The Invention Factory – Fostering Innovation in Freshman and Sophomore Engineering Students

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Abstract - **Invention Factory® (I.F.) is an intensive, non-credit bearing, six week summer program at The Cooper Union in which students conceive of an invention, research prior art to ensure that the invention is patentable, prototype the invention, and refine their prototype by presenting it to new and diverse audiences of guest evaluators each week. Over the past three years we have seen our students (ranging from rising freshmen through newly graduated seniors) greatly increase their self-confidence, building skills, presentation and organizational skills, and technical writing skills. (Each team of two students writes and files a provisional patent application by the end of the program.) I.F. is immersive – students work through lunch, and often stay late into the evening. While teams compete for significant cash prizes for 'Best Invention,' all teams tend to work cooperatively. I.F. inventions tend to be simple enough to be prototyped quickly, which permits the work of a freshman to be competitive with the work of a senior. A number of inventions created in Invention Factory have begun to move forward commercially. We propose that programs similar to Invention Factory be offered to freshman and sophomores to increase student engagement and to develop diverse skills important for engineering practice.**

Index Terms – Invention, Innovation, Maker, Patent

"I learned about patents and how to make an invention. But most importantly, I learned a life lesson: there is really nothing stopping us from going out and inventing." [1]

A NEED TO FOSTER INNOVATION

A generous gift from an alumnus [2] of The Cooper Union was directed by the donor to be used "to promote research, to improve pedagogy in STEM disciplines, and to sponsor entrepreneurship." This gift motivated the authors to create an extracurricular program that would foster innovation in our youngest students. We began by reviewing Cooper Union's core engineering curriculum for freshman and sophomores, which, though famously rigorous, consists primarily of traditional lecture style courses in calculus, chemistry, and physics taken in lock-step with other students in their major and year.

Our review concluded that our current curriculum:

- Contained project-oriented courses such as "Senior Project" that demanded a high level of technical work and focused on presentation skills, but failed to address a fundamental question of modern entrepreneurship – Does my invention fill a need? Does it have a customer? [3]
- Failed to provide training in reviewing prior art (in the patent law sense of that term). [4] Such training is valuable for at least two reasons. First, by studying relevant prior art students have the potential to make true advances in their fields, rather than reinventing the wheel. Second, it facilitates student inventors' ability to commercially exploit their intellectual property. Such training is likely to be valuable to many engineers even if they do not have an entrepreneurial bent. Searching the prior art with Google and Google Patents requires only a few hours of instruction. [5]
- Failed to give our students an appreciation of the nature and scope of patent protection, or any sense of how patent protection is obtained. Going beyond prior art, we believe that engineering students inclined towards inventive activity should be familiar with the patent requirements of novelty [6] and non-obviousness [7].
- Failed to provide for periods of sustained creative effort required to innovate. Many of our students take six or seven classes each semester. As a result, our freshmen and sophomore students are frequently highly stressed and working inefficiently during the academic year, either by multitasking [8] or by "putting out fires" (ignoring a course until shortly before an exam will be administered or a deliverable is due) Our students simply do not have adequate time to focus on creative projects, which require long periods of uninterrupted effort. [9] The problem of student overload was a disincentive to adding a credit-bearing course in innovation/invention to the current curriculum during the academic year, or to modifying an existing course.
- Would benefit from additional creative design and prototyping work beyond that contained in existing junior and senior coursework (e.g., "Senior Project" or "Capstone Design Project"). Design and prototyping work bolsters the student's C.V. and her portfolio of completed projects.
- Does not, in the eyes of employers of our students, contain sufficient coursework that develops communication skills and teamwork.

The program we have designed is extracurricular, and therefore not subject to ABET oversight, however a credit-bearing version at another institution might satisfy most or all of ABET's "a-k criteria" [10].

INVENTION FACTORY

Invention Factory® (I.F.) is a summer program for engineering students at The Cooper Union in NYC. In this intensive six week program, student teams conceive of an invention, check the prior art to insure that their invention meets the requirements for patentability, make a functioning prototype, present the invention weekly to 'guest evaluators' of diverse backgrounds and professions, and continuously refine their invention based upon feedback from the guest evaluators, I.F. faculty and I.F. students. By the end of the program, each student team has drafted and filed a provisional patent application for their invention, giving the invention a measure of domestic patent protection for one year. Provisional applications are straightforward to draft [11] and inexpensive [12] to file. Student teams retain full ownership of their intellectual property. On the last day of the program students compete for "Best Invention" with a first prize of $5,000 and a second prize of $3,000.

I.F. is a program in inventing – including the steps of careful problem selection, creative problem solving, project management, rapid prototyping, design iteration, and product pitches. I.F. is not a program in entrepreneurship. There are no business plans, case studies, or discussions of raising capital as would be found in traditional entrepreneurship programs. Nor does I.F. employ intensive customer research and interviews, the business model canvas, and the development of a minimal viable product as would be found in a modern Lean Launchpad program. However, similar to Lean, I.F. focuses on insuring that our students produce inventions that might be marketable products meeting significant customer needs.

There is a misconception that inventions are produced by a rare breed of individuals who are highly creative, highly motivated, and *highly trained*. Invention Factory operates under the assumption that, given the right conditions (resources, constraints, promotion, and a healthy degree of luck) commercially viable inventions may be produced by freshman and sophomore engineering students and not just the engineer 10 years "out" from school or the drop-out entrepreneur (e.g., Bill Gates).

Participating students range from rising freshmen through graduated seniors in each of our degree-granting programs (B.E. in Chemical, Civil, Electrical, Mechanical Engineering and B.S.E.), but the program attracts primarily freshmen and sophomores.

Students participating in I.F. are required to be present from 11 a.m. to 5 p.m. each weekday, but frequently work late into the night and on weekends. Students are not permitted to have any outside obligations (e.g., part time employment, summer jobs) during I.F. With a few exceptions, such as utilizing nearby machine shops or presenting to guest evaluators, I.F. takes place in a single laboratory in which ten teams of two students prototype their inventions, informally present their work to each other, take working lunches, and are subjected to the smallest number of lectures that will enable them to use 3D printers, a laser cutter, micro-controllers, and to craft a provisional patent application. Each team has a budget of $2,000 for materials and each student receives a $1,000 stipend.

I.F. essentially consists of four phases. In the first phase (the four to six weeks preceding the start of the summer program), students are emailed two or three ideation (brainstorming) exercises to warm them up creatively.

In the second phase (the first week of I.F.) students select partners, choose a problem to attack, and begin to craft inventions to solve their problem. On Friday each student team has six minutes to present their invention and six minutes for Q&A. The two I.F. faculty and the remaining eighteen I.F. students vote on each team's invention proposal. Each team must receive at least 10 up-votes from I.F. students and at least one up-vote from an I.F. faculty member in order to proceed with their concept. I.F. students may not up-vote more than seven inventions.

The criteria for up-voting an invention are similar to those employed in the competition at the end of the program. These criteria are: meeting a need; understanding the science; distinguishing the invention from the prior art; being superior to the prior art; manufacturability; usability; cost; impact; sustainability. While these are the formal evaluation criteria, I.F. faculty encourage students to be bold – to propose concepts that make their hearts race. Proposed inventions must satisfy a number of other requirements: they must be tangible; they cannot consist entirely of software; they must be safe (no chemistry, no exposed high voltages); they must be practical.

Students failing to obtain a 'passing' score on Friday are required to present again on Monday – either refining their initial invention or proposing an entirely different invention. In the three years of invention factory each student team has either passed on Friday (typically seven or eight out of ten teams) or passed on the following Monday.

The third phase of I.F. (weeks two through five) consists of cycles of prototyping and weekly presentations to outside evaluators. Half of our students present each Tuesday, the other half present each Thursday. [13] When students are not presenting they are prototyping or working on their presentations, with I.F. faculty assisting as needed.

In the fourth phase of I.F. (week six of the program) teams finalize their prototypes and refine their presentations (which often include live demonstrations, graphics, self-produced videos and CAD animations). Invention Factory concludes with the competition for "Best Invention."

Given the tight schedule, we prefer that students present a first prototype relatively quickly (in week two or three). Therefore inventions tend to be relatively simple in structure and also tend to be mechanical or electro-mechanical. Examples of I.F. inventions are displayed on our website, InventionFactory.org. The site currently contains professionally produced videos for many of the I.F. inventions produced in the first two years of the program.

The structure of I.F. allows students to work closely with faculty on many aspects of their inventions. Each student team interacts with the I.F. faculty all day, every day, throughout all phases of invention – from the initial identification of an 'arena' (a problem space) that interests the student, to the selection of a specific problem, to vetting proposed solutions, to project management, rapid prototyping, presentations, the patent process, and occasionally recreational activities. With this connection between students and faculty, the I.F. faculty can focus on the overall development of the student, rather than merely delivering a body of technical knowledge. A mentor-mentee relationship between a freshman/sophomore student and a faculty member may be a valuable component of an institution's student retention program.

In contrast to yearlong senior projects, which students often fail to complete to faculty members' expectations, nearly all IF inventions have been successfully completed at the end of six weeks. This is due to our careful management of resources and constraints, the immersive nature of the program and our frequent prodding. The process is often nonlinear. Sometimes our students succeed after a few unsuccessful design and prototyping iterations. [14] Ultimate success, especially after repeated failure, provides our students with a significant sense of accomplishment and self-confidence. We believe that students passing through I.F. learn the value of persistence.

The structure of I.F. follows the "Just-In-Time" approach to education. Students learn about patent law shortly before starting to draft their provisional patent applications. Students who need to use 3D printers, or need to become 'experts' on, e.g., fabric-to-plastic adhesives, acquire these skills "just in time." To the extent that I.F. faculty may lack requisite expertise, we turn to experts within the institution, e.g., machinists or graphic designers.

The use of weekly "guest evaluators" provides several benefits. Students learn to think on their feet when unexpected and difficult questions are posed. Guest evaluators frequently have expertise relevant to particular inventions, and offer suggestions or point out unanticipated problems, greatly improving the final prototype or presentation. Guest evaluators have also, on occasion, disagreed with I.F. faculty on the merits of an invention, challenging students to resolve the conflict. Guest evaluator sessions are videotaped, and reviewed the following day, with one or both faculty members privately critiquing each team's presentation. To avoid faculty bias, our philosophy and practice is to enthusiastically coach every team towards the goal of being having their invention selected as "Best Invention" – whenever we are working with that team.

THE IMPORTANCE OF VIDEOS

Since the first year of the program, we have commissioned professional videos, displayed on the I.F. website, that promote the work of our student inventors, the Invention Factory program, and The School of Engineering at The Cooper Union.

In the first Invention Factory, the "Rapid Packing Container" was chosen as the "Best Invention." The YouTube video for this invention went viral. [15] As a result of the success of the "the box" video, student inventors Chris Curro and Henry Wang became celebrities in the packaging world. They won the 2014 'Innovation by Design' Award from FastCompany, were invited to speak at two major conferences (PostalVision 2020 in 2014, PSFK), and met with representatives from companies such as Amazon and UPS. Chris and Henry reached an agreement with an investor to commercialize their invention. The success of the Rapid Packing Container video provided valuable PR for Invention Factory.

In I.F.'s second year, we produced nine videos, one for each completed invention. These videos were presented at Quirky, Inc. [16] Quirky is a company that takes ideas or prototypes for products, presents them to the "Quirky community" for voting on an evaluation night ("Eval"), and in the event of a well-received ("up-voted") proposal, takes over all remaining phases required to bring the product to market (including engineering, marketing, packaging, advertising, distribution). Quirky shares revenue with its inventors as well as members of its community who make substantial contributions to the product's development.

In a typical week Quirky receives approximately 3,000 submissions and picks eight to ten for that week's Eval night. After visiting The Cooper Union and reviewing the inventions produced in the summer of 2014, Quirky decided to bring all of the I.F. inventions directly to a dedicated "Cooper Union Eval night," bypassing the general queue. At Cooper's Eval [17] four of eight inventions presented were up-voted by the thousands of Quirky community members watching the live webcast. The eight students who created these four inventions have a chance to earn significant royalties should their products reach market. Reaching market will depend upon a number of factors, including intellectual property issues, manufacturing cost, and anticipated market size. In the Quirky context, these are problems that I.F. students need not address. Our students are free to continue their studies and perhaps move on to another invention.

From the first days of creating Invention Factory, we envisioned the possibility that students could become "serial inventors," generating one invention after another, without becoming entrepreneurs. Quirky's business model makes it possible for undergraduates to become serial inventors. Henry Wang, of the Rapid Packing Container team, validated this concept by submitting an unrelated invention, a toy, to Quirky recently. His invention was up-voted. [18]

While professional videos are expensive, accounting for about 20% of our total I.F. budget each year, they have been crucial to the overall success of the program.

PRACTICAL CONSIDERATIONS

Practical considerations for running the I.F. program can be grouped into 6 categories:

1. **The application process:** Over the past three years we have experimented with different approaches to soliciting applications and selecting students from the applicant pool. We have variously required: faculty recommendations, essays, portfolios of existing work, proposals for possible I.F. inventions, and personal interviews. We seek to identify students who are enthusiastic about the program.

   We have found that I.F. is most appealing to freshman and sophomores who often do not have other significant summer opportunities. Juniors and seniors are more strongly drawn to external REU programs, externships, and paid summer employment. Upperclassmen also have more curricular options for project work. We have observed little difference between the creative abilities of freshman and seniors.
2. **The ideation process:** One of the main challenges for I.F. faculty is how to assist students in conceiving of bold and compelling ideas that are also suitable for the program (i.e., simple to prototype). Since the program culminates in a competition, all students must start from a level playing field – no pre-existing projects are allowed. This means that students have one week to meet a partner, converge on a novel idea, and describe it persuasively enough to be up-voted by their peers and I.F. faculty. Although in 3 years of Invention Factory we have not had a single group fail to propose an invention that was eventually up-voted and more or less successfully prototyped, we are not satisfied with our current structure. We have modified the structure of the program's first week each year.

   For example, in 2013 we ran five group ideation exercises in the first week. In these exercises, students worked in teams of five to generate novel solutions to a problem that we described in careful detail. We wanted to spark bold ideas by introducing a curated set of real world problems for I.F. students to consider. This was an ineffective use of time. Students dutifully completed our ideation exercises, but had limited time to generate their own, unrelated inventions. In 2014 we reduced the group ideation exercises from 5 to 3, which left more time for students to talk informally. In 2015 we included a single group ideation session, leaving plenty of unstructured time for informal discussion with I.F. students and I.F. faculty.

   During "unstructured time" I.F. faculty move table-to-table, sometimes separately, sometimes together, asking students, "what do you have?" We encourage students to begin by selecting a problem "arena." For example: problems faced by the elderly and infirm, currently living alone, who wish to continue to be self-reliant. As I.F. faculty, we try to avoid two extremes: allowing our students to flounder and selecting (and even solving) their problems for them.

   The potential inefficiency of this process is illustrated by a recent, but rather extreme example: a team first proposed a rotisserie attachment to a stove (uninteresting to us). They then proposed a device that would be inserted into a tailpipe to reduce automobile emissions (too ambitious and requires scientific knowledge that rising sophomores lack). By Friday they converged on an improved dry erase marker, but the idea was down voted by their peers (technically unfeasible and trivial). By Friday evening they were considering a coffee stirrer made out of sugar (unoriginal, trivial). On Monday they presented a device to discourage children from sitting too close to laptop/computer/television screens. This invention was narrowly up-voted, however was poorly received by the first set of guest evaluators. In the end, the team invented a device that improves the safety and efficacy of delivering CPR. Typically teams converge more rapidly than this example.

   Some initial ideas are trivial and impractical because students are confined to a laboratory and are staring at objects in their vicinity. Yet, sending I.F. students out of the building to conduct interviews or do ethnographic studies seems unproductive because in the experience of one author (E.L.) who has taught Lean methodology for two years, such interviews/studies take a great deal of time and prove to be far more valuable for the refinement of an invention than for its initial conception. Regardless of our concerns about efficiency, the roughly 30 inventions that have been spawned by the first three years of Invention Factory have, with few exceptions, been well received by diverse evaluators, judges and the Quirky Community.
3. **Managing the prototyping process** – We have been slowly streamlining the process of making orders for components, tracking receipts and reimbursements, maintaining prototyping machines, providing technical guidance to students, and feeding I.F. students. Each of these tasks is time consuming. We employed a skilled student technician to maintain our equipment [19], place orders for prototyping components, and oversee the general operation of the lab.

   The details of I.F.'s budget are included in Table 1. This budget does not include the costs of professionally produced videos (which will depend on the scope of the videos), the cost of several 3D printers and printer consumables, or the summer salary of the two faculty members. [20] I.F. faculty review and approve all student purchases in advance. We have streamlined this procedure by creating dedicated accounts with a small number of vendors (Amazon, McMaster, Newark Electronics), all of which are capable of next day or 2nd day delivery.

   Each team of two students in I.F. has a budget of $2,000. Few spend a substantial fraction of their total, but this generous budget is a critical part of the program. The perception of plenty encourages exploration of approaches to solving their problem and expedites the design process. For example: one student team working on redesigning humidifiers purchased and dismantled several models early in their design process. The cost of these devices was roughly $400, but had we announced a budget of $500, the team likely would have husbanded their resources in the anticipation of expensive future purchases. In doing so their development/iteration of prototypes would have been slowed down.

TABLE 1: I.F. BUDGET

Item	Cost	Notes
Student Stipend	$20,000	$1000 * 20 students
Supplies/Components	$20,000	$2,000 * 10 projects
Food	$6,600	$10/meal * 22 people * 30 days
Provisional Patent App Fees	$650	$65 * 10 groups
Prizes (1st, 2nd)	$8,000	$5,000, $3,000
Student Assistant	$6,000	
Total	**$61,250**	

4. **Managing the twice-weekly critiques** – Eight guest evaluators are invited to the twice-weekly sessions (half of the teams present each Tuesday, half each Thursday). Guest evaluators are not permitted to evaluate the same invention twice, so they may participate in a maximum of two sessions. We therefore have to find between 32 and 64 quality evaluators each summer. This task became easier each succeeding year, as guest evaluators from previous years were frequently eager to return. We also received substantial assistance from Cooper Union's development office in contacting alumni to serve as guest evaluators.

   We ask guest evaluators to be honest and to "be nice, but not too nice." We also organize coffee and refreshments for the evaluation sessions. The following day we critique each team's performance by reviewing the videotaped evaluation sessions.
5. **Concluding the program** – Student work intensifies in the last week of the program. Working until the early morning hours is common. A number of diverse tasks remain for I.F. faculty, including ordering awards (we print oversized award checks and order glass plaques), reviewing provisional patent applications, and reviewing final versions of presentations and prototypes. At the competition for "Best Invention" each team is given five minutes to present their invention to the judges. The students then leave the room, giving the judges an opportunity to examine prototypes and patent applications, and determine what questions, if any, they will ask each group. The students return to answer these questions and leave the room again, for a second conference at which the judges will pick the first and second place winners.
6. **Post program logistics** – An important part of the success of Invention Factory are the professional videos that promote the student inventions. Making these videos, managing the dedicated website, and promoting I.F. at alumni gatherings requires a great deal of time. The video shoot in particular requires many steps, from organizing students to regroup for a weekend of shooting, to writing scripts, to branding details (logos, color schemes), to addressing a myriad of post-production issues. We have also found that students need a great deal of advice on how to manage their success as their inventions gain popularity – the viral video of the rapid packing container for example spawned hundreds of emails from influential companies, potential investors, and potential customers.

ASSESSING INVENTION FACTORY

In these first three years, assessment of Invention Factory has included informal student feedback, both solicited and unsolicited, indications of interest in some inventions from potential investors and manufacturers, up-votes from Quirky on four of nine inventions from Summer 2014, as well as nearly four million hits on a YouTube video for an invention from Summer 2013. Formal assessment of Invention Factory's impact on creativity and communication skills will begin with the summer 2016 program. We will consider two possible null hypotheses:

1. *Invention Factory does not enhance creative potential or creative output*

Pending IRB approval, we will employ the Torrance Tests of Creative Thinking ("TTCT") to test the first hypothesis. The Torrance tests, [21] which date from 1966, are generally regarded as reliable and valid measures of divergent thinking (problem solving through the exploration of many possible solutions). Though some disagree, [22] the TTCT is the most widely used, researched and respected measure in the field of creativity. [23, 24] Two "Figural" and two "Verbal" forms of the test are available; hence both tests are suitable for pre- and post-testing. The tests explore creative strengths such as fluency, flexibility, and originality of thought. We will require the pre-test (Version A of the Figural form) as part of the Invention Factory application process, however admission to Invention Factory would be "blind" to the results of the TTCT. After a mandatory post-test (Version B, of the Figural form), standard statistical analysis will determine if we might reject the first null hypothesis. It is important to note that care will need to be taken on administration, as a number of studies have shown that the simple direction "be creative" (given in violation of the test administration instructions) significantly enhances performance on divergent thinking tests. [25]

The authors appreciate that "creativity is very messy". [26] Creative potential differs from creative output, and possession of the former does not necessarily result in the generation of copious amounts of the latter. [27] There is disagreement in the field as to whether creative potential is stable or mutable. Though the TTCT is considered a valid measure of "creativity" there is some new work that adds another component of creativity. Psychologists Guillaume Furst, Paolo Ghisletta and Todd Lubart, in a recent paper, [28] consider a two stage creative process – "generation" and "selection" – and postulate that different and apparently conflicting personality traits contribute to each stage. During "generation", many possibilities should be considered – requiring the traits of plasticity and divergence (appropriate for TTCT testing). During "selection" a useful result is chosen through criticism and evaluation, which requires the trait of convergence (associated with standard "intelligence testing"). Hence our use of the TTCT may provide useful information about the first half of the overall creative process as described by Furst, et al.

Regardless of how well creativity is understood, the authors are aware that opportunities for our freshman engineering students to exercise their creative potential are inadequate, as they are immersed each semester in their studies of chemistry, calculus, and physics. In 1983, Torrance, reflecting on many years of research and experiences with creative individuals, stated: "One of the most powerful wellsprings of creative energy, outstanding accomplishment and self-fulfillment seems to be falling in love with something – your dream, your image of the future." [29] Invention Factory, which requires students to select their own projects, and immerse themselves in them, may be an engineering student's first such opportunity. Atman et al. note that "even two design experiences do not improve a student's ability to consider broader context in their design process." [30] It is therefore vital to give undergraduate engineering students an opportunity to start cycles of ideation, validation, and iteration as early as possible and to repeat them as often as possible. Invention Factory is one of those opportunities.

2. Invention Factory does not improve communication skills.

Despite claims by universities that they have worked hard to improve the communication skills of their engineering undergraduates, employers continue to report deficiencies in these skills. In one review of the literature the authors suggest that communication skills emphasized in the classroom (i.e., detailed descriptions of work presented to colleagues possessing similar technical backgrounds) are different than the communication skills desired by employers (i.e., concise delivery of big-picture concepts for more diverse audiences). [31]

Given the parameters of weekly guest evaluation in Invention Factory – five minute presentations to diverse panels of professionals, followed by unpredictable and sometimes aggressive Q&A – the oral communication skills emphasized within I.F. seem more in line with the requirements of industry than of academia. Similarly, patent applications are particularly well suited for developing written communication skills. Each begins with an "Abstract" capped at 150 words, which, by virtue of its length, can only address the big picture. Successive sections describe the invention in greater detail, with the "Detailed Description of the Invention" section describing each element of the invention and how it connects and functionally relates to all of the other elements. Thus, in a single document, the author of the application must cover several levels of description from "the big picture" to the most technical subject matter. We have not yet designed a mechanism for testing the second hypothesis. We have considered two possibilities. As previously noted, we record our students' weekly presentations to guest evaluators. These video presentations might be objectively evaluated by third parties (e.g., posing questions to viewers about the capabilities or underlying principles of the students' inventions). Our concern about this approach is that such testing could conflate our students potentially improving presentation skills with the rapid evolution of the inventions themselves. To eliminate this problem, we are considering that Invention Factory students might be asked to present a pair of talks (one pre- and one post-program) on an invention other than their own. These videos might be the subject of objective testing by third party viewers to measure possible gains in communication skills. Over the next year, the method of assessing improvement in communication will be selected.

PERCEPTIONS AND RECEPTION

Some Cooper Union faculty members have dismissed Invention Factory as a program in developing "gadgets," rather than in tackling "important" problems. To this charge we have a number of responses. First, there is great value in having students attack problems they can solve in six weeks. Second, I.F., for many students, will be their first experience in project management, and managing a small project is good practice for managing a larger one. Third, there is value in having students iterate a process of designing and prototyping that repeatedly fails before it eventually succeeds. Fourth, freshman and sophomore students may not yet possess the technical knowledge to attack complex problems, but should still be given the opportunity to participate in all stages of a realistic engineering development process, which may include the need to develop commercially viable products.

Problem-Based Learning (PBL) is a well-documented methodology that promotes students to develop a deep contextual understanding of the design process, effectively building student engineering expertise. [32] Invention Factory has all of the essential elements of the PBL cycle. Namely: student teams are presented with a complex, ill-structured problem; students work to define the problem and to identify what they know is relevant to the problem; students identify what they need to know and how they will learn it. The cycle is repeated until either the students arrive at an acceptable solution, [33] or in the case of Invention

Factory, the program ends. In either case the solution is presented in written and oral forms.

The I.F. program seems to have tapped into an unmet desire for applicants to our institution. Invention Factory is credited by senior administrators with *almost doubling* the number of undergraduate engineering applications at The Cooper Union at a time when we might have expected a drop, due to the school's change from tuition-free to tuition-charging degree programs. I.F. has been heavily promoted through our Admissions Office through a number of mechanisms including social media [34], live presentations to potential students, high school guidance counselors, and alumni events. Videos that feature our student inventors lends themselves well to such promotional efforts.

The alumnus who initially funded Invention Factory was so pleased with its results that he continued to fund the program more generously in successive years. Similar programs for high-school students have been initiated at "feeder high schools" for The Cooper Union.

Each year we ask students for feedback at the end of Invention Factory. We receive overwhelmingly positive responses such as "life-changing" and "the most important thing I have done at Cooper." As I.F. faculty we echo these sentiments. Creating and running Invention Factory have been the most rewarding experiences we have had at The Cooper Union.

REFERENCES and ENDNOTES

[1] Quote from one Invention Factory student after the summer program concluded. http://www.cooper.edu/engineering/news/first-ever-invention-factory-awards-5000-grand-prize-best-student-idea
[2] Edward Durbin (EE, '48) created The Edward Durbin and Joan Morris Innovation Fund at The Albert Nerken School of Engineering at The Cooper Union.
[3] Ries, E., "The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses", *Crown Publishing*, 2011.
[4] Informally, prior art is information, most commonly in the form of products, patents, and publications, that is available to the public and may be relevant to the patentability of an invention. An invention is not patentable unless it is sufficiently "new."
[5] Invention Factory students are taught to search based on patent class and subclass. They repeat and refine their prior art searches throughout the program so as to keep pace with their evolving inventions.
[6] 35 USC §102. An invention lacks novelty, hence is unpatentable, if it is essentially identical to an invention disclosed in a single prior art reference.
[7] 35 USC §103. Obviousness is a notoriously complex subject. We do not expect I.F. students to be able to determine if their invention is obvious in light of multiple prior art references. AW provides some guidance in this area.
[8] http://www.nytimes.com/2013/05/05/opinion/sunday/a-focus-on-distraction.html describes the deleterious effects of multitasking. See also: http://www.npr.org/2013/05/10/182861382/the-myth-of-multitasking
[9] Amabile, T.M. et al., "Time Pressure and Creativity in Organizations: A Longitudinal Field Study", *Working Paper – Harvard Business School*, 2002.
[10] http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2015-2016/#objectives
[11] Provisional applications do not include claims. Claim drafting should be left to experienced patent attorneys or patent agents. Claims are the most critical part of a regular (non-provisional) patent application, as they define the bounds of the property right, and are the basis for suing infringers.
[12] Currently the cost of filing a Provisional Patent Application with the U.S.P.T.O. is $65 if the student qualifies as a "micro-entity." http://www.uspto.gov/patents-getting-started/patent-basics/types-patent-applications/provisional-application-patent
[13] Presentations to guest evaluators take place late in the early evening to fit the schedules of working professionals.
[14] One group devoted the first three weeks of the program to developing an ankle rehabilitation device. Their prototype demonstrated the impossibility of meeting their design goals. They decided to address an unrelated need – bicycle safety. In the remaining weeks they designed and prototyped a novel and impressive lighting system built into bicycle pedals.
[15] https://www.youtube.com/watch?v=xExVzADFeWo As of June, 2015, there have been about 3.8 million views of this video.
[16] Quirky came in third on a list of "The World's Top 10 Most Innovative Companies in the Internet of Things" by Fast Company, Inc. http://www.fastcompany.com/most-innovative-companies/2014/industry/the-internet-of-things
[17] http://www.ustream.tv/recorded/59030857
[18] https://www.quirky.com/invent/1651443/
[19] Our I.F. prototyping equipment includes a VersaLaser laser cutter, several 3D printers, and traditional hand tools. Our students also have access to a machine shop and a wood shop.
[20] We work ten hours a day, five days a week during the six week program, for a total of approximately 300 hours, but additional tasks during the academic year (e.g., public relations; website development; oversight of professional videos; advising successful teams as to "next steps") account for several hundred additional hours.
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