be tested and falsified [10] and not a rule to be memorized.
4 A SUSTAINABLE UNDERGRADUATE RESEARCH PROGRAM

While a traditional undergraduate research experience will provide all the benefits that lead to a creative transformation in the student, we propose a more ambitious program. The questions that we want to address in this section include: (i) how do we design a formal research program that includes undergraduates? (ii) how does one bypass the problem of insufficient prerequisite mathematical knowledge among undergraduates? While we do not claim to have the answer to these questions, some plausible answers are possible based upon experience and insight.

To address the first question, we argue that much like the requirement to take courses towards a degree, there must be a research requirement which all mathematics/physics students must undergo. We realize that not all students are heading for a research profession, however our very point is that research is not a skill to be acquired and is not be done with the goal of going to graduate school; it is an end in itself. The fruits of undergraduate research are plentiful and have been discussed above [18]. In particular this activity allows students to actively participate in the shaping of knowledge and be infused with an excitement for learning that might last years beyond the formal education years. The problem with a conventional project-course usually done in the last year of the student’s tenure is that it treats research as an after-thought and as being secondary to the formal course.

The research experience must begin even before the student formally enters the program in the junior year (in most schools); the student enters the college with a big question in mind; a question that interests, excites, infuriates them; a question that they would like the answer to and are willing to pursue for a long time, beyond the college years. Ideally the big-question is framed in the context of the mathematical sciences and can be appropriately refined with the help of faculty mentors. The purpose for the big-question is for the student to always be mindful of the big picture; college curriculum often has the tendency to trap the students in the details of the profession. The onus then falls on each and every faculty to motivate the students in their respective classes. The big-question is a way to allow the students to find their own personal meaning and personalizing their educational experience. Every course then becomes a means to find insights to the question and there is a very personal stake for the student in taking each class.

The research experience can be tied to the big-question whereby the student works with a faculty on a related research problem which is
to be conducted in a systematic and traditional manner. This leads
us to the second question about the background knowledge. The big
question provides the starting point for the students’ investigation and
must be formally documented as a thesis at the end of their college ed-
ucation. It should allow students to take their research as far as their
abilities without fear of judgment. Students can be asked to read arti-
cles: technical, non-technical, biographies all of which serve to educated
and inspire; write essays: mathematical and non-mathematical writing
can both be a very creative experience; give talks: formal and informal
Students therefore get trained in the tried and tested method of rigorous
research, yet allowing them to evolve creatively to their own desired lev-
els. Background knowledge therefore becomes less of an issue; the more
advanced and motivated students can produce works of higher creativity
levels which may be published, presented etc. but every student can be
guaranteed to have a fulfilling experience, the ability to synthesize their
college coursework and draw connections, undergo a creative transforma-
tion and develop the skill sets to allow for a creative evolution for the
rest of their lives.

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1We propose that the research program not be graded or judged.


