

# Reverse Engineering Inspires ME Freshmen at NJIT

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**Abstract** - New Jersey Institute of Technology at Newark NJ (NJIT) has introduced a systemic change with the launching of the concept of Learning Communities for the entering freshmen. Initiated in Fall 2011, the program has generated abundant interest and is yielding rewarding results. As part of this initiative, the Department of Mechanical and Industrial Engineering (MIE) at NJIT has introduced *Reverse Engineering* as part of the curriculum for the entering freshmen with Mechanical Engineering as their major. The MIE educational staff has creatively blended Reverse Engineering with the existing Fundamentals of Engineering Design-101 (FED-101) curriculum yielding successful learning outcomes. Freshmen experience the role of a Product Design Engineer in a corporation from ideation to product release. The inspiration, which the freshmen experienced through the success and sense of accomplishment in their Reverse Engineering projects, is propelling them to innovate and excel.

**Index Terms** – Engineering Design for Beginners, Freshmen Mechanical Engineering Curriculum, Innovation, Learning Community, Reverse Engineering, Experiential Learning.

## INTRODUCTION

Entering freshmen in Mechanical Engineering major, in their first semester at NJIT, enroll in a two-credit course, FED-101. As they make their transition into the University curriculum the freshmen learn Graphics Communication, Engineering Drawing and 3Dimensional Computer Modeling in FED-101. Being the first course that one takes in their major, FED-101 is also intended to give the freshmen a firsthand appreciation of their chosen major, Mechanical Engineering. Creo Parametric 2.0 [1], earlier known as Pro Engineer [1] and later Pro Engineer Wildfire [1] is the software of choice for this course. Every freshman registered in this course is required to learn and use the software and create 35 different models of progressively increasing complexity. These models include part models, assembly models, part drawings and assembly drawings along with bill of materials. This places the freshman student in two unfamiliar territories: Learning new and complex software and building meaningful 3Dimensional concepts. Secondly, they are required to model mechanical engineering components using the software. Most freshmen are unfamiliar with the functionality of the mechanical engineering components. Virtually rendering 3Dimensional models of the various mechanical engineering components is

indeed a challenging task even for the most dedicated student. Reverse Engineering lends itself to not only meet this challenge with confidence, but also to inspire the entering freshmen by making their experience more meaningful.

## WHAT IS REVERSE ENGINEERING?

*“Reverse Engineering is the scientific method of taking something apart in order to figure out how it works. Reverse Engineering has been used by innovators to determine a product's structure in order to develop competing or interoperable products. Reverse Engineering is an invaluable teaching tool used by researchers, academics and students in many disciplines.”* [2] Of course, this invaluable technique does involve *“an act that would otherwise be considered a copyright violation.”* [2] Whereas, *“copyright law has allowed these reverse engineering copies as a form of ‘fair use.’”* [2]

Advocates of this innovative discipline have claimed that it *“is the process of extracting the knowledge or design blueprints of anything manmade.”* [3] They have shown that it is the *“process of discovering the technological principles of a device, object, or system through analysis of its structure, function, and operation.”* [4]

## WHAT ARE ITS BENEFITS TO THE INDUSTRY?

Embracing Reverse Engineering as a means to learn is nothing new. For instance in the aggressive commercial world, the first set of customers who would buy a new product as soon as it is announced is the competing companies. The competitors buy the new product with the intention to disassemble them and to discover the trade secrets within. They use such information to innovate their own products. In the academic field of science and engineering, most researchers repeat the experiments that their peers have performed. By repeating the experiments the researchers understand the state of the art and use that knowledge in their own research innovation. Narh and Surjanhatta, Mechanical Engineering Faculty, NJIT have explored reverse engineering in connection with FED-101 course in 1996-‘97 under the umbrella of an NSF funded study and have reported positive learning outcomes. [5]

## INNOVATIONS JOURNAL

As a first step in the introduction of Reverse Engineering, the educational staff at NJIT has integrated into their

curriculum the *innovations journal*. It is a systematic, scientific and disciplined process of reporting what one understands when one observes a product. The word *innovation* as used in this context implies that it is a *means to innovate*. To complete the journal, each week, the student is required to observe and analyze at least one product that they come across and report in a formal journal. The report will consist of a sketch, a description, functionality of the product, likely materials and finishes used. The report doesn't just stop there. The students take the product they observed to the next level by suggesting ways to improve and extrapolate.

Figure 1 is a reproduction of sketch portion of an entry from an innovations journal. If a student meticulously observes and analyzes one product a week, in the four years of undergraduate experience they would have made dynamic observation of more than two hundred different products. This meticulous journaling would not only improve his or her success as an interviewee for a job in a corporation but also as a future employee of the corporation.

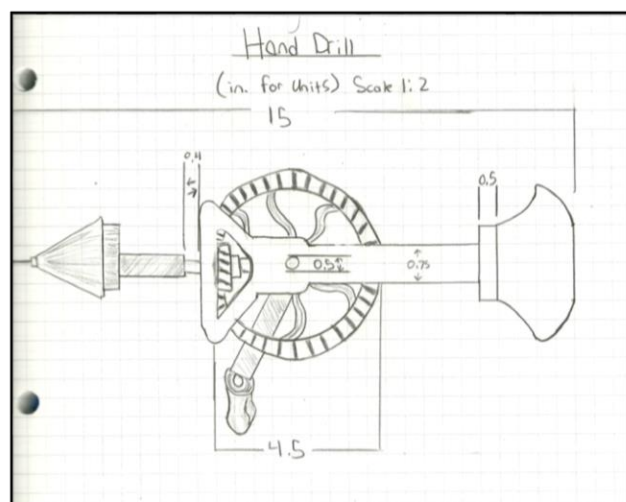


FIGURE 1

SCOTT BOHN, "HAND DRILL," INNOVATIONS JOURNAL ENTRY, FALL 2012

This is a successful and positive experience, since no entry in the journal is a wrong entry. Former students have reported in their journal diverse products ranging from nail-clipper to kitchen-can-opener, from hand-drill to window-blinds mechanism, and the like. Starting from the FED-101 classroom some students have cultivated this rewarding mode of observation as a personal hobby, continued the *innovations journal* and have effectively built for themselves an intellectual toolbox. Observing and analyzing something new every week is indeed a rewarding hobby to pursue.

Needless to state that innovation is not inborn. Innovation cannot be taught by instructions. Nor is innovation a chance possession of a few favored individuals. Innovation has to be inculcated. Meticulous observation and diligent journaling is one way to inculcate priceless innovation.

## TEAMS

To manage the Reverse Engineering project effectively the entering freshmen class is divided into teams of three students following an extensive survey. Experience level with CAD tools, familiarity with mechanisms, degree of personal enthusiasm, and attitude are all assessed in the survey. With these assessments the survey guarantees homogeneity within the team. Teams are formed in the third week of the semester and team building activities are unequivocally encouraged throughout the semester.

## PROJECT

Following the orientation with their innovations journal, the self-directed teams are empowered to identify a product of their choice for Reverse Engineering, one per team. Primarily products chosen are of appropriate complexity and comprise around twenty unique components. In the past, some teams have chosen to work on more complex products, such as Double Drum Base Pedal, Spinning Fishing Reel, Gum Ball Machine and the like. Freedom in selecting the product for Reverse Engineering instigates a sense of ownership with the product among the motivated teams.

In Fall 2012, 120 students who were enrolled in FED-101 were involved in Reverse Engineering. They were divided into 40 teams. They worked on 20 different products. The products the student-teams worked on include,

Bicycle Chain Cleaning Device,	Car Scissor Jack,
Double Drum Base Pedal,	Dial Padlock,
Flat Blade Paper Trimmer,	Foot Air-Pump,
Garlic Zoom Grater,	One Touch Stapler,
Gator Grip Super-G Ratchet,	Pogo Stick,
Handheld Adjustable Paper Trimmer,	Razor Scooter,
Leatherman Multi-Function Tool,	Scissor Mouse,
Single Cylinder Engine,	Skate Board,
Spinning Bicycle Wheel,	Slap Chop,
Spinning Fishing Reel, and	Staple-less Stapler.

## PROJECT MANAGEMENT

In approving a project proposed for Reverse Engineering, care was taken that no more than two teams engage in any one product. Having a wide variety of products stimulated a healthy learning environment and promoted originality. Where like products were proposed and pursued by two teams the teams generally belonged to two different sections. Thus there was limited interaction between the two teams. Such teams worked independently, producing varied outcomes. The student-teams working on like products discovered different solutions for a problem on a particular component and compared them to understand how one procedure is better than the other. When students solved a difficult-to-create model they shared the information with the entire class with pride. The Reverse Engineering project created numerous positive encounters for team-learning.

## RESEARCH

(No Model)

R. BOWE.  
WHEEL.

No. 582,486.

Patented May 11, 1897.

*Fig. 1.*

*Fig. 2.*

*Fig. 3.*

*Fig. 4.*

*Fig. 5.*

*Fig. 6.*

*Fig. 7.*

*Fig. 8.*

Inventor  
Reuben Bowe  
By H. S. Dodge  
Attorney

J. H. Bowe  
Frank T. M. Rand

FOR OFFICE RECORD SEE INVENTORIAL JOURNAL, MAY 11, 1897.

“WHEEL,” COVER PAGE OF US PATENT 582 486, MAY 11, 1897

The next step in Reverse Engineering is disassembly of the product used. At times the disassembly process required support from the technicians in the machine shop. *“For many engineering students, a classroom exercise in mechanical dissection might be the first time they’ve ever taken something apart. Nowadays, fewer students enter college with any hands-on experience with technology.”* [6] *“They’ve spent most of their time on the computer and have lost that intuitive sense of working with tangible things.”* [6] It is this *“hands-on experience with various parts that helps them when they begin designing products of their own.”* [6] Product Design is abstract in itself. One’s *“ability to reason about those things in the abstract is so much more powerful if you’ve actually touched the systems on which you’re going to do engineering.”* [6] The student-teams maintained meticulous notes documenting the disassembly, step by step. In most cases care was taken so the disassembled units can be reassembled at the end of the study and brought to its original working condition.



TEAM 29, JEFFREY PABLO, HARSH PATEL AND KRUPAL PATEL,  
"GATOR GRIP SUPER-G RATCHET", DISASSEMBLED PARTS, FALL 2012

## DESIGN TASK PLAN

**5<sup>th</sup> First Year Engineering Experience (FYEE) Conference**  
**F4**

modeled, breaking them up into manageable subassemblies. Like in any industry, each part or assembly is assigned a unique number in accordance with an agreed-to numbering system. A robust part numbering system is an essential and vital nomenclature in the design, manufacture and life cycle of a product in any corporation.

TABLE 1  
TEAM 29, JEFFREY PABLO, HARSH PATEL AND KRUPAL PATEL,  
“GATOR GRIP SUPER-G RATCHET,” DESIGN TASK PLAN, FALL 2012

<b>DESIGN TASK PLAN</b> <b>GATOR GRIP SUPER G RATCHET</b> <b>LIST OF PARTS ASSEMBLIES, PROJECT 12</b>				
#	Part Number	Description	Quantity	Remarks
1	11229088_120200	Spring-Loaded Gator Catch (Sub)	1	Sub Assembly
2	11229088_120201	Pin	54	
3	11229088_120202	Spring, Pin	54	
4	11229087_120203	Holder, Hexagon	1	
5	11229087_120204	Center tab	1	
6	11229088_120205	Spring, Center tab	1	
7	11229086_120100	Gator Grip Wrench Assembly (Top)	1	Assembly
8	11229086_120101	Handle Mold	1	
9	11229086_120102	Handle	1	
10	11229088_120103	Direction Changer	1	
11	11229086_120104	Catch Socket	1	
12	11229088_120105	Shaft	1	
13	11229086_120106	Ball 5mm, shaft	1	
14	11229088_120107	Catch Holder	1	
15	11229086_120108	Washer	1	
16	11229086_120109	Plastic Shaft	1	
17	11229087_120110	3 Wave Washer	1	
18	11229087_120111	Retaining Ring	1	
19	11229088_120112	Stopper	1	
20	11229086_120113	Pin, lock	1	
21	11229086_120114	Ball 3mm	3	
22	11229088_120115	Spring, long	1	
23	11229088_120116	Spring, small	1	

By parsing a part number which the student-teams have evolved and used, one will be able to determine, the year, semester, the student who designed the part model and the project and (sub)assembly to which the part belongs. The student-teams learned the importance of the part numbering system and used it meticulously. Using the Design Task Plan, the student-teams learned to plan their work before they actually accomplished their project. The student-teams found the Design Task Plan very useful in assessing, planning and distributing their workload within the team and in tracking the progress of the project.

### MEASUREMENT

It is at this point, the student-teams are ready to start part design and modeling. In the few weeks that had elapsed the students have learned some 3Dimensional computer modeling with the help of text book sketches and click-by-click procedures and tutorials. Based on this knowledge they recognize the need and importance of dimensions in the modeling of a part or assembly and for it to function.

In order to obtain the dimensions, the student-teams measured the disassembled parts using simple metrology



FIGURE 4  
TEAM 20, FAZAAD ALLY, EVAN MCARTHUR AND JONATHAN SWEET  
“SLAP CHOP,” DISASSEMBLED PARTS, FALL 2012

instruments such as Calipers and recorded them on a hand-drawn sketch. Some student-teams went to the extent of using Adobe Photoshop to record the dimensions on the photographic images of the parts.

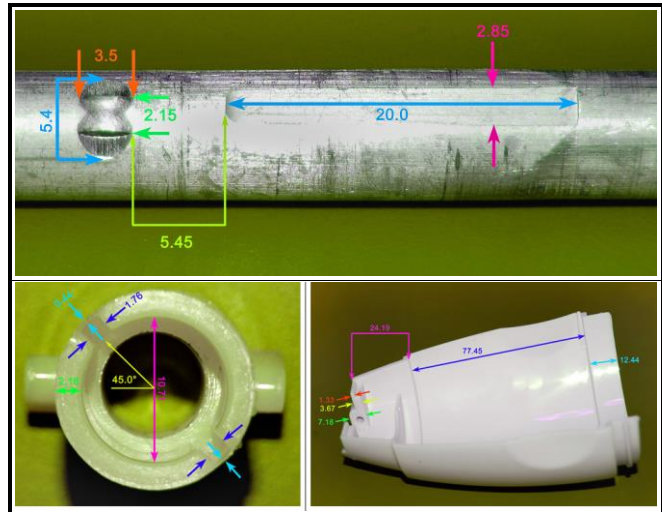


FIGURE 5  
TEAM 20, FAZAAD ALLY, EVAN MCARTHUR AND JONATHAN SWEET,  
“SLAP CHOP,” DIMENSIONS OF PARTS, FALL 2012

Figure 5 shows dimensions recorded on the photographic images of the parts of Slap Chop, earlier seen in Figure 4. This diligent, virtual record of dimensions was used to communicate between members of the team as they progressed with the project. The primary goal is to convert the dimensioned sketches into 3Dimensional computer models built to the correct dimensions.

### DESIGN INTENT PLAN

Student-teams discussed with the instructor the procedure to build the models one by one and took notes during the discussions. Soon they discovered that they had to learn advanced modeling techniques to construct some of the part models. They no longer depended on ‘click-by-click’



procedures and tutorials to model the components. The student-teams learned several advanced modeling techniques with great ease during one-on-one meeting with the instructor.

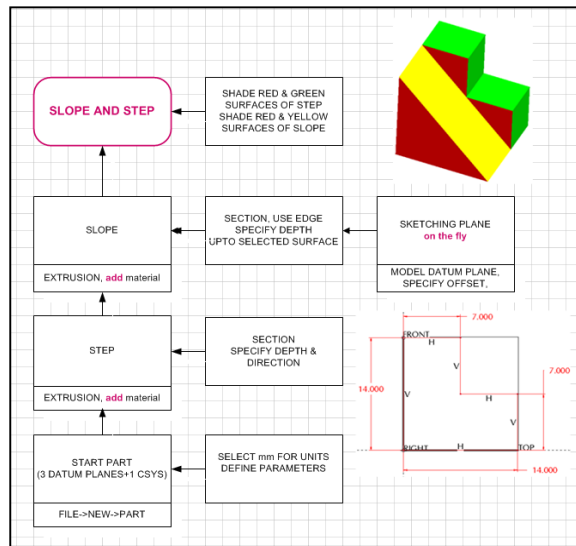


FIGURE 6  
“SLOPE AND STEP,” DESIGN INTENT PLAN SHEET, DIPS.  
COLOR SHADED PART MODEL SHOWN ABOVE

However, for complex parts student-teams prepared Design Intent Plan Sheet (DIPS), prior to starting the design of such 3Dimensional models. DIPS is a simple flowchart which can be documented using Microsoft Visio. The flowchart shows the sequence of steps involved in building the 3Dimensional computer models of parts in Creo Parametric 2.0 [1]. It is an efficient way of documenting the action-plan for modeling. Figure 6 shows the DIPS for a very simple part model as an illustrative example.

### ASSEMBLY

When the part models are completed, the student-teams assembled them in Creo Parametric 2.0 [1]. Some of the assemblies required detailed planning and some required advanced assembly techniques. For example, the assembly of the 36 spokes in a bicycle wheel had to be divided into four different patterns based on how they are laid out. The holes drilled in the double-walled hollow bicycle rim had to be modeled at four different angles to facilitate the four different patterns. Figure 7 shows one of the patterns and Figure 8 shows all four patterns in the assembly of spokes and wheel.

In a physical Bicycle Wheel, however, the technician assembling the 36 spokes on the wheel will be able to bend the spokes slightly and assemble them correctly. This is not possible in a virtual assembly. Complex projects of this nature gave the students a lot of insight into the realities of design and a good understanding of the various Manufacturing and assembly practices.

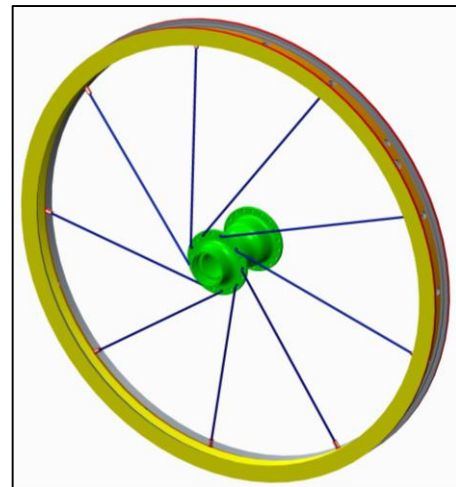


FIGURE 7  
TEAM 14, JOHN PROCACCINI, VISHAL RAM AND TREVOR RYAN,  
“ONE OF FOUR PATTERNS IN ASSEMBLING SPOKES,”  
SPINNING BICYCLE WHEEL ASSEMBLY, FALL 2012

### ADVANCED MODELING

The student-teams learned advanced modeling techniques such as, helical spring design with a variety of end preparations, constructing thread forms on screws and nuts, revolved-blend design, variable-section-sweep, certain features in surface modeling, certain features in sheet metal

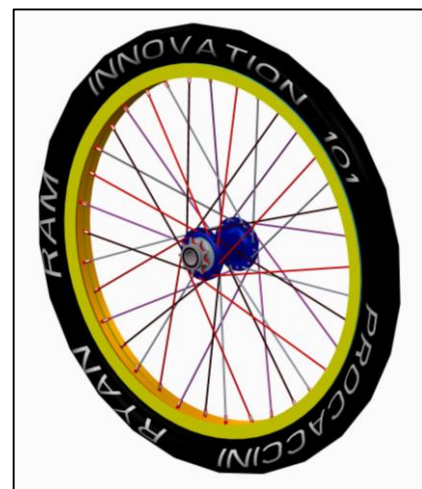


FIGURE 8  
TEAM 14, JOHN PROCACCINI, VISHAL RAM AND TREVOR RYAN,  
“ALL FOUR PATTERNS IN ASSEMBLING SPOKES,”  
SPINNING BICYCLE WHEEL ASSEMBLY, FALL 2012

modeling, gear modeling, family tables, relations in repeat-region of bill-of-materials and the like. Students in individual teams learned them all with great interest and ease during one-on-one meeting with the instructor. It was meaningful to the students since they were creating the 3Dimensional models as they were holding in their hands the physical part to be modeled. Learning to build 3Dimensional computer models with the real parts in their

hands is the best way to acquire the skills to later build 3Dimensional models from one's imagination.

Most students also learned how to design a mechanism, integrate dynamic motion characteristics, create animations and conduct kinematic analysis. All such advanced modeling techniques are taught in upper level classes, which the freshmen learned on their own initiative with interest and ease.

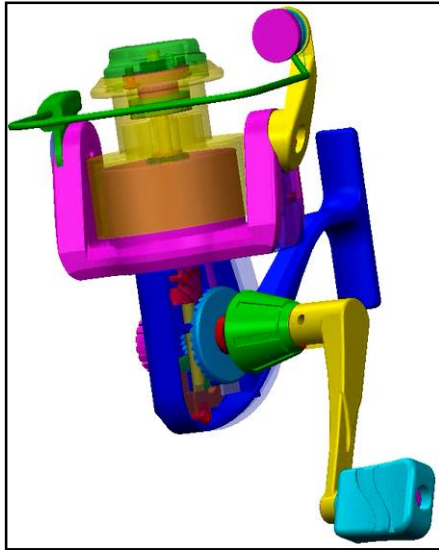


FIGURE 9

TEAM 4, RICHARD JOHNSON, KEVIN KIKOMEKO AND JOSEPH KRAMER  
"SPINNING FISHING REEL," MECHANISM ASSEMBLY, FALL 2012

Figure 9 shows a Spinning Fishing Reel assembly. This assembly comprises of more than 65 unique parts. The team that built the complex part models and assembly also learned advanced mechanism animation, enjoyed the work throughout the project and excelled in their presentation which was filled with complex animations.

Several students reached out to peers in need of assistance, besides working with their own. For example, Christopher Moyer mentored a team in addition to working with his own in completing reverse engineering of Single Cylinder Engine seen in figure 10. Inspired and enthusiastic, Christopher Moyer said, *"It was quite stimulating helping others learn while I learned from them. We learn better when we teach. Engineering is about seeing perspectives; there are many ways to accomplish one task."* Engaging students in instructing each other in a productive way is a fruitful way in teaching. It trains them work harder, learn better, apply their training aptly and retain the learnt material longer.

#### INNOVATION 101 SHOWCASE

At the culmination of the Reverse Engineering project each student-team compiled a comprehensive technical report and a poster to present their project. They presented their project in a showcase, the Innovation 101 showcase. Figure 11 shows one of the teams that presented their project at the fall

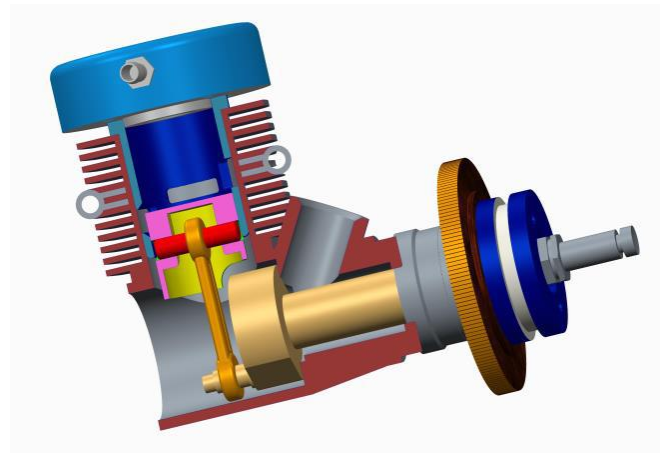


FIGURE 10

TEAM 08, NICOLAS MARTINEZ, JONATHAN MAZZOCOLI AND  
PETER MENASES, "SINGLE CYLINDER ENGINE."  
PEER MENTOR: CHRISTOPHER MOYER, FALL 2012

2011, showcase event. The showcase simulates 'product release' event in a large corporation. Senior design managers from local industries volunteered, attended the showcase event and judged the projects. This presented the



FIGURE 11

TEAM 16, NORA AHMED, ADITI SURMA AND LINDSEY BALL,  
"POSTER, REPORT, COMPUTER ANIMATION AND PARTS EXHIBIT,"  
INNOVATION 101 SHOWCASE EVENT, FALL 2011

student-teams an opportunity to be eloquent and clear in presenting their reverse engineered product to the judges. The students grew competitive in their ambition to win *Star of the Section, Star of the Show* awards. This is an unique opportunity for students to communicate technical information to a trained and qualified stranger, measure their own performance and get constructive feedback from mature leaders from industry

#### THE SUSTAINED IMPACT

The positive impact that spawned from the students' immersion in Reverse Engineering does not stop at the end of the fourteen-week semester. Apart from inspiring the

freshmen, Reverse Engineering also provides a practical means to foster innovation. Students who showed a flair for innovation during the project phase are invited to participate in a newly begun extracurricular activity, named the Innovative Design and Engineering Activity, idea!™. One of the important goals of idea!™ is to mentor future freshmen in Reverse Engineering in the following Fall. In addition, some members of idea!™ have been invited to pursue Summer Undergraduate Research Program (SURP) internship. During research students receive a stipend. Through their Summer Research, these student researchers have developed a portal for Mechanical Engineering design concepts aptly called the “design well™.”

### **design well™**

‘design well™’ is a search-enabled, relational database currently evolving as a repository of computer animations of mechanism simulations. When fully developed, ‘design well™’ will provide design ideas to engineers involved in Product Design in Mechanical Engineering as well as idea-seeking entrepreneurs world-wide. ‘design well™’ is available at [www.designwell.ME](http://www.designwell.ME). Originally announced in January 2012, the portal has evolved through the contributions of the undergraduate student researchers of NJIT who debuted a prototype on December 5, 2012.

### **INSPIRATION LEADING TO INNOVATION**

Development of ‘design well™’ has inspired its contributors. The inspiration led them to innovate. As they were developing the mechanism animations, the student researchers also developed and demonstrated conceptual design animations for viable new commercial products: *an exercise machine, a floor moping machine, and a walker*. Construction of the prototype walker is currently being pursued. PhysioPed™, the walker, when built, will be a very useful aid to patients undergoing physiotherapy offering several unique advantages. After its construction and testing in a nursing home the developers intend to secure an US patent for the PhysioPed™.

### **CONCLUSIONS**

In conclusion it should be observed that Reverse Engineering is not a substitute to traditional design pedagogies. Nevertheless, Reverse Engineering has proved to be a viable and vital technique to introduce Product Design to freshmen.

The rewarding experience of Reverse Engineering in just fourteen weeks does not stop with providing a sense of accomplishment, breeding self-esteem, but also exposes the freshmen to experience industry-level product design from concept formation to product announcement. It provides an opportunity to the freshmen to present their projects and

articulate on their products to mature design leaders from industry.

As they acquire the talent in design, freshmen learn team work, to work together in a team cohesively. This is a natural byproduct. Conscientious freshmen recognize that “*teamwork will bring the success which an individual cannot achieve working alone.*”

Furthermore, freshmen who excelled are invited to take their training to the next level by involving in Summer Undergraduate Research Program. Student Researchers have developed a dedicated portal providing product design ideas. Some students have demonstrated conceptual design for useful new products.

Reverse Engineering not only inspires our freshmen ME Learning Communities, but also leads them to innovate and excel!

### **ACKNOWLEDGMENT**

The authors acknowledge the unparalleled support received from the NJIT Community Connections & Learning Community implementation team, particularly Provost Dr. Ian Gatley and Associate Provost Dr. Judith Redling throughout initial launching of the program in 2011.

Several design leaders from industry volunteered and dedicated their time and talent in support of the innovation 101 showcase event. They served as judges and helped in accomplishing the goal of the event. The authors are indebted to them for their dedication.

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