”Full Paper: Stimulate PRIDE* in Freshmen with Reverse Engineering”

Mr. BALRAJ SUBRA MANI, New Jersey Institute of Technology
Prof. I. Joga Rao, New Jersey Institute of Technology

"Full Paper: Stimulate PRIDE* in Freshmen with Reverse Engineering"

Introduction:

Every successful outcome needs a first step: Freshmen entering any university do so with lots of anxieties and lofty expectations. In a technology or engineering institution, FED-101 is the first course a freshman would enroll in their chosen major, in their first semester. FED-101 is intended to expose them to what to expect when they become an engineer in their chosen discipline. No common curriculum across various universities dictates how such intended outcome would be delivered. Years ago, Mechanical Engineering Department at NJIT had chosen to use 3Dimensional modeling using Creo Parametric 4.0 [1] solid modelling software, *aka* Pro/Engineer [1], Wildfire [1] in FED-101. Solid modelling is used as a design tool in mechanical product design. However, product design is not the only career path in Mechanical Engineering. From ideation to product realization, product design has many steps. Apart from competency in product design, time management skills, hands on ability, intellectual-property-exploration skills, technical report writing skills, presentation skills, and team-working are all essential to succeed as a product design engineer in industry. A successful product design engineer in industry has to be a master of all such skills and more. Learning a new and complex solid modeling software and building meaningful 3Dimensional concepts is in itself a challenging task for freshmen. Freshmen in general, are unfamiliar with the functionality of the mechanical components. Needless to say, that a FED-101 instructor has a challenging task of combining this with the challenge of exposing the freshmen to the demands of the industry.

Stemming from an industrial background, our instructors resorted to RE. This helped to blend Purpose, Responsibility, Individuality, Determination, and striving for Excellence, in this endeavor. This represents the art of building *character* in the minds of the young students. Non-pedagogical as it may be, that is exactly what we did in 2010 in a pilot project and found it very rewarding. That is what we continued to do since then making this program a success. This paper describes the steps in this systematic approach to implement RE.

What is reverse engineering?

Experience is the teacher of all things. [2] RE is an invaluable learning experience and a teaching tool. It is "a scientific method of taking something apart in order to figure out how it works." [3] The technique does involve "an act that would otherwise be considered a copyright violation." [3] Whereas, "copyright law has allowed these RE copies as a form of *fair use*." [3]. According to Professor Sheri Sheppard, Stanford University, "currently, about 30 universities have integrated the method *(of RE)* into their teaching."[4] Sheppard had a job at Chrysler, where the company sent her to mechanics school for three months where she learned to take things apart and rebuild engines, transmissions and brake systems, something she had not done as an undergraduate. She reflects how much one learns though the *kinesthetic* of touching stuff. "The reality is that very little design is actually new design," argues Sheppard, "good designers have a catalog in their brain of stuff-of mechanisms, of devices, of machine elements." Dr. Kwabena Narh et al, NJIT, has reported the positive course outcomes of RE, when the method was evaluated in a two semester pilot project in 1996-97 at NJIT. [5] *Competitive analysis*, is a

different flavor of RE, pursued by most industries. In this, RE helps to understand a competitor's product and to discover the trade secrets within. Such information are essential for them to innovate their own products since such knowledge may not otherwise be available completely in public domain. The author is personally familiar with competitive analysis from Motorola, Inc. "While conventional engineering transforms engineering concepts and models into real parts, in reverse engineering real parts are transformed into engineering models and concepts." [6]

Program evaluation and review technique (PERT) and Project plan:

Plan your work and then work your plan. [2] FED-101 is a one semester long, 2-credit course, which lasts for a duration of about 15 weeks. In light of the compact period, a very detailed plan

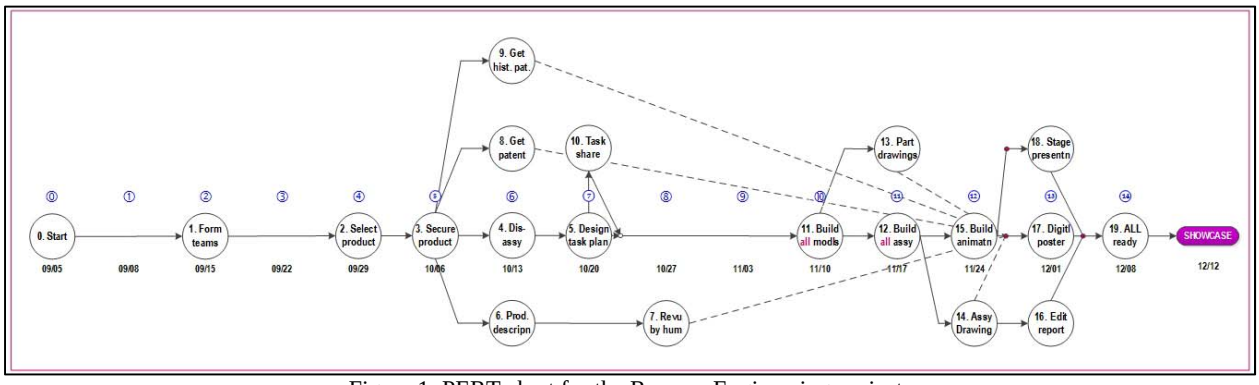
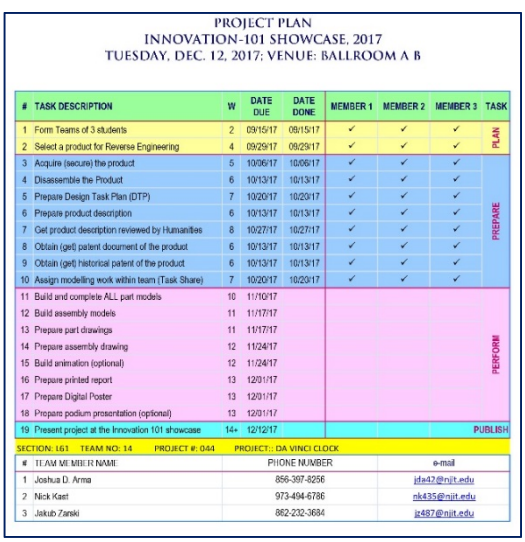


Figure 1: PERT chart for the Reverse Engineering project



PROJECT PLAN
INNOVATION-101 SHOWCASE, 2017
TUESDAY, DEC. 12, 2017; VENUE: BALLROOM A B

#	TASK DESCRIPTION	W	DATE DUE	DATE DONE	MEMBER 1	MEMBER 2	MEMBER 3	TASK
1	Form Teams of 3 students	2	09/15/17	09/15/17	✓	✓	✓	PLAN
2	Select a product for Reverse Engineering	4	09/29/17	09/29/17	✓	✓	✓	
3	Acquire (secure) the product	5	10/06/17	10/06/17	✓	✓	✓	PREPARE
4	Disassemble the Product	6	10/13/17	10/13/17	✓	✓	✓	
5	Prepare Design Task Plan (DTP)	7	10/20/17	10/20/17	✓	✓	✓	
6	Prepare product description	6	10/13/17	10/13/17	✓	✓	✓	
7	Get product description reviewed by Humanities	8	10/27/17	10/27/17	✓	✓	✓	
8	Obtain (get) patent document of the product	6	10/13/17	10/13/17	✓	✓	✓	
9	Obtain (get) historical patent of the product	6	10/13/17	10/13/17	✓	✓	✓	
10	Assign modelling work within team (Task Share)	7	10/20/17	10/20/17	✓	✓	✓	
11	Build and complete ALL part models	10	11/10/17					PERFORM
12	Build assembly models	11	11/17/17					
13	Prepare part drawings	11	11/17/17					
14	Prepare assembly drawing	12	11/24/17					
15	Build animation (optional)	12	11/24/17					
16	Prepare printed report	13	12/01/17					
17	Prepare Digital Poster	13	12/01/17					
18	Prepare podium presentation (optional)	13	12/01/17					
19	Present project at the Innovation 101 showcase	14+	12/12/17					PUBLISH

SECTION: 161 TEAM NO: 14 PROJECT #: 044 PROJECT:: DA VINCI CLOCK

#	TEAM MEMBER NAME	PHONE NUMBER	e-mail
1	Joshua D. Arma	856-397-8256	jda47@njit.edu
2	Nick Kast	973-494-6786	nk435@njit.edu
3	Jakub Zanski	862-232-3684	jz487@njit.edu

Figure 2: Project Plan

is vital. PERT and Project Plan are introduced as the tools of project management to accomplish the RE projects on schedule. Apart from managing the time-bound RE projects, the freshmen benefit by learning hands-on time management skills, which is essential for their success at the university and after. In the 50's US Navy developed the project management technique, PERT to identify, organize, schedule and coordinate the tasks within a project. Also known as, the Critical Path Method (CPM), meticulous application of PERT will impart full control of a project and help complete a project in a timely manner. Figure 1 represents the PERT chart for the completion of a RE project. Microsoft Project [7] is a computer software technique to accomplish the same results without needing to draw the graphical network and more popular as project management tool today. In addition to the PERT, students are also introduced to a Project Plan, which resembles the output of Microsoft Project. In this the same events indicated on the PERT have been grouped into four categories namely, Plan, Prepare, Perform and Publish in a *Table* format. Unlike the Microsoft Project or PERT the inter-dependencies are not built into this chart. Figure 2 illustrates the Project Plan, prepared in Microsoft excel. [7]

Team formation:

Teamwork will bring the success, which an individual cannot achieve working alone.[2] To manage the RE 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 to guarantee homogeneity of knowledge, attitude and enthusiasm within the team. Teams are formed in the second week of the semester and team building activities are unequivocally encouraged throughout the semester. Experience has clearly shown that homogeneity of the team, mutual trust and lavish communication between the members of the team are fundamental to the effectiveness of the team.

Project identification:

If you can dream it, you can do it. [2] Selection of a project is a very important phase. While it is good to dream big, the students should be cognizant about the time available at their disposal. Any existing product with about 40 to 50 unique parts would be a good choice for RE. Each team will choose a unique product. Often teams from two different sections have worked on the same product, but independently. Pursuing a unique product for RE nurtures ownership, and fosters individuality. Having a product that the team likes promotes a sense of purpose. Once a team has finalized the product for RE, the team is identified with their specific product. Most importantly, having a unique product for each team has completely eliminated any scope for plagiarism, although it will add significantly more work for the instructor. A good project should have some mechanism kinematics opening the opportunity to learn and apply mechanism animations later. Selecting something unique exposes the students, with exceptional opportunities to learn more, and involve more with the instructor. Students gain popularity in cases where a novel product is chosen for RE. Students are encouraged to discuss with the instructor in finalizing a product for RE. More than 200 different products have so far been used for RE in this program. Anything from simple Kitchen-can-openers to complex Dial gauges, Fishing Reels, Lawn mower engines have been used as RE projects successfully. This is very useful to the instructors since they will have to constantly develop new procedures to model parts with unique features, which they can later use as class models. Having complex models brings the students and instructors closer removing their inhibition in approaching the instructors for help. The students learn to ask for help from seniors and upperclassmen – the entire community getting actively involved. Involvement improves learning. The inspiration this brings into the community, not just the freshmen class alone is profound.

Product description:

When something can be read without effort, great effort has gone into its writing. [2]. Each student team writes a 1400 character long product description. This size is limited to fit the space allocated for each project in the showcase brochure. The product description is treated as one of the writing assignments for their Humanities course. Consequently, the product description is reviewed by the Writing Studio or the instructor in English. These descriptions are published in a showcase brochure released on the day of the Project Showcase. Last year, on the seventh annual showcase was also published in public domain as an online flipbook and can be found on the portal *http://online.anyflip.com/xozo/boql/mobile/index.html#p=1*. [8]

Apart from the opportunity to engage in a writing exercise, the student teams are also involved in publishing a printed brochure and understanding the importance of written communication skills.

Product patent and historical patent:

The US patent system adds the fuel of interest to the fire of genius in the discovery and production of new and useful things [2]. The best way to learn about a product is to read and understand its patent documents. The freshmen are introduced to the search procedure of US patents. As an extension, they also dig deeper to read and understand patents relating to prior state of the art and discover an interesting and very old, historical patent. Freshmen students understand what changes in a product or concept, allowed the additional claims to secure a new patent. This is a very valuable training particularly at the freshmen level. The fact that some students created a patent time-line chart entirely on their own (Figure 3) shows how much this has inspired the freshmen.

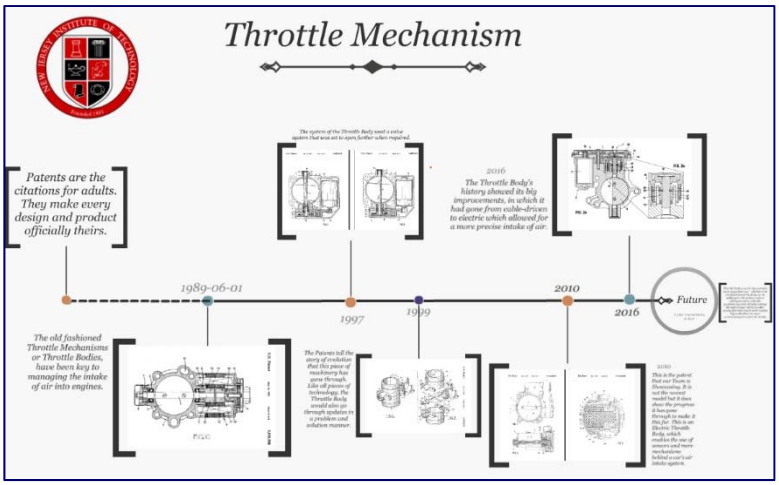


Figure 3: Patent time-line by Patryk M. Golaszewski, Nazeem I. Patel and Jared L. Stein

Modeling:

Destruction for Construction. [2] Student-teams begin their modelling task of the RE product by *disassembling* it into its individual components. They are required to maintain meticulous record as they disassemble. This will help them to reassemble and bring the product back to its original functional level later. For many freshmen this perhaps is the very first time they have ever disassembled a product with their own hands, to understand its mechanical design. A one-on-one meeting between the instructor and the team members follows this activity. This is an important meeting and is one of great pride for most team members as they are able to share their discovery of how the product works with their instructor in a university setting, share with one who listens to them with great interest. During this informal discussion with the team, the instructor also discusses possible materials, finishes and broad manufacturing methods for each part. For many team members this defines the purpose of the RE activity and stimulates their individuality. Often discussions also dwell on other innovative ways the product could have been designed. This open-ended discussion is a source of great inspiration to most teams.

A list of tasks is a list of opportunities-Design Task Plan (DTP). A second important activity that follows product discussion described above is to prepare a DTP. This is a comprehensive list of sub-assemblies and parts that make up the RE product. The instructor helps to identify the various logical sub-assemblies in the RE product. All the parts that go into such sub-assemblies and the parts that go into the main assembly are organized into a systematic and sequential list.

Each unique part is assigned a unique part number according to a numbering system defined in figure 4. The DTP helps the team members to assign the modeling tasks among the team members and later for monitoring the progress. This list is truly the list of *opportunities* in the RE endeavor. Figure 5 shows a partial DTP of a two-stroke engine is shown.

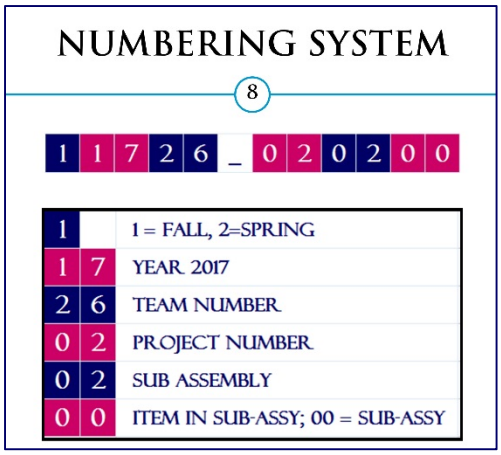


Figure 4: Typical Numbering System

DESIGN TASK PLAN
TWO STROKE ENGINE
LIST OF PARTS ASSEMBLIES, PROJECT 02, TEAM 26

#	PART NUMBER	DESCRIPTION	QUANTITY	REMARKS
1	11726_020200	DIP STICK ASSEMBLY	1	SUB ASSEMBLY
2	11726_020201	TUBE, DIP STICK HOLDER	1	
3	11726_020202	O-RING	1	
4	11726_020203	COVER	1	
5	11726_020204	O-RING	1	
6	11726_020205	DIP STICK	1	
7	11726_020300	MUFFLER ASSEMBLY	1	SUB ASSEMBLY
8	11726_020301	UPPER HOUSING	1	
9	11726_020302	LOWER HOUSING	1	
10	11726_020303	COVER	1	
11	11726_020400	RECOIL STARTER	1	SUB ASSEMBLY
12	11726_020401	CASE	1	
13	11726_020402	PULLEY	1	

Figure 5: Design Task Plan by Alexzander J Hunt, Robert Ivko, Navin R. Sirihochai and Peter J. Stobinski

Every block of stone has a statue inside it and it is the task of the sculptor to discover it. [2]

Figure 6: Computer model of a two-stroke engine byAlexzander J Hunt, Robert Ivko, Navin R. Sirihochai and Peter J. Stobinski

3Dimensional solid modelling is at the heart of the learning activity in this course. Freshmen learn to use the solid modeling software, which is very complex in itself. They use textbook models to learn the software. The instructor provides step-by-step modeling procedure representing various concepts in the case of the class models. However, no such click-for-click procedure is readily available or provided for the RE models. It is the responsibility of the teams to come up with the modeling procedure for the RE part models. Of course, the instructor is available for guidance; senior class students are available for mentoring. This represents applying what the students are learning in class to solve a real problem. The physical parts are measured using simple tools such as calipers to determine the dimensions. In some situations, the students are encouraged to assume appropriate dimensions for lack of suitable instruments for measurement. Students modeling the RE parts are holding the physical part in their hands as they model and this makes a huge difference in their understanding. As a simple example, they are taught to make a 'plate with hole' model in the class. They, later apply the same knowledge when they are ready to make the model of a washer holding the physical washer in their own hands. The learning makes a lot more sense. From time to time, the teams have come across very challenging models. As an example, in 2015 one of the teams came across the need to design an oblong spring. This was a rare and complex model. The model was later realized using surface modeling concepts, which is far beyond the level of a

freshmen class. When there is a purpose and a need the team will discover the solution however complex they may be. This motivation and determination of many students in various teams is profuse. There are numerous other examples that has inspired the students. Each model that the students create is a great *opportunity* for the student community. Many students take advantage of the opportunity. Some may find it hard since this may not suit their aptitude. Over the past seven years, we have witnessed the complexity of the products selected by the student teams for RE have been steadily on the increase. Figure 6 shows the reverse engineered two-stroke engine. Success in completing the assembly ahead of schedule has stimulated several teams, to generate animations of their design. Many students learn animation procedures, a much higher level of training, entirely on their own. All the teams produce comprehensive reports and presentation. They take their work to the annual open showcase, and present to judges from local industry. This celebration resembles a 'product release' event in an industry. Some teams indulge in lightning podium presentations. At the showcase, the entire class also publishes a comprehensive showcase brochure consisting of all product descriptions.

Conclusions:

Whatever you do, do it with Passion! That's more than just a slogan. Over the past seven years we have witnessed this strenuous exercise of blending RE in FED-101in small teams has helped shape the *character* in numerous freshmen, leaving in their minds an everlasting memory of the school they attended. What more gratifying experience would any teacher seek? Each team pursuing a different product for RE offers ample room for individuality and innovation. Palpable surge in their self-esteem is typically and invariably evident after the showcase event. Here is something that they will remember about their first year in the university for their Life.

Incidental course evaluation at the end of the semester has revealed distinct improvement in retention. Many students identify their possible aptitude mismatch, if any, for their chosen major at an early stage, helping them to initiate corrective action right after their first semester. Although the data has not been published, we have observed distinct indication of improvement in retention and early adjustment of major, if cases of mismatch. By exposing the freshmen to the values of ***P**urpose, **R**esponsibility, **I**ndividuality, **D**etermination and **E**xcellence*, this non-pedagogical approach of teaching through Reverse Engineering indeed breeds *PRIDE*[*] in our freshmen students!

References:

[1] Cero Parametric 4.0, Pro/Engineer, and Wildfire are the trademarks of Parametric Technology Corp., MA, USA.
[2] Quotes: Julius Caesar, 52 B. C.; Dave Ramsey; Walt Disney; Enrique Jardiel Poncela, Play writer, Spain; Abraham Lincoln; GD Naidu, Industrialist, India; and Michelangelo
[3] http://chillingeffects.org/reverse/
[4] Corrina Wu, "Some Disassembly Required," ASEE PRISM, October 2008.
[5] Kwabena A. Narh et al, "Innovations in Freshman Mechanical Engineering Curriculum at New Jersey Institute of Technology," International Journal of Engineering Education, Great Britain, Vol 16, No. 5, pp 457-467, 2000
[6] Tamas Varady, Ralph R. Martin and Jordan Cox, *Reverse Engineering of Geometric Models, An Introduction, in Reversing: Secrets of Reverse Engineering*, IN, Willey Publications, Inc. Indianapolis, IN, 2005.
[7] Microsoft Project and Microsoft excel are trademarks of Microsoft Corporation, USA
[8] Ashley C. Pettesch and B. S.Mani, "Innovation 101 Showcase" brochure - online flipbook format, *http://online.anyflip.com/xozo/boql/mobile/index.html#p=1*