AC 2009-2376: CREATIVITY MEETS NO BOUNDS: DEFEATING THE MYTH OF
THE CAVE

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Abstract

We are a team of nine highly and self-motivated undergraduate students and one professor trying to, and at times succeeding in, being inconspicuous. We are an interdisciplinary team from several areas of the Computer and Electrical Engineering programs at the University of Puerto Rico, exploring novel ideas of products that can become feasible projects for the capstone design course. The approach to our work contrasts with many conventional engineering education practices, which place emphasis on highly structured and formal procedures and solving problems proposed by faculty members or by industry partners. Although we still meet in the formal setting of a classroom and one research laboratory, the sessions differ significantly from regular classes, appearing more like creative meetings à la “Dick Van Dike Show” where restraints to ideas are lifted as far as possible until engineering and project management criteria are recalled to put our feet back on the ground. The undergraduate research course started with a presentation of creativity and innovation techniques from which students chose initially four of them: brainstorming, force field analysis, 5W/H questions and analogy/metaphor. Eleven ideas were initially proposed, ranging from an alarm clock for all types of sleepers to a virtual office. These creativity techniques were variably used to enrich and analyze the ideas. Finally, and using an idea filtering technique invented by the team, which we refer to as the “survivor idea challenge”, the set was reduced to three projects ideas which we have coined as “My Guide”, “Smart Recycling System” and the “Turing Desk”. Despite the apparent informality, the team elaborated and carefully followed a work plan which by the end of this year will lead to deciding one project that additionally to be subject to realistic constraints, will also meet our own constraints of containing work for all the areas of the team members. This paper describes the approach, the experience of the team and the results achieved.

The Problem At Hand: Becoming an Effectively Creative Engineer

Attempting to define “engineer” as a verb yields a very interesting description: “skillfully or artfully arrange for (an event or situation) to occur”. What is refreshing about the description is that it opens a door to the possibility of “engineering” to be some long lost form of art! This would contrast widely held notions about engineering being a technical science. Avoiding a philosophical discussion of whether engineering is an art or a science, we will take this definition for its face value. The fact that the word “artfully” is in the definition, should hint at the use of creativity within engineering. However, if we look into most engineering curricula, we will find no evidence of the use of creativity as a methodology for engineering education. Taking a view into our own campus (and extrapolating to any other ABET accredited university) the average undergraduate
student’s life consists of answering tests, participating in extracurricular activities, and performing undergraduate research at different levels. On campus, the defining moment of an undergraduate engineering student comes by way of his or her Capstone Engineering Design in which students come together to work on a project that deals with their particular field of study. For purposes of demonstration, the ECE Department’s Computer Engineering Capstone Course has as its course description: “[Capstone] course in which student teams design a project to solve a complete Computer Engineering Problem considering engineering standards and realistic constraints. The project should integrate both hardware and software.” This is one of the very few times in our curriculum that a student is given the free choice of coming up with a solution to a problem that they themselves propose. Even more so, it is one of the few times a student is given the chance to be creative. Add to that the fact that this design course exists at the departmental level; that is, there is no design course offered that is truly interdisciplinary. It is reminiscent of what many universities try to avoid when they hire professors for tenure: inter-breeding. Before we can attempt to describe our creative approach to tackle this problem, we must look at the problem head on: Where do we stand within engineering education? Why do we still lack creativity in the classroom? Why is this a problem?

A Situation Report on Engineering Education

A relatively recent report on engineering education, by the Carnegie Foundation for the Advancement of Teaching revealed that undergraduate engineering programs struggle to transmit a base of technical skills, leaving even less room for students to develop their own professional identity necessary for engineers in this new century. According to the report:

…professional schools…should aim for an increasingly integrated approach to the formation of students’ analytical reasoning, practical skills, and professional judgment. Although some engineering schools have introduced programs, teaching methods, or curricular structures that attempt to integrate these professional goals, none offers a comprehensively networked approach.

In other words, the main problem behind engineering education is not in teaching fundamental technical skills, but rather integrating these skills in order to become professionals. The report continuously emphasizes the need for practice-like experiences, where would-be engineers (engineering students) would move from the classroom into the field, becoming active participants within engineering. From this we can conclude, that a more interactive way of teaching is necessary. In addition to promoting a more interactive and collaborative environment, our approach to assess the need for more interactive teaching focuses on the use of creativity. We believe that engineering education stands to benefit greatly from fostering creativity inside the classroom, as we will later detail.
Engineering Education: A Brief Assessment on Creativity

There are several writings on the use of creativity inside the classroom, with all of them coinciding (albeit in different ways) on one thing: there is not enough. A study carried out in 2007 indicated that engineering students experience almost no creativity as part of their academic experiences\(^4\). This situation is not exclusive to engineering education. A different study has also shown computer science disciplines to struggle in trying to include creativity and design in their teaching and research\(^5\). What is shocking about all this is that, this is not a new problem! In a 1998 conference it was noted that few courses in the standard engineering curriculum require or even encourage creativity: “Students often feel that creative behavior is actively discouraged in their classes.”\(^6\) This heightens the importance of our approach: through the use of the creative techniques and environment we propose, we intend to show that creativity can be integrated in and enrich engineering education.

Riddle Me This: Why does this continue to happen?

If we as engineers are supposed to engineer new things, and thereby be creative, why do we still suffer from a lack of creativity in engineering schools? The answer could lie in the inflexibility of engineering education itself\(^7\). Several remarks have been made regarding the issue of why engineering schools are slow to change. Some hold the accrediting institutions (such as ABET in the case of engineering) responsible: “More ambitious methods of teaching can lead to more complicated processes for proving compliance with accreditation standards.”\(^7\). However, within ABET (which is of particular interest to engineering education) there is no criteria that limits the use of any particular teaching method within the board’s “Engineering Accreditation Criteria”\(^8\). Others claim that the engineering curricula itself (and all their implications) are to blame. There are two notable examples for this reasoning: The first is that faculty members are very protective of their curricula\(^7\). For engineering education to change, faculty member attitudes about the courses they teach would have to change. Their pedagogical strategies might have to be rethought (possibly against their will), so that they may find new ways of teaching the same material differently. That would be the equivalent of telling over 5,000 years of (combined) experience across the world that their methods of instruction (that they have come to know and love) are not necessarily appropriate; a very unpleasant and unwelcoming experience. A second reasoning that might explain why we should hold curricula responsible for engineering education’s inflexibility, is that the curriculum is too full. In a recent workshop on engineering education titled “Engineering Education in the 21\(^{st}\) Century”, the keynote speaker humorously pointed out the fact that within the standard engineering curriculum “…we still have four semesters of continuous mathematics, irrespective of the fact that these students will probably never integrate anything, ever again.”\(^9\) Despite the differences of opinion of why the standard engineering curriculum is stagnant, we can at least appreciate that there is definitely cause for worry. If we look for things to add to the curriculum in
order to make it more adaptable to today’s age, we would be walking in the wrong direction. However, if we were to use the time we are granted (which ranges from eight to ten semesters) to better educate our would-be engineers, we would be taking a step in the right direction. Our approach to creativity-enhanced learning aims to be a pillar for that first step.

**Value Added: Creativity as a High-Value Commodity**

If the challenges that modern-day engineering education face are not enough motivation to consider creativity for enhanced learning, perhaps the high marketability of novel engineering concepts will be more persuasive. Looking beyond the academic scope reveals that in the industry there has been a strong commitment with the use of creativity. Several successful companies\(^\text{10, 11}\) have prided themselves on the atmosphere that they use in order to foster creativity and “design thinking” in their employees. Therefore, exposure to these types of environments would help the synergy between students and their potential creative employers. One of the main determinants in the success or failure of an enterprise is its ability to innovate, which requires creativity.\(^\text{12}\)

What all the aforementioned information means is that there are many motivations for being creative. The phrase “Innovate or Perish” seems appropriate to succinctly describe the problem scenario we face with engineering education.

**From Words To Action: Our Approach To Engineering Creatively through Participatory Action and Problem-Based Learning**

Just as we would expect that engineering a solution to a modern day problem would require a non-linear mind, we would also expect that dedicated research is needed to come up with new ways to infuse the classroom with creative thinking. However, our unorthodoxly creative study and work methods were informally developed and were not the original intention of our work. The original premise of our work was motivated by engineering students seeking as a goal the development of an idea for a Capstone design course project. After the initial meeting, we informally discussed the guidelines of what we would do to achieve our goal, and without knowing it we became participatory-action researchers. What is more, as the process began, the increasing focus on developing a design project led to identifying a problem in society which we could solve through said project; a problem-based approach to engineering.

**Participatory Action Research defined**

Participatory Action Research (PAR) is a research methodology where the motivation driving the research is to create a positive social change.\(^\text{13}\) It embraces participation and reflection from within the target of study. In this case, the social aspect we would like to positively affect is engineering education. The key
behind PAR is that you must become part of the crowd in order to effectively study it.

Problem-Based Learning defined

Our observations on standard engineering education involve standard protocols that follow the same pattern. First, fundamentals of the course of instruction are discussed. Second, new theory is built upon those fundamentals. Lastly, we look at what are the types of problems engineers (of our particular field) face, and apply the new theory to solve those problems. In this scenario, only at the end do we understand what the purpose of learning the theory was. However, problem-based learning works in the opposite direction. Project-based learning (PBL) is a technique of instruction that involves messy, complex problems encountered in the real world as a stimulus for learning.

What PAR and PBL imply for our particular situation

There are several things that these two methodologies imply for our work: First, the professor must become part of a crowd of students. Second, students must be able to reflect and act upon teaching strategies, determining whether they are getting the desired results or not. Third, students must be able to show awareness to address social needs, and capability to identify the particular problems that can be solved within society through the use of engineering. Fourth, the synergy of teachers and students must be enough to foster independent, and collaborative learning. Finally, students should be able to think in an environment, which is their own; that is, external critiques or entities, which could affect creative thought, should be avoided. These implications are paramount for our methodology and are the fundamental base off of which our observations of creativity come to light.

The Proposed Environment

As previously mentioned, our study of the effectiveness of creativity inside the classroom when combined with problem-based learning was an afterthought in our work; in other words, an epiphany. We now go into detail of what exactly happened that allowed us to become (unaware) participatory-action researchers who followed a problem-based approach. In the sections that follow we explain the creative environment that was our day-to-day. This is what we propose should become part of the standard for the next generation of engineering education: our complete methodology in detail.

Methodology: Becoming One With the Student

This setting started out as an ad-honorem course, motivated by the desire of engineering students to research something patentable, which could serve a greater good for society, and would be implementable in the capstone design
course. It was later given structure via an Undergraduate Research Course, titled “Idea Incubator”. Within the first meetings of this initiative, guidelines were set that were to be observed at all times, and were intended to allow the student to feel like a true scholar.

The Unofficial Guidelines on Creative Thinking

The first guideline was: Relax. Ironically, this was a serious implication. All activity in the classroom was allowed; from using cell phones to laptops, from eating to taking a nap (a team favorite), as researchers, we were all allowed to do whatever we felt like doing, all within the context of what our plans aimed for.

The second guideline was: No one, under any circumstances, shall call the research advisor “professor”. Ever. What is more, the penalty for failing to do so was failure in the undergraduate research. Even though sarcasm and humor is evident in this guideline, it is the cornerstone of our research: there was no explicit hierarchy to be present that would pose a threat to the comfort level that allows ideas to flow freely.

The third guideline was: Everything goes. Even though this seems like an extension of the first guideline, it was made explicitly clear. Nothing would be cast away for fears of being “too ridiculous”, “too farfetched”, or “too insane”. Whatever was proposed was written down and later looked at. This applied to all ideas that came up as part of discussions, as well as to our demeanor inside the classroom. The key was this: the moment the team walked through the classroom door, the area became a safe haven from outside eyes.

A Problem Oriented Approach and Creativity Techniques Unveiled

After the “rules of the game” were set, we began the entire process. Our problem-based approach came in the form of the first task: coming up with product ideas. Taking into consideration aspects like feasibility, applicability, marketability, and almost any other word that ends in “-bility”, the team was asked to think of a social problem solvable with a potential product; in other words, we were to identify technological voids within our society that were of interest, of impact, or just plain cool. Eleven ideas came out of the whole process and attended questions such as: “How can I better get up in the morning?”, “How could I charge my cell phone without plugging it in?”, and “How can we get people to recycle more?” These problems sparked great interest and removed the initial skepticism of the group relating to what was actually going to be done.

After the ideas were written down, creativity techniques used for questioning and analyzing those ideas were discussed. These techniques were meant to become a starting point from which ideas could be critically and creatively analyzed. The team was exposed to over seven creativity techniques, which varied in style and
implementation. Because of time constraints, three techniques were selected that would be applied to all the ideas generated throughout team discussions. A brief overview of the three techniques used follows:

**Force Field Analysis**

Uses the concept of two parallel universes to describe the idea. First, describe the idea in an ideal world, where the ideal assumptions for scientific problems (such as no friction, no heat dissipation) come to life. Then turn around one hundred eighty degrees, and describe the idea in a non-ideal (bordering on catastrophic) world. A spectrum is then drawn with the two worlds at each end, and starts with the idea in the middle. Taking examples from the two worlds, external “forces” are identified that could contribute to the idea moving to one side of the spectrum or the other. This kind of “mental boundary testing” helps in identifying possible implementation problems that could become very realistic.

**Analogy / Metaphor Technique**

Formalizes a traditional way of understanding the unknown, by translating it into known objects or situations. Phrasing the idea into statements like “This idea reminds me of / behaves like…” helps to concretize elements of what your idea could potentially end up as. This technique also involves the use of equations by trying to “add” items that would “sum up” to the idea being analyzed.

**5Ws / H Questions**

This technique uses information-gathering questions with a twist. The questions “Who?”, “What?”, “Where?”, “When?”, “Why?”, “How?” are asked about anything and everything in the project. Typical questions include: “What technology does this idea rely on?”, “When would this be available?”, and the very important “Who would want to use our product-idea?” This methodology helps clarify intricate details about project ideas since these often-general questions can pick out inconsistencies and dependencies that might go by unchecked.

**A new creative technique emerges: the birth of “The Survivor Idea Challenge”**

Having analyzed all the ideas that were generated, we now stood atop piles of information that covered most aspects of an initial engineering design: social impact, economic cost, similar available products, technologies required, and possible implementation strategies. What was left was to decide upon an idea. Over the course of the idea analysis, the team had become infatuated with some ideas, while had immediately learned about the (current) technological impossibility of others. A way of separating the worthy ideas from the set was desired. An arena where respectful debating about the idea’s details could take place was needed. And thus, “The Survivor Idea Challenge” was born.
The team split into three groups (of two participants or more) that would rotate in role. The first of the groups was called “The Defenders”. They were in charge of defending the idea in question. The second of the groups was called “The Attackers”. These were in charge of trying to prove how unequivocally flawed the idea was. The final group was known as the “Devil’s Advocate Group”. This group was composed of all the people neither in the first, nor second group, and was responsible for attacking both parties throughout the debate. The fact that this debate also follows the Unofficial Guidelines on Creative Thinking allows for the use of chair-racing, jokes, and food breaks. This is what sets it apart from traditional debates, in that everyone becomes actively involved at the same time, not just speaker vs. speaker.

**Old Habits Die Hard: A Quantitative Analysis of Ourselves**

Out of scientific curiosity, we realized a group self-assessment to see if our techniques were applicable only to our group because of our particular learning style or not. To characterize the team, the students and the professor answered the Index of Learning Styles Questionnaire. The analysis of the questionnaire on learning styles indicated that students fell predominantly in the strongly visual group, as shown in Table 1. The moderately active, balanced-sensing and balanced-intuitive were next in terms of number of students in those groups. However, when analyzing the styles as a whole it is clear that the students of the team were all visual and (except for one) were also active, while they were distributed almost uniformly between sensing-intuitive and sequential-global. These results do not come as a surprise since in a previous study conducted on students of the same generation and a similar population Jiménez et al. found that students of the same generation and a similar population were also predominantly visual. The high percentage of active learners among the students of this group contrasts with a more balanced distribution between active and reflective found in Jiménez et al. These results also contrast with the professor results which show a moderately reflective, strongly intuitive, balanced-verbal and global individual.

<table>
<thead>
<tr>
<th></th>
<th>Balanced</th>
<th>Moderate</th>
<th>Strong</th>
<th>Total</th>
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<tr>
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<td>3</td>
<td>1</td>
<td>6</td>
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</tr>
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<td></td>
<td>4</td>
</tr>
<tr>
<td>Intuitive</td>
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<td></td>
<td></td>
<td>3</td>
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<tr>
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<td>0</td>
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<tr>
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<td>3</td>
</tr>
<tr>
<td>Global</td>
<td>2</td>
<td>2</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

**Table 1: Summary of students preferred learning styles.**
Using a standardized benchmark, we also compared the General GPA and Concentration Area GPA of the students in the team with the graduating classes of the last three years, from 2006 to 2008 with a total population of 548 students of the same undergraduate programs. The results show that the students of this team have average GPA’s slightly higher than the graduates of the last three years as shown in Table 2. However the minimum GPA’s are significantly higher than the graduates’ while the maximum GPA’s were not much lower than the graduates. These results seem to indicate that the students’ performance in this experience is driven significantly by motivation.

Table 2: Comparison of Students’ General and Concentration GPA.

<table>
<thead>
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<th>GPA</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
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<td>2006-2008</td>
<td>Concentration</td>
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<td>3.15</td>
<td>4.00</td>
</tr>
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</table>

A Wise Use of Teaching Time: The Effectiveness of our Approach

Since we believe that this work cannot only be measured quantitatively, we decided to measure the effectiveness of our methodologies qualitatively. A crucial component of PAR is continuous reflection on the current social state of the participatory research’s group of focus. In an attempt to catalogue the current state of the team, five questions were asked to the entire group (professor included) about their general thoughts and opinions of the entire experience. The questions were directed individually to each member of the group, and were answered in confidentiality.

The overall mood behind all the answers of the group was that this experience was nothing compared to anything they had seen thus far. Within the environment we created, the team felt a different comfort level alien to anything they had experimented in their first years at college. Notable was the fact that many mentioned the fear felt when first arriving at college and that this type of environment should be encouraged earlier on.

There was a unanimous agreement by all members that more experiences like these are needed. However, not all members felt that this type of approach should be applied to all aspects of an engineering curriculum, but that should become an integral part of the core curriculum.

Amazingly, even when directly asked for experiences that they did not like, some team members were unable to provide feedback. This provides strong evidence that students do enjoy creative-enhanced educational experiences. Among the most challenging experiences was the problem of dealing with team critiques and
disagreements. This was not completely unexpected; it comes with being a diverse team. However, if more experiences like these could be warranted, constructive criticism might become an easier thing to bear.

The one truly refreshing thing out of the team’s feedback is that every single team member learned something. However, each one learned something different. One team member learned from a new mentor. Another team member learned how to not criticize ideas before they are given a chance to surface. Yet another team member learned about teamwork. Even though these are soft skills (which are necessary as an engineer), the focus of the group was to develop an idea, not a technical description or product. Moreover, if the team had remained strictly focused on merely fulfilling the course objective, the team might not have learned all these skills. The fact that the team learned so much in so little time paves the way for creativity to make its case in engineering education. Needless to say, all team members would repeat the experience again.

Looking Back: Achievements

The whole endeavor provided many experiences some of which have intellectual property safeguards. For example, the ideas that were generated (and their corresponding details), as well as the ideas selected for further implementation will not be discussed. However, other more relevant milestones were achieved. The fact that an idea that will be used for a Capstone design course was generated within the environment that we were allowed to experiment in is noteworthy.

In the coming months, the idea that we have selected for full implementation will be worked on for technical specifications. Across the different areas of Electrical and Computer Engineering that the team comprises, the intent is to use other engineering design classes to develop the modular components that, when integrated, will implement our product idea. What this means in academic terms is that this group of undergraduate students, from a problem statement chosen by the team itself, has developed a plan of study, tailored to their particular field of interest, which could be compared to what is expected of graduate students at the Masters, and PhD level.

Conclusion

The question whether engineering is truly an art or a science will never be truly answered, but from our experience we can attest that it is a little bit of both. Our approach to the use of creativity and problem-based learning within the undergraduate classroom not only drew positive feedback from all the participants, but also laid the base for developing potential intellectual property within our campus.

At the end of the process, the team was asked to try to explain our experience to an external entity. As if by instinct, and by drawing reference to Greek
mythology, we came up with an analogy to our experience: Plato's work in "The Republic" - The Myth of the Cave. When asked to explain why that particular example the answer was simple: within engineering education, we typically do not see beyond what is presented to us as the reality of engineering. This is presented to us in a fashion that seems more scientific than hands-on, based on past theory and methodology instead of creativity and innovation. Amazingly, this millennia-old example serves to illustrate human nature in education. When faced with the unknown or unfamiliar, the immediate reaction is of resistance instead of open-mindedness and acceptance.

Right now, we are at a fork in the road along the path to engineering education. One path is heavily traversed, and is the one that educative institutions normally take; it is more worn and beaten. Along it, we can appreciate the current state of engineering education: fixated on the heavy use of courses and traditional methods of instruction. The other path is fresh and barely noticeable and has many obstacles created by the first path; this is a path educative institutions seldom take. It is reminiscent of Robert Frost’s “The Road Not Taken”. Much like Frost, we took the road less traveled by and it has made all the difference.

If people were given the chance to be creative they would be. This is evident in history. Works such as the incandescent light bulb, the telephone, the transistor radio, and the Internet are innovations that in their time no one could have foreseen. These solutions were creatively engineered as solutions to problems of light, communications, and connectivity. However, the challenges we face are different, and they are growing. It is up to educators to provide opportunities where creativity is nurtured, in order to meet these challenges. As educators and engineers, will we stand in the way of innovation?

Bibliography

8. ABET. [Online]. http://www.abet.org/Linked%20Documents-
UPDATE/Criteria%20and%20PP/E001%209-10%20EAC%20Criteria%202012-01-08.pdf
Video recording.
http://www.google.com/support/jobs/bin/static.py?page=about.html&about=eng
12. S.C. Kitsopoulos, "Leadership connections: communication, diversity and creativity," in 
http://www2.fhs.usyd.edu.au/arow/ar004.htm
15. Copyright ©1993 by Richard M. Felder and Barbara A. Soloman. Based on material in R.M. 
Analysis of Behavior Patterns in Generation Y Engineering Students and their Implications in 
the Teaching-Learning Process. Accepted for publication at the 2007 ASEE Annual 
17. Plato, "The Allegory of the Cave". The Republic. [Online]