

# Learning CAD/CAM and CNC Machining through Mini-Car and Catapult Projects\*

VINCENT H. CHAN

*Department of Mechanical Engineering, Ryerson University, Toronto, Ontario, Canada.*

*E-mail: v7chan@ryerson.ca*

*A new project was introduced in the fall of 2000 to second-year mechanical and industrial engineering students. The goal of the project was to reinforce the lectures in the areas of CAD/CAM software and its use for computer numeric controlled (CNC) machining. The project requires student teams to design from a common kit of stock materials. Experiences gained in the CNC machining lab taught the students the importance and the intricacies of machining. A student survey at the end of the project strongly suggested that this was a very effective way to learn about CAD/CAM and CNC machining.*

## INTRODUCTION

CNC MACHINING has been a mainstay of manufacturing for many years. With advances in CAM software, it has become easier and quicker to machine complex surfaces that were never before possible. This is true not only for industry but also for education. This change has been reflected in the curriculum at Ryerson University, with the use of CAM software and its application to produce the student's designs.

The mechanical engineering program at Ryerson University, in Toronto, Canada, incorporates three core manufacturing classes during the four-year undergraduate program. CNC machining is taught as part of their second manufacturing class. An introduction to traditional machining is covered in the first manufacturing class. Students are familiar with the operation of manual shop machines, but have yet to be exposed to computer controlled machines.

In the lecture periods, students are introduced to the G-code language used for CNC machines. During the lab periods, the students are exposed to a MS Windows-based CAM software, which can take their CAD drawings and generate the necessary G-code automatically. Both the lectures and labs are reinforced by a semester-long project, where student teams design and build either a rubber band powered mini-car, in the case of mechanical engineering students or a catapult, in the case of industrial engineering students.

Similar to many engineering programs, the program at Ryerson is heavily loaded with courses in the basic math and sciences. This course marks one of the first engineering projects where students can apply much of the theoretical knowledge that have learned, such as physics, dynamics, mechanics and stress analysis.

## OBJECTIVES

The primary objective of the project is to reinforce the lecture and lab material on CNC machining. Secondary objectives include the fostering of design concepts, communication and team working skills.

Previously, the students only simulated the machining of their parts. It was found that students often missed the intricacies of machining, such as work-piece holding and tool-path planning. It was anticipated that by introducing the CNC machining lab, this would provide active experimentation in Kolb's learning cycle [1–4]. By spreading out the machining time over a four-week period students were allowed to go back to the computer lab and refine their strategy before the next machining session.

As an accredited undergraduate engineering program, much attention is paid to the design content in each of the courses. The project is used to introduce students to many generic design concepts, such as defining the problems, setting the goals, generating and selection of design solutions. Projects have often been successfully used to teach students the intricacies of engineering design [5, 6]. In this particular project, students are forced to implement knowledge from many of their courses, for example calculating wheel torque from first principles taught in first-year physics or optimizing gear ratios, as taught in their mechanics of machines course.

A study by the Society of Manufacturing Engineers [7–9] outlines the top 'competency gaps' from new engineers that include skills such as project management, product design and teamwork. In an attempt to close some of these gaps, the organization of the project has been devised to provide students the opportunity to learn many of these important skills.

\* Accepted 3 February 2004.

Table 1. List of items include in the student's kits for mini-car and catapult projects

No. of items mini-car	No. of items catapult	Description
5	3	101 × 178 × 6.4 mm [4 × 7 × ¼ inch] medium density fiber board
2	2	101 × 51 × 12.7 mm [4 × 2 × ½ inch] medium density fiber board
5	2	Plastic ball point pen—blue
2	4	Paper clips
6	4	#8 12.7 mm [1/2 inch] long sheet metal screw
1	1	Small birthday candle
1	1	8 × 11½ inch white paper
0	1	12 inch cotton string
10	10	Size #64 rubber bands
4	0	#10 washers

## DESCRIPTION OF THE PROJECT

The student's ultimate goal is to turn their designs into a working prototype. Each of the student teams is provided with the same basic kit of materials. To create a level playing field, no other materials can be added to the kit, other than glue or paint, which the students must supply themselves. The students are also provided with access to CAD software (AutoCAD 2000) from which they use to design their projects and CAM software (Pathtrace's EdgeCAM 3.0) to generate the G-code to machine their part. Students are not permitted to use any power tools from home, as all parts must be created on the lab's CNC machines. Access to CNC milling machines is limited, again to ensure that no team has an unfair advantage.

The project kits consist of materials commonly available at hardware and office supply stores and is listed in Table 1.

If the students lose or break any of the parts in the kit, they are provided with the model numbers and can purchase replacements at local stores. Extra boards are also provided, should the students discover errors while machining their parts. However, students are only allowed to replace parts, and cannot go over the original allotment of materials in the final product. The mini-cars and catapults are weighed before the competition to ensure compliance.

Students are introduced to the project on the first lecture. They are given one month to form groups and propose a design. The second month is spent using EdgeCAM to generate the necessary CNC machine code. The last month of the project, students spend machining their parts out of the MDF boards using the CNC machines. The project finishes with a competition. Three of the fifteen project marks are awarded depending on how well the design performs in the competition. Of course, more importantly to the students, the winning team gets 'bragging' rights.

Although second-year courses on manufacturing often have a component of CNC machining, the part(s) that are made are often simple and only have one or two fitting pieces [10–13]. Due to the different constraints of the project, the students must design and manufacture multiple fitting parts

with sliding and rotating pieces. This allows the students to apply some of the metrology concepts learned in the earlier manufacturing course. It is the scope of this project which takes the student from the design idea, to CAD, CAM and to the final working prototype, that exposes students to the complete design process. By spreading the machining labs over four lab sessions, students are allowed to reflect on their previous lab sessions and optimize their machining strategy for the next session. This experience, combined with the theory taught in the lectures, reinforces the students' learning cycle.

## PROJECT PHASES

The project is divided into three phases; design, manufacture and competition. Unfortunately, due to the size of the classes, and the limited availability of the student CNC machines, each of the teams are quite large. Logistically, the class is divided into smaller lab sections, of approximately 15–20 students in each section. This is used to advantage in arranging the management of each of the teams by student project managers, who are selected by the students themselves in each of the sections based on their design proposal. Therefore, each lab section is a team that is led by the project manager(s). There are typically 90 students in the mechanical engineering class and 40 students in the industrial engineering class.

In the first phase, the design phase, the students are given one month to come up with a design proposal. The students are allowed to partner with another student in their same lab section. They then give a short five-minute presentation to the rest of the lab section. At the end of all the presentations, the lab section then elects the best design proposal. The student(s) of that design then become the team's project manager(s).

It is the task of the project manager to finalize the design and layout the required parts in the design on the boards of MDF. An example of a typical layout of all the parts necessary to build a mini-car can be seen in Fig. 1 and for the catapult in Fig. 2. The project managers must also assign groups of students the responsibility to manufac-

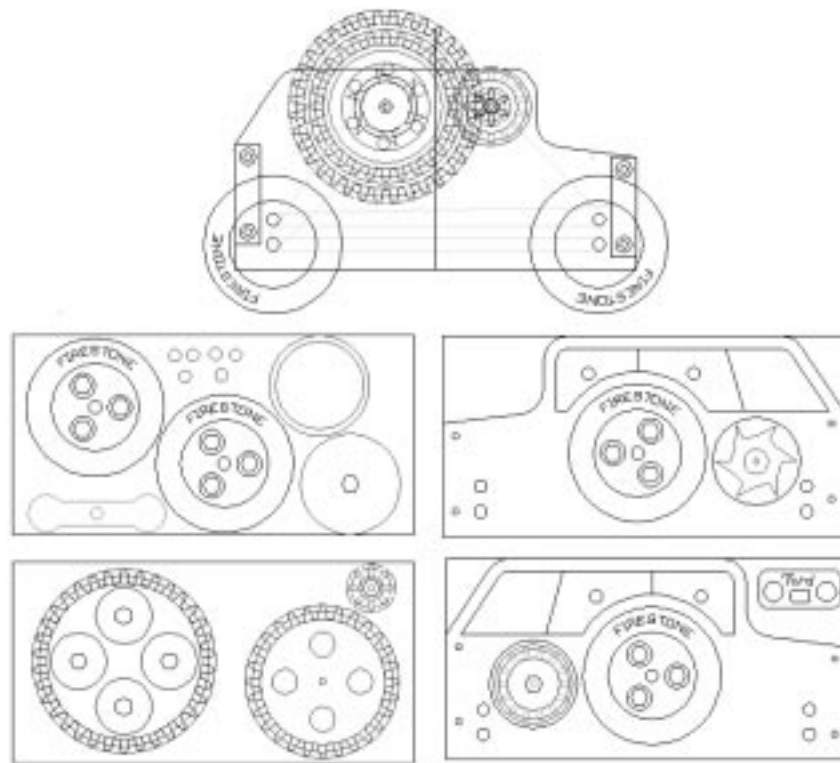


Fig. 1. Typical layout for mini-car project.

ture the parts and schedule the machining times for each of the manufacturing groups in their team. Finally, the project managers must ensure that the parts are assembled correctly to the specifications of their design.

In phase II, during the second month of the

course, the students must use the CAM software to turn the CAD drawings into the correct CNC machine code. Both manual G-code programming and the use of the CAM software are taught to the students in the first four weeks of the course. Once the G-code is finished, the students must submit

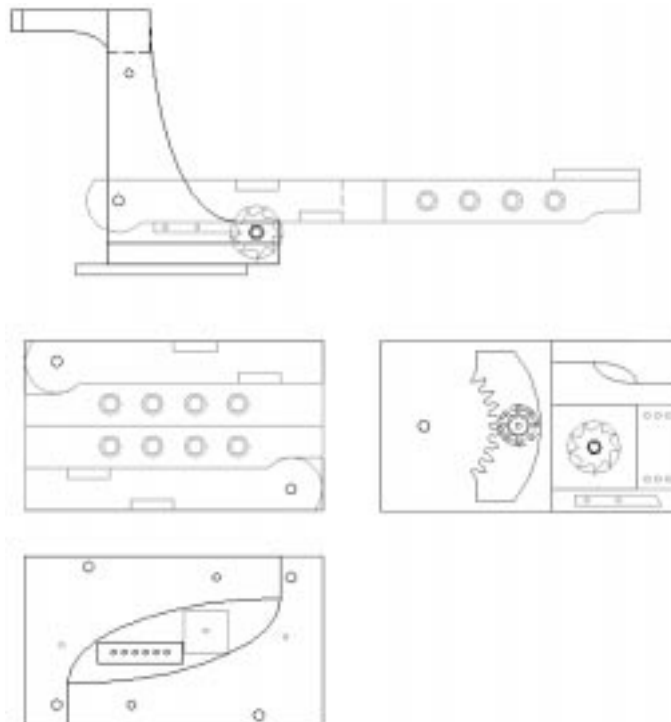


Fig. 2. Typical layout for catapult project.

interim reports before they are allowed to enter into the CNC machining lab. This allows for one final check of the generated G-code. The students use a small tabletop CNC milling machines made by MaxNC Inc. and Sherline Products Inc to mill their parts. Simple PC-based controls are used to read in the generated G-code and send the appropriate commands to the machines.

Phase III of the project is the actual competition, generally held during the end of the third month of the semester.

For the **mini-car** project, there are four different competitions:

1. Design judging, where faculty and technical staff are asked to judge each of the cars.
2. The drag race, where cars are run in heats of two against each other.
3. Uphill  $4 \times 4$ , where the cars must traverse an uphill obstacle course.
4. Tug-of-war, where two cars are connected to each other.

For the **catapult** project, the competitions are:

1. Design judging.
2. Distance launch, where the catapult must hurl the projectile the farthest distance possible.
3. Target launch, where the teams are trying to hit a bull's eye target.
4. Accuracy launch, where the teams try to knock over pylons.

## IMPLEMENTATION OF THE PROJECTS

After the introduction of the project to the class, the students were quite excited about the project. A large number of different and unique ideas and

designs were presented to the teams for consideration. Although students were often disappointed at not getting elected project manager for their team, they were all soon working together towards building the team design.

One of the main problems with teaching CNC machining using CAM software is that students get the impression that what the CAM software shows will work perfectly on the milling machine. Although EdgeCAM does perform well at generating G-code, it does not evaluate the cutting strategy (if any) employed by the students. For example, students often cut parts out of the stock material before cutting the details in the interior of the parts. The verification animation in EdgeCAM would show this sequence of cuts, however, it does not show the part breaking free, leaving the student the impression that their machining code was sound. Other problems included students not choosing the correct post processor to generate their G-code and forgetting where they specified the part zero.

Before being allowed to machine their parts, each team was taught how to set up the CNC milling machines. The demonstration includes mounting the stock material onto the machining bed and specifying the part zero. Emergency stops on the machines were also discussed, as were proper safety procedures. Use of eye protection was also strictly enforced.

Although the MDF board can be cut with quite intricate details, students often designed details that were extremely thin and delicate. After the first machining session, students were more realistic about what could be cut. They also began thinking seriously about cutting strategies, both to reduce errors in the cutting order and also reducing the amount of time required to machine their

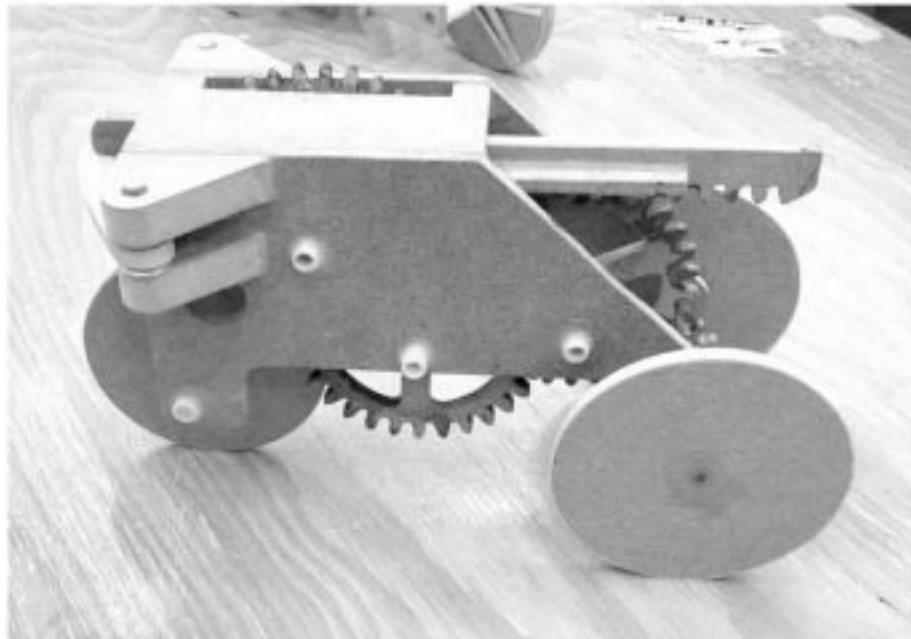


Fig. 3. Picture of completed mini-car.

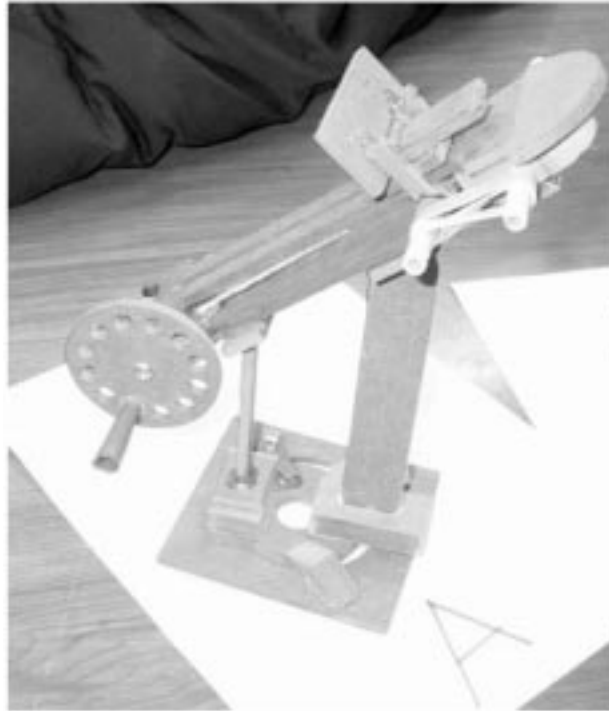


Fig. 4. Picture of completed catapult.

parts. A picture of one of the student team's completed cars is shown in Fig. 3 and a picture of one of the student team's completed catapults is shown in Fig. 4.

A two-hour period was used to stage the competition. For the mini-car project one of the universities' gymnasiums was booked. Lanes were set up for the drag race, as well as tables for the design competition and tug-of-war. A special uphill obstacle course was built out of plywood, to test the car's  $4 \times 4$  climbing abilities. For the catapult project, space was cleared in one of the bigger labs in the department. Targets were laid out for the students to aim. Records were made in all of the different competitions and points awarded to the teams.

#### ASSESSMENT OF THE OBJECTIVES

In order to assess the effectiveness of the project in meeting with the objectives the students were surveyed at the end of the term. The first 12 questions on the survey allowed students to rank the validity of each question from a scale of 1 to 5, where 1 was strongly agree, and 5 representing strongly disagree. The 12 questions were grouped into three main questions, addressing the objectives of Design, Teamwork and General engineering application. As well there was space for three written answers. Table 2 outlines the questions that were asked in the questionnaire and the results of the survey.

As can be seen by Table 2, the response on the

Table 2. Results of the questionnaire.

	Strongly agree (%)	Agree (%)	No opinion (%)	Disagree (%)	Strongly disagree (%)
1. The project was effective in applying theory taught in class.	33	62	5	0	0
2. The project also allowed me to apply theory from other classes.	15	75	10	0	0
3. The project taught me about design and my design skills.	19	67	14	0	0
4. My design skills have improved because of this project.	19	52	29	0	0
5. The project has helped me to learn how to work in a team.	29	57	14	0	0
6. My ideas and concerns were taken seriously by the team.	30	50	20	0	0
7. The project helped me communicate better with other team members.	40	25	35	0	0
8. The project allowed me to meet and get to know other students better.	50	30	20	0	0
9. My interest for engineering has grown as a result of this project.	35	45	20	0	0
10. I found project to be satisfying and challenging.	40	45	15	0	0
11. I spent more time on the project than I could really afford.	5	55	25	15	0
12. This project is an effective way to teach CNC machining.	65	20	15	0	0

project was quite positive. On the four design questions, the average response rating was 1.9, which is slightly above 'agree'. It should be noted that on the question, 'The project was effective in applying theory taught in class' rated an average of 1.7, with 33% of the students strongly agreeing. On the teamwork questions, the average rating of the four questions rated an average of 1.9, which again, is slightly above 'agree'. It should be noted that the distribution of the answers was slightly wider in this section than in the design section. One surprising result was seen on the eighth question: 'The project allowed me to meet and get to know other students better.' There was an overwhelming response as 50% of the students rated that question as 'strongly agree'. Although this was the second year these students have been together, evidently they have not had very much of an opportunity to work together. In the general section, 80% strongly agreed or agreed that their 'interest for engineering has grown'. 85% of students either strongly agreed or agreed that they 'found the project to be satisfying and challenging' and that this 'was an effective way to teach CNC machining'. On the amount of time students spent on the project, 60% thought they 'spent more time that they could afford,' whereas 40% disagreed or had no-opinion. This indicates that an area for improvement might be allowing for more lab time to complete the project.

These results reinforce the success of the project in meeting its objectives. Written comments on Question 13 'What problems did you experience?' were mostly about communication and misunderstanding problems between specific team members. On Question 14 'What would you do differently?' most students respond that they would spend more time planning the machining sequence. On Question 15 'What would you change with this project to make it better?' the most popular answer was to

make the groups smaller and increase the number of milling machines and access to them.

## CONCLUSIONS AND RECOMMENDATIONS

It is often hard to get students excited about the curriculum. The mini-car and catapult projects overcame this problem and have far exceeded expectations, not only in reinforcing classroom theory, but also in having students applying ideas from different areas of engineering into their design. Discussions with other professors in the department have revealed that students have been talking to them to discuss design possibilities. At the competition, not only were students from the course attending, but students from other years.

This project has been run for both the fall and winter terms over the past two years. Comments from the students and faculty have been very positive and constructive. Improvements have been made to the project in response to the student's comments. In the fall of 2002, three more desktop CNC machines were added to the lab. This should allow for smaller student teams (about 5–6 students/team) and more active involvement of all the students in the team. As well, the computer lab has been upgraded with faster PCs and with the latest version of MasterCAM 9.0. A specific post-processor, custom written for the control software used here at Ryerson was a part of the new software installation. This should allow for fewer problems, both in software issues and compatibility problems in the CNC lab.

*Acknowledgements*—I would like to thank Mr. Devin Ostrom, P. Eng., Technical Officer in the Dept. of Mechanical Engineering, Ryerson University for all his patience and perseverance in running the CNC lab during these student projects.

## REFERENCES

1. J. E. Stice, Using Kolb's learning cycle to improve student learning, *ASEE Engineering Education*, 77(5) Feb. 1987, pp. 291–296.
2. R. M. Felder and L. K. Silverman, Learning and teaching styles in engineering education, *ASEE Engineering Education*, 78(7) Apr. 1988, pp. 674–681.
3. G. P. Waldheim, Understanding how students understand: a prerequisite to planning effective teaching-learning methods, *ASEE Engineering Education*, 77(5) Feb. 1987, pp. 306–308.
4. R. Felder, Matters of style, *ASEE Prism*, Dec. 1996, pp. 18–23.
5. C. L. Dym and P. Little, *Engineering Design: A Project-Based Introduction*, John Wiley and Sons, Inc., New York (2000).
6. A. C. Hansen, P. K. Kalita, P. W. L. Lyne and L. E. Bode, Introducing engineering design concepts with a micro steam car project, *Proc. ASEE Annual Conf. Exposition*, Session 2208, Montreal, Canada (June 16–19, 2002).
7. M. E. Hacker and T. M. West, Teaching manufacturing engineers how to optimize technical and personnel systems: closing the competency gaps in manufacturing education, *Proc. SME Int. Conf. Education in Manufacturing*, ER98–335, San Diego, USA, (Oct. 14–16, 1998).
8. R. L. Mott and J. A. Houdeshell, Addressing competency gaps in manufacturing education, *Proc. SME Int. Conf. Education in Manufacturing*, San Diego, Oct. 14–16, 1998, ER98–326.
9. T. Cebeci, Broadening the manufacturing practitioner's education, *SME Manufacturing Engineering*, 130(1) Jan. 2003, pp. 16–17.
10. R. Radharamanan, Multidisciplinary design experience in engineering education, *Conf. Proc. INTERTECH 2002*, Santos, Brazil, Mar. 17–20, 2002.

11. J. Farris, J. Ray, First Year engineering product realization, *Conf. Proc. NCIIA 6th Annual Meeting 'Beyond Boundaries'*, Arlington, VA, Mar. 14–16, 2001.
12. G. P. Neff *et al.*, Using a multi-course project to integrate CAE, CADD, and CAD/CAM, *Proc. ASEE North Central Section*, Apr. 7–9, 1994.
13. J. Ray and J. Farris, Integration of design and manufacturing processes in first-year engineering curriculums, *Conf. Proc. 30th ASEE/IEEE Frontiers in Education*, Kansas City, MO, Oct. 18–21, 2000.

**Vincent H. Chan** is an Associate Professor in the Department of Mechanical & Industrial Engineering at Ryerson Polytechnic University, in Toronto, Ontario, Canada. He received his B.Sc. from the University of Waterloo, a M.Sc. Degree from Queen's University at Kingston, and a Ph.D. from the University of Victoria. He has worked as a design engineer for Omni Tool Ltd. in Windsor, Ontario, Canada and is presently performing research in the areas of machine vision and advanced manufacturing.