

“Toying” to Learn for 21st Century Product Development Environments: Computer-Aided Design, Collaboration, and Rapid Prototyping

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Abstract

A successful hands-on learning environment has been developed for a computer-aided design and prototyping class (ME444). *The goals for this course are a) to help students learn multi-dimensional aspects of advanced product design and b) to allow them to practice in a collaborative environment while prototyping a working toy.* The learning environment combines (1) hands-on use of the Intranet for computer-based learning, (2) a team-based project to prototype a real product, (3) virtual design and assembly of the student-created toy using CAD, (4) realistic budgeting and design constraints, and (5) advanced prototyping techniques. The first phase of the course focuses on learning advanced CAD tools using web-based learning software. Both the instructor and teaching assistants help students in the laboratory. The students design a toy conceptually as they become familiar with CAD tools. In the second phase, each group designs a toy using a budget to buy standard parts such as motors and controllers. The complete design, assembly, and simulation of functionality of the toy are performed using advanced CAD tools. The constraints of the rapid prototyping process are included in the design criteria. In the last phase, a working prototype of the toy is created using a laser-based rapid prototyping process for the end-of-semester product fair. The course creates a sense of ownership of the project by allowing students to design their own project.

Introduction

An observation made in 1965 by Gordon Moore, co-founder of Intel, was that the number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit was invented. Data density has doubled approximately every 18 months, which is the current definition of Moore's Law. Most experts, including Moore himself, expect Moore's Law to hold for at least another two decades. The improvement of computation power has spawned many innovations in software in diverse areas. Early Computer-Aided Design (CAD) was used for time-consuming computations in the shipbuilding and aerospace industry. However, it was cumbersome to use and accessible to only a few large corporations. In time, computers became cheaper, and interactive software was enabled through the commercialization of the mouse and

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improved graphical user interfaces. Software in various domains became more specialized, and mechanical CAD was born in the present form. Along with CAD, other Computer-Aided Manufacturing (CAM) software for planning and developing manufacturing, such as cutter paths, improved significantly. Analysis software using finite elements became an integral part of the design process. Today, it is possible to purchase different software that can help in several aspects of the design process and manufacturing simulations.

The rapid increase of computational power continues to empower designers and engineers to perform more of the design and manufacturing using advanced software. The capabilities of advanced software continue to affect all phases of design and manufacturing. Today's CAD and CAM software have become a commodity. The prices have continued to decrease and their capability has continued to expand over the past decade. Product variety has increased, products have become more complex, and product life has become much shorter. In contrast, the product design cycle time continues to reduce. The number of products being designed and developed has reached an all-time high. With the specialization of the manufacturing industry today, the various aspects of design and manufacturing tend to be distributed. Product Data Management (PDM) tools were designed with the advent of the Internet; now emphasis has shifted to Product Lifecycle Management (PLM) tools.

Past educational efforts in CAD include education-related use of rapid prototyping, self-taught web-based learning, team project-based learning, and design-manufacturing integration. The usefulness of CAD/CAM tools in the learning process and job market utilization is unquestioned. What remains to be studied is how much and in what depth they should be taught¹. A wide range of studies have used CAD instruction in the undergraduate curriculum². The relationship between industry and engineering/technology academic programs is constantly evolving and redefining itself². Classroom lectures are compared with self-teaching in order to impart to the students the learning process³. Industry's growing demands for students with integrated design and manufacturing experience and knowledge of advanced CAD software has resulted in many universities developing some form of CAD curricula. For example, many universities including Purdue have now eliminated traditional graphics course and replaced it with a CAD related course. Rapid design and prototyping laboratories have also been established in many universities. The laboratories are integrated with CAD/CAM courses including teaching design for automated assembly^{4,5}. Computer-aided design (CAD) tools, used in conjunction with personal workstations, have already brought about major changes in engineering practice. Web-based services supporting mechatronic systems design is described for a graduate level engineering course at Stanford. WebCT, a web-based course management tool, is used in a self-taught solid modeling course at Rensselaer⁶ which uses it as an archiving system for past projects, student profiles, local vendor directories, and presentations. How universities teach and use CAD and CAM continues to evolve with the changes in the tools themselves.

Our goal was to develop a framework for a course that could continue to reflect the advances in design software. We created an environment and process for the learning to occur in a setting where the students are self-motivated. Learning also occurs through errors and difficulties in collaboration in team settings. To further ensure long-term success, we imparted a process by which students could learn such software and are productive in team-based settings. We thus provided a foundation for continued growth and competency as new tools and methods were

developed². At the same time we wanted to provide a collaborative learning environment that is student-driven and where creativity is encouraged naturally. To the best of our knowledge, our course is the only one on its scale to integrate learning advanced design using CAD tools, team-based projects, rapid prototyping and realistic constraints and budgets. The course management processes and methods are themselves unique.

The primary objectives of the course are to help the students to:

- Quickly learn and become productive in advanced CAD programs.
- Become familiar with computer-based prototyping.
- Experience emerging and new industrial environments for design and product realization applications.

Some of the sub-objectives are to include:

- Theory as a part of practice.
- Practice-based design and collaboration to learn product development.
- Integration of design and manufacturing issues.
- Preparing an engineer for the 21st century.
- Incorporating knowledge of current technologies and tools at the senior level, thus improving students' marketability in a competitive market.

Development of Computer-Aided Design and Prototyping Course (ME444)

With the availability of CAD tools, our curriculum at Purdue in 1991 began formulating means by which undergraduates could learn to use advanced software in the design process. Interactive CAD software was introduced in the laboratory while, at the same time, the course covered various theories including geometric modeling, numerical analysis, optimization, and some aspects of finite elements. Students also learned to write interactive graphics programs. In time we realized that the industry required engineers to do design with CAD. For this reason, engineers with only undergraduate degrees were seldom called upon or trusted to run analysis software. Furthermore, analysis software required significant learning and appropriate practice typically available in graduate courses. We thus avoided the misuse of advanced analysis by those who did not fully understand the underlying principles and its use as a substitute for their own learning⁷. We made a decision to focus the course on learning CAD and using the interactive tools while other detailed aspects of analysis were left to other specialized courses. This transition occurred in 1995. When we started using CAD to design and prototype in the classroom, training material was not available, so CAD instruction material had to be developed. With subsequent changes and new releases in software, this instruction material became obsolete. When the first books for training and learning to use CAD became available, these books improved the course. With the more advanced instruction and improvement in CAD user interfaces and processes, the students were able to design more challenging parts and assemblies in the course.

In 1997, Purdue acquired rapid prototyping capability, a stereolithography (SLA) machine. We were now able to design and manufacture a prototype that performed some simple functions of the final product. The use of rapid prototyping to make the toy prototypes was possible because the functionality of toys was not significantly affected by the SLA parts. The students were able

to visualize spatial and assembly constraints with the prototype and make the toy functional. In time, we were able to introduce multimedia learning, so the value of the instructors in the labs moved to the next level. The students were able to learn much more during their time in and outside the lab. The teaching assistants and instructors started playing a much more important role by helping students in a personalized setting with advanced concepts. We then introduced the idea of the students designing their own projects in teams in the earlier part of the course. The latter portion of the course would be spent by the students converting their original design concept to CAD models. The final stages were spent building a rapid prototyped product, when the parts that they ordered arrived and could be assembled with SLA parts. We required the toys to be fully functional. The first test case of the course was successful in principle.

The concepts developed in this learning environment are applicable to computer-based cooperative learning. The ME444 learning environment, which is built around prototyping the toy, is one of a kind. To the best of our knowledge, no parallel course exists in any of the universities. ME444 provides our students with a competitive edge in the marketplace. The entire coordination of the course, including the rapid prototyping of the projects and creation of the full prototype, is a unique process. The overall process of ME444 is shown in Figure 1.

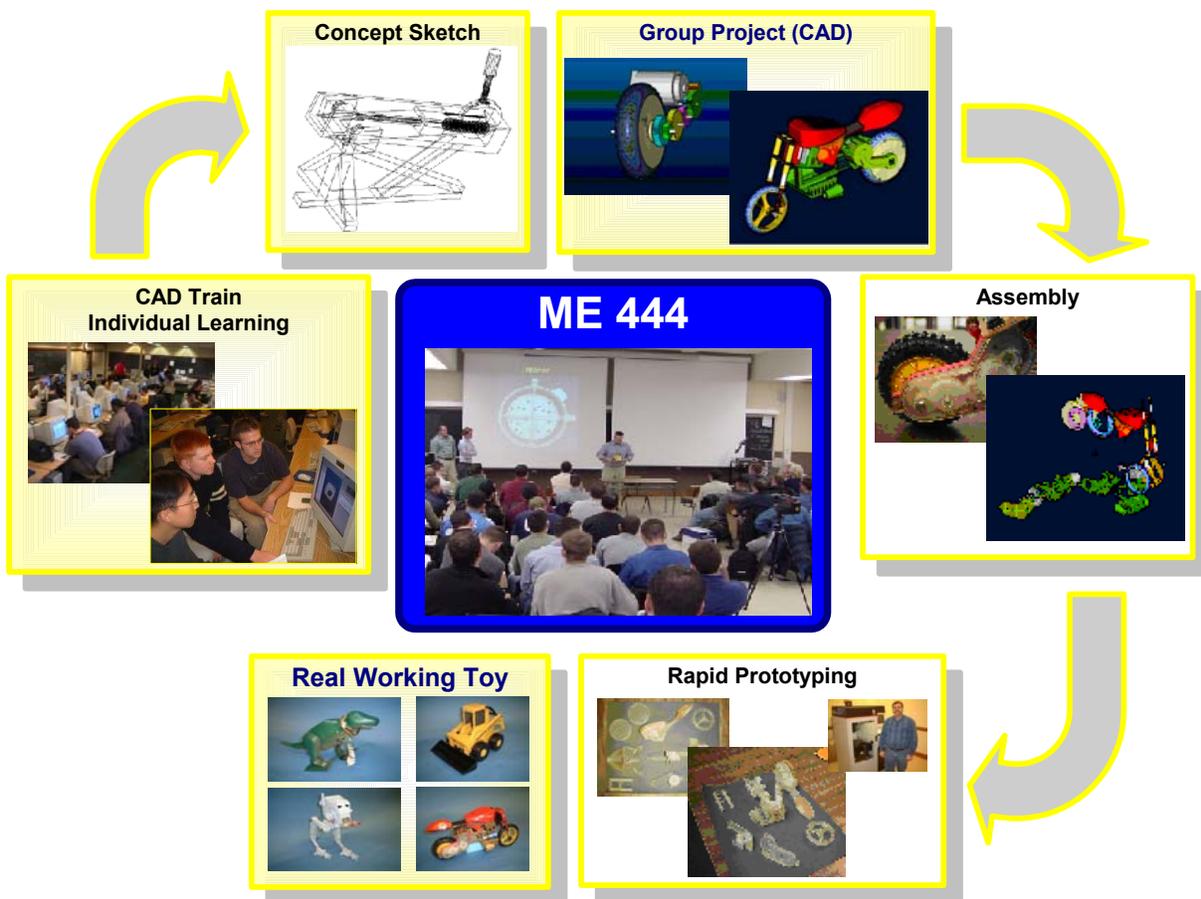


Figure 1: Overall schematic of the course flow from individual CAD learning, concept development and design through collaboration in teams, virtual assembly, rapid prototyping, final assembly, and testing.

Description and Objectives

ME444 combines engineering fundamentals and hands-on use of commercial software to teach the use of modern computer tools for engineering design and prototyping. An entirely new and unique approach has been developed to teach the team design process while integrating advanced CAD. It consists of two 2-hour lab sessions and one 50-minute lecture per week and is based on hands-on learning and the use of web-based tools in both the lectures and laboratory. The traditional pedagogy is primarily an instructor-centered “broadcast model.” The instructor decides on the learning objectives, the sequence, the reading materials, and the evaluation procedure. The classroom is a way of aggregating students and creating an effective distribution channel for moving knowledge from the instructor to the student(s). The web model of learning and team-based project we have developed for ME444 is based on a different set of principles: Both the instructor and students are co-developers of the course and the learning experience. This pooling of knowledge is critical to creating an exciting learning experience, especially when it comes to bringing the experiences of each student to the classroom, allowing cross-fertilization to occur.

Finally, our goal is to create frameworks and tools that are appropriate to the new methods of cooperative and collaborative learning. The labs are not lecture-based; instead, students use the time to first learn CAD and then discuss their toy development projects. They continue to learn while implementing their projects, since the earlier CAD learning cannot be customized to individual project needs. The evaluations are also collaborative. During the final presentation, the student teams evaluate each other anonymously. In turn, the instructor reviews their evaluations along with independent external judges, which removes any bias. We adopted the Intranet and then adopted WebCT early to disseminate the class exercises and manage the student groups. WebCT is also used to manage the calendar, assignments, student feedback, quizzes, and weekly bulletin board. We have no paper-based transactions with the students. All submissions including final design are done on the web. We now also use a computer-based e-learning program called Coach (from CADTrain) to help students learn CAD in a self-paced manner. This is a learning model for the next-generation collaborative and distributed design. The use of the Intranet allows easy access to Coach without the need to distribute and copy the material. There are four homework assignments and two quizzes that the students finish and submit online. They are evenly distributed throughout the semester and their purpose is to ensure and monitor the students’ progress.

Students also learn about effective information sharing and collaboration. Since we allow freedom to use other CAD packages they choose to use a different program to make standard parts such as gears in drag and drop CAD software such as IronCAD. Some students choose to use SolidWorks to design complex parts. In these cases, they may run into compatibility problems and learn about interoperability and file sharing issues. Design constraints are given early so the students will think and plan ahead before they do the design. Some of the constraints are total allowed volume (material used), total build height, minimum wall thickness, and trapped volume. Not every part needs be built. The students also have limited budgets so that they can purchase parts if necessary. Most of the students use computers to do their searches and purchase parts online. They also learn to use kinematics packages to do a simulation of their

“virtual model” designs. They then choose to learn an animation package and do an animation if the system is too complex.

When students finish learning CAD software, they learn to use 3D lightyear rapid prototyping preparation software to set up their parts in the SLA machine. They save their CAD files in STL format and import them into 3D lightyear software. This software has to be learnt before they start doing their individual detailed designs, since the machine capability is a constraint on size and number of parts they can make. Then they check to make sure that all of their parts can fit into the working envelope of the machine. Students often have to modify many of their parts so that all the parts can be made with one setup. While the parts are being built, they get a brief introduction and learn the basics of ANSYS finite element analysis software. Once all the parts are built into the RP machine, they assemble the machine and check for errors. Table 1 lists weekly topics of lectures and lab sessions.

Table 1: ME444 semester schedule.

Week	Lecture & Lab	Project
1	Modeling: General Interaction	
2	Solid Modeling and Parametric CAD Models	
3	Sketches and Constraints	Begin forming project teams.
4	Part Modeling Techniques	Plan project & start preliminary proposal.
5	Assembly Modeling	Preliminary proposal due.
6	Linkages in Assemblies	Provide feedback on preliminary proposal.
7	Advanced Modeling	Submit final project proposal
8	Work on Project	
9	Project Discussion, SLA Preparation	
10	Introduction to FEA	
11	2D Solid Elements , Work on Project, Start ANSYS	Submit files for prototypes & reports.
12	Introduction to ANSYS (tutorial and examples)	
13	Finite Element Modeling, Introduction to Pro/FEM	
14	Introduction to Pro/FEM	
15	Discussion of Final Presentation and Report	
16		Final Presentation

Because of the RP machine’s limitations, the parts often have to be tweaked and fixed. The students need to compare their model with their CAD design and virtual model to make sure it works properly. Even if the finished model does not work properly, students can learn a lot. For example, some teams that made the wall too thick have a heavy assembly, which causes problems if the motor they purchased was not powerful enough to move it. Many students end up with parts without enough clearance between mating surfaces, which causes problems during assembly. Others do not use high enough resolution when creating STL files, so the finished parts come out very rough and the students need to spend a long time “cleaning” them up. Thus, learning from mistakes is also an effective means of learning. Most of these errors are recorded and introduced the following semester. Table 2 shows the SLA material property and post-processing guidelines that we developed from past experiences. This information is continuously updated and available to students online.

Table 2: Design guideline for parts to be made with SLA

Build height limit is 3.00”	
Parts made by the SLA must be positioned on the 10 by 10 platform so that: “no stacking”: Parts cannot overlap in the vertical direction. Each part must occupy its own “footprint” on the platform. “no pooling”: The part should not create a “pool” of entrapped resin inside its boundaries as it is made layer by layer. For example, a bowl should be oriented opening to the side, not the top or bottom.	
Minimum allowable thickness of the SLA parts is 0.060 in. for strength. Tolerance achievable for SLA parts is +/- 0.003 in. SLA parts are porous and must be painted to be waterproof	
Material Properties:	
Density 1.215 g/cm ³	Thermal Conductivity: 0.2002 W/m*K
Tensile Modulus: 2400-2500 Mpa	Tensile Strength: 59-60 Mpa
Flexural Modulus: 2000-2300 Mpa	Flexural Strength: 80-85 Mpa
Impact Strength: 27-30 kJ/m ²	Hardness is 85
Thermal Expansion Coefficient: 90 ppm/K (20-40 deg. C)	
Post processing: SLA Parts <u>can</u> be finished by most of the conventional machining techniques:	
<ul style="list-style-type: none"> • <u>General:</u> Medium cutting speed (65m/min) and slow feed with high speed steel tools. Lubrication is not necessary but can help cool the workpiece at higher speeds and for threading on a lathe. • <u>Milling:</u> HSS tool for steel; speed 90-300 m/min, feed rate below 300 mm/min; cutting depths of more than 0.5 mm per pass or with higher feed rates may cause slight chipping at the trailing edge. • <u>Sawing:</u> A hand saw (blade for steel), circular saw (blade for steel or aluminum) or band saw (blade for steel or aluminum) can be used; cutting speed about 75m/min; a coarser grit diamond sawblade at 1500 m/min has been used successfully. • <u>Drilling:</u> Easily done on a lathe or drill press, with rpm adapted to bit diameter (1000-2000 for bits of 1-5 mm, 200-500 for 5-15 mm bits); friction of the tool can heat and deteriorate the surface of the hole; lubricate for better results; a wood or plastic block should be used as a support to prevent chipping of the exit side of through holes. Finishing with a reamer results in a smooth hole with particularly precise diameter. • <u>Tapping:</u> Use a screw tap for steel at slow speed; for blind holes, manual tapping is preferred; lubricate for best results. • <u>Threading:</u> Can be done on a lathe using a 60 deg. C HSS lathe-tool at medium speed (e.g. 5.0 m/min.). Due to material hardness, the surface quality of the threading may be a problem. For good quality threading, finish the thread using small cutting depths (e.g. 0.05-0.1 mm). 	

Rationale

The global information revolution and a rapidly changing environment have led to significant changes in product development in the past decade. The products have grown increasingly complex in shape and form, while the product development cycles have continued to shrink. The ability to use software to fully develop a product that the students conceive and design in teams simulates product-based concurrent and cooperative learning.

Twenty-first century engineers must also be able to quickly adapt to new tools and processes as they emerge. For efficient product development, the ability to communicate, negotiate, and work in an interdisciplinary team environment is critical. To provide ME students with the experience of (1) working in a resource-limited interdisciplinary product development environment, (2)

make decisions to reduce risk, and (3) innovate, we have developed a new approach with hands-on and project-based learning by using the Intranet. An instructor and teaching assistants enable learning in this environment, which is flexible for different modes of learning. Also, the laboratory-based course is ideal for variety of self-paced projects with different types of modeling needs and suits the learning styles of individual students.

A critical need to revitalize engineering design education by introducing advanced tools and concepts in the curriculum had first to be recognized. We recognized this need for the students' customers – “industries.” Newly-hired engineers must be able to contribute directly in industry without first going through costly and lengthy training programs. Engineers must be able to design with constraints, manage designs, and function effectively in teams to rapidly realize products in industry. Learning advanced tools for design cannot be taught in a traditional classroom. Also the CAD and other computer-based packages have many features and have become increasingly complex. Mastering the advanced tools is critical because the environments are changing fast. Lectures and demonstrations cannot help students learn advanced CAD/CAM tools. To learn advanced software, the best way to learn is by “doing” and “experiencing,” not just “seeing”^{8,9}.

History of Continuous Innovation

One of our broad goals was to energize the undergraduate curriculum in the CAD area. Initially, we experimented with versions of the course where there was a significant amount of theory but little practice. During our interactions with industry, we noticed that engineers with undergraduate degrees hired in industry were expected to use CAD tools in advanced environments. Only a small fraction of them went on to work in industries that create such tools. Also the advanced tools were beginning to emerge. We anticipated the need for students who not only had advanced knowledge in using such software, but who were also able to work in groups to design products collaboratively.

Initial versions of the practice-based course left little time to implement what the students had learned. However, with a few trials and iterations, we were able to reduce the initial learning to a few core concepts. Then we designed the toy project in order for the students to practice the use of the software. In addition, the students learned additional features of the software based on what their projects demanded. This method of “pull” learning what is required is critical in complex engineering environments. Seldom will the person be able to master a tool completely before he/she uses it; much of the learning has to occur in real-time. When we modified the course in order to include more hands-on experiences, the enrollment surged. The students' marketability and performance in interviews improved. Students' positive comments about the course in turn increased the enrollments automatically. The overall enrollment in the ME department has not changed much but the number of students registering for ME444 each semester has continued to increase. Eventually, the demand for the course far exceeded the enrollment limit of 44 imposed during the Fall 1994 and Fall 1995 semesters. Since 1996, ME 444 has been offered in both the Fall and Spring semesters with enrollments reaching around 80 students each semester (Figure 2). It is the most popular technical elective in the history of the department. We continue to experiment with introducing new ideas into the course each time. Some of these changes have worked and some have not been as effective; however, we have

learned from the earlier changes and have come up with better versions of the course each time. In the Spring of 1999, the course content was further improved by using full web-based multi-media CAD learning software.

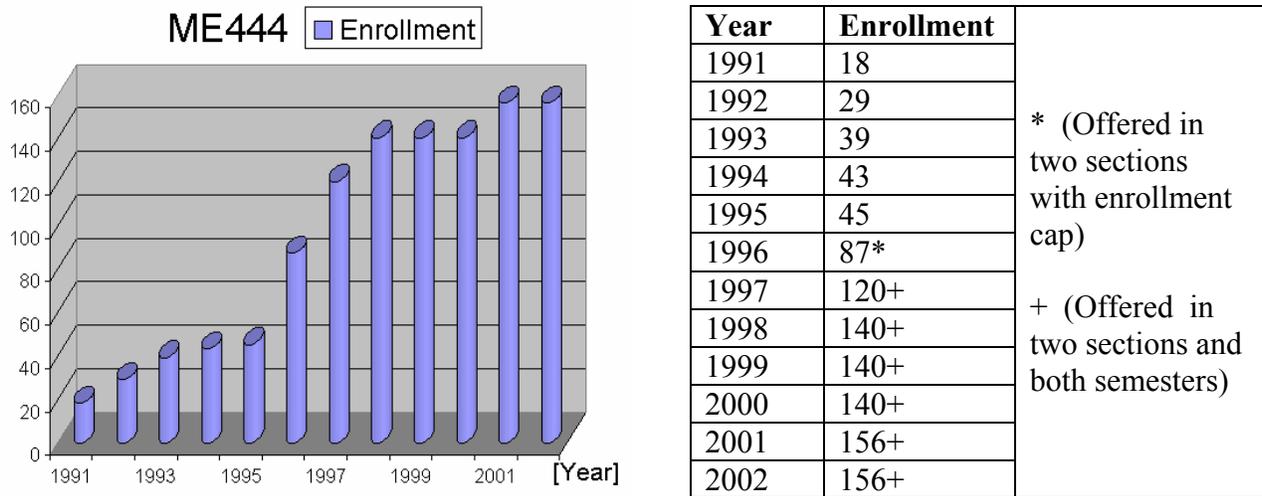


Figure 2: Continuous increase in enrollment for ME444, now offered both semesters (78 students each semester) as a technical elective, is very unusual in engineering.

Examples of projects and student comments

Senior Scott Wolfe stood by his giant ladybug toy, painted in red with black dots. Upon the press of a button, a motor inside the shell allowed the bug to move forward and the light also to flicker at the same time. Later, Wolfe said the following about ME444: *“This was the best mechanical engineering project I’ve ever done where you actually get to design a product, then got to make something to see if it actually worked.”* Senior Shane Kondo also enjoyed the course: “It’s also the only final we’ve had doughnuts and coffee.” What may at first have seemed like a simple project, however, wasn’t all that simple. His team designed a tank that shoots gumballs. “We learned a lot about engineering constraints,” he said sipping coffee. “Something as simple as a shooting mechanism is so complicated.” While some students showed off their products, Jeremy Basham, a senior, was lamenting the death of his R2-D2 toy. “Its motor blew!” he exclaimed several times when others kept asking him what had happened. He said the motor had worked two days ago. Basham said he wasn’t worried about losing points on the day of the final, however. “I’m going for the 10 points for the coolness factor,” he said. “Cause guess what? Star Wars is all the rage right now!” Students also learned significantly from the failure of their products. Many of the toys students designed were as advanced as the *remote controlled toy shaped like a high performance stunt motorbike* capable of balancing and turning, as illustrated in Figures 3 and 4. Senior Bala Ganesan, who designed this award winning motorbike, went on to work in Dell and then to MIT for graduate work.

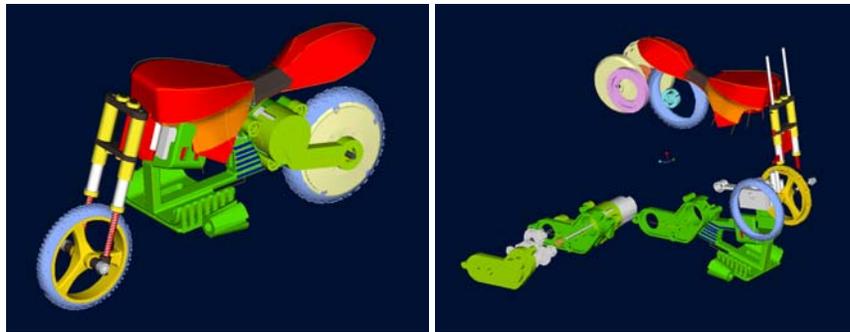


Figure 3: Top down view of virtual prototype from computer-aided-design and an exploded view of the bike's mechanical parts.



Figure 4: The physical prototype was made using SLA-stereo lithographic technique. SLA is a common rapid prototyping technique, which produces acrylic and epoxy parts. The unpainted parts are shown to the left. The gearbox housing and transmission is shown unpainted to the right

One group designed and made a single cylinder engine (Figure 5). The action included the crankshaft, piston, camshaft, and follower/valve motions. The motion was powered by a small 12V gear motor. The virtual model used relations to simulate all actions of the physical mode, including cam-follower interaction and the compression and extension of a spring. By using a virtual model, proper lengths and other parameters of the mechanism were tested and adjusted before the final design was submitted for rapid prototyping.

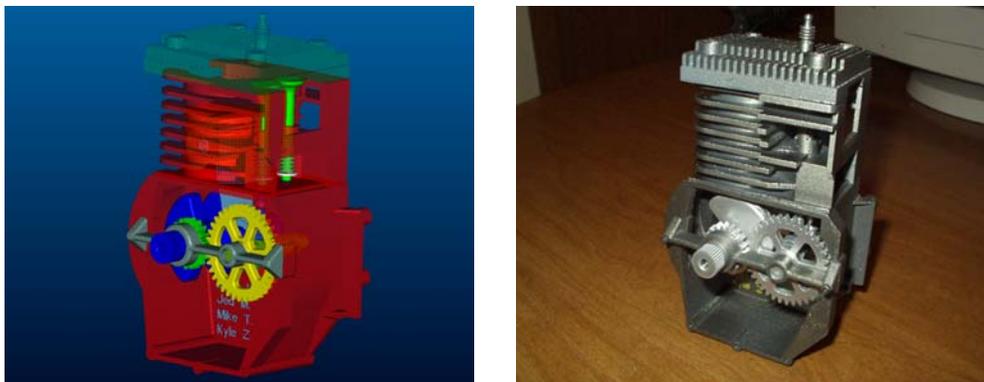


Figure 5: Virtual model of single cylinder engine and rapid prototyped model

Students continue to remember ME444 throughout their careers and in specific work situations when their work benefits from their learning. They even bring their parents to the school to show off their project creations. It creates a relationship of the students to the school and Purdue University. Hundreds of prototype toys have been created, some of which are shown in Figure 6.



Figure 6: Some of the working toys designed and made by ME444 students: A van with rocket launcher, singing and dancing Purdue Pete, maze puzzle, and tractor.

All of these projects are archived and available online (Figure 7). Students look at these summaries to see other students' past work and to come up with something different that nobody else has tried.

<p>Group 12 KEVIN EDWARDS, RHEX FEARNOW, JONATHAN SOEFAJIN, ANDREAS CROSIER</p>	
	
<p>The remote control vehicle we have designed is modeled after the “Gravedigger” monster truck. An AM transmitter is used to send signals to the car, which is capable of moving forward via an electric DC motor and steering left and right using one servo. Front and rear suspension has also been included in the design. Parts to be made using SLA include the front chassis, rear chassis, chassis pin, front shock tower, two front A-arms, two spindles, two rear body posts, motor mount, cylindrical axle mount support, and truck body. Additional parts used from the team include transmitter, receiver, battery pack, speed controller, DC motor, servo, rear shock assembly, rear axle, hubs, wheels, and tires. The virtual prototype was designed using Pro/Engineer and replicates all motions capable of the vehicle including the rotation of the tires, the front wheels turning left and right, and the front and rear suspension moving up and down.</p>	

Figure 7: An example of past project summary available online

In 2001, ME444 teamed up with a graduate level mechatronics class to design smart toys. Graduate students in the mechatronics class worked with ME 444 students to design various sensors and circuits for their team. Collaboration among students in different classes became a big challenge, and most students relied heavily on electronic data-sharing and communication.

Needing to incorporate various sensors added more constraints to their design. All sensors had to be able to be mounted or enclosed inside of the toy. One team designed a toy police car that had speed detecting circuits on board. In their project presentation, when an approaching toy car was under the preset speed limit, the toy police car just sat still. However, when the approaching toy was “speeding,” the lights and siren on their toy car came on and it started to chase after the speeding toy. One team made a tank that with an infrared sensor. It went around in a circle and searched for a target. The target was a small device which emits infrared signal. When the tank found the target, it would approach, aim, and fire plastic bullets. This collaboration effort between two courses was extremely difficult to organize because of various time constraints with the SLA machine schedule and the difference in the progress between the two classes.

Impact on Student Learning

Student learning in the 21st century has to be life-long especially with rapidly changing technologies. It is critical to provide students with the skills and confidence to learn advanced tools in the real world. Most students, including those who enroll in ME444, have not had experiences with advanced CAD tools to the level that they can function competently in real-world product design environments. Most mechanical engineers work in environments related to the development, design, and manufacture of products or service operations in design and manufacturing. Hence, use of advanced tools is critical for their career development. Employers see a strong need for such engineers.

Team-based collaborative product development has become a critical skill in the real world. Current trends in engineering will continue to require engineers to collaborate on product development relying on the use of modern computer-based tools. The students learn that it is possible to significantly reduce product development time by “virtually prototyping” the product. Prototyping can be done early within the development process. Such environments allow for including manufacturing early in the design cycle. Thus, students can practice “concurrent engineering,” which allows reduction in product development errors and times. Such savings in product launch can mean significant revenue for companies in a competitive world. Therefore, it is critical to be able to link the student’s thinking to concrete hands-on experiences in the curriculum, thus enabling long-term retention of concepts.



Figure 8: Hilal and Jeffrey testing their toys before the final presentation (left). Henry is showing off his hovercraft to his peers during the final presentation (right).



Figure 9: Dustin is setting up his group's remote controlled garbage truck demo (left). Norbert and his teammates are explaining their toy to the class (right).

Future challenges and ongoing development activities:

We learned a lot from the history of this course about developing unique learning concepts and environments and about changes occurring in industry. Our interaction with industry on advanced product development as well as on computer-aided software also helps anticipate changes that will be needed in the course. During the early offerings of this course, the time was just sufficient to teach the use of the software. Support materials for learning were not available. However, with time, the tools themselves have become more user-friendly and support materials have become available. The students were able not only to learn to use the tools but also to practice building toys that simulated real-world scenarios. We were able to prototype the toys and teach the students use of analysis tools while their toys were being prototyped. In a similar manner, we saw more changes in 1998-2001 than in 1988-1998. These changes in the environment continue to impact the nature of this course.

Real-world product development environments continue to change rapidly. In addition to CAD tools, new tools that will manage product data and information are being developed. Student exposure to these tools, along with virtual manufacturing tools, is critical. To continue to keep the course on the cutting edge, we plan to introduce these advanced tools in the unique learning framework we have developed at Purdue University. Since the students design and manage their toys in teams, using advanced tools for managing their products and interactions is a natural fit for the course environment.

Conclusion

Computer-Aided Design and Prototyping (ME444) we have developed at Purdue University combines engineering fundamentals and hands-on use of commercial software. This course proved to be a popular and highly successful approach for introducing advanced CAD software and a realistic environment for new product design and prototyping. The ME444's web-based model of learning CAD using student defined projects and teams to create working toy

stimulates creativity. The pooling of knowledge is critical in bringing the experiences of each student and the instructors to the classroom and allows peer learning to occur. Students enjoy creating toys and find the overall project experience exciting. The informal feedback from students has been very positive and the maturity level of CAD skills that the students develop demonstrates the effectiveness of our approach.

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Biography

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