Design and Manufacturing for Mechanical Engineering Education Using Hand-made Electric Vehicles

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Abstract

This paper describes engineering education achievements performed by 4th year synthesis class. Since its inauguration in April 1997 the Kochi University of Technology has overseen nine years of engineering education and the objectives of the synthesis class are based on this experience. Knowledge of design and manufacturing is considered to be as important as the basic sciences of mathematics and physics for mechanical engineering, and laboratory experience provides an active learning opportunity alongside classroom learning. As a capstone learning course, student teams in our laboratory have designed and manufactured hand-made electric vehicles. This project provides useful information to consider the future design and the production process of EV. Their experiences are reported here.

Keywords

electric vehicle, engineering education, 3D-CAD, ABET, capstone design

1. INTRODUCTION

The Kochi University of Technology was opened in April, 1997 and since then has delivered up-to-date engineering education such as first year seminars using real products [Sakamot et al. 1999], computer assisted English education [Greene, 1998; Hunter, 1998], and so on. In this report we describe a laboratory activities carried out by the mechanical engineering 4th year synthesis class.

Two extracurricular (out of class and no credit) events [Sakamoto, 2001] provided the catalyst for the capstone projects. The first was the Eco-power Race. In November 1997, the Kochi Eco-power Race organized by Toyota Vista Kochi was held in Kochi, and three teams from the Kochi University of Technology participated. The second event was the Electric Vehicle Rally. In August, 1998, the Shikoku Electric Vehicle Rally, organized by a committee of high school teachers and university educators was conducted in Shikoku, the smallest main island of Japan. Since then our laboratory has encouraged the design and manufacture of electric vehicles and robots as a capstone project.

Electric vehicles are being developed and sold in small numbers now, but at the present time they are far from perfect. They can not run very far, they need to be recharged frequently which requires a long time, batteries are heavy and expensive, and so on. However in the near future fuel cell vehicles will become commercialized which will make gasoline-powered vehicles less common. Against this background the students in the laboratory began to design and manufacture hand-made small-sized electric vehicles capable of short-range running as a capstone project course in their 4th year. The vehicles chosen were electric two-wheeler and three-wheeler motorcycles and a robot designed as a planet probe vehicle.

The students selected their target inventions and discussed their project aims, content, ideas, and schedule, then designed and finally manufactured their vehicle or robot. This report outlines the results.

2. DESIGN EDUCATION FRIOR TO CAPSTONE PROJECTS

In order to prepare capstone projects for the 4th year students in the laboratory, we have design courses in our department in the followings. The first is a preliminary design lecture for 1st year students, which is a simple 3D-CAD, CG, and computer literacy course. In the 2nd year, the department has system design I (lecture of drawing), and system design II (lecture of machine elements), and a general CAD/CAM/CAE lecture. In the 3rd year, we have three design courses. The first is a design exercise for an assembly of a manual winch, which one of the authors is responsible. The second is the other exercises by the other faculties. The exercises consist of a machining machine and a factory robot. The third is in each faculty' hand, since the design course is conducted by students who start to join in each faculty' laboratory after the latter half of the 3rd year.

Therefore, the one of the authors is responsible in a de-

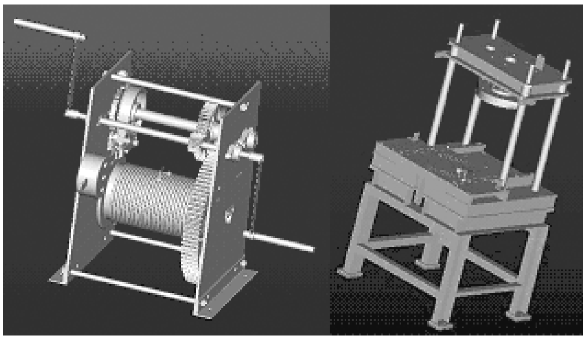

Fig. 1 Assembly design examples for 3rd year students (Left: manual winch, right: bearing setting tool)

sign exercise of a manual winch as a class lesson and of a special design lesson in our laboratory. The special design lesson we selected in 2005 is a bearing setting tool. Figure 1 shows the manual winch for a class lesson and a bearing setting tool for our laboratory lesson. Both consist of about 40 parts, and students need to make the 3D-CAD drawings as well as assembly drawings. Since one of the authors thinks that the first design action comes to create an image for products and the image is highly important, the design capability depends on how they can make the image. 3D-CAD lessons will assist the capability. The next step for capstone design and manufacturing for 4th grade students is how they can plan a product they aim. Obtaining the aimed product, they design and manufacture, and this lesson will lead a practice to manufacture or develop a product in the real industrial society. The followings are the examples for design and manufacturing by students as future engineers. Since students have learned design and manufacturing in their 1st-3rd years, the aim for capstone projects is for each student to consider and perform their project by themselves.

3. ELECTRIC MOTORCYCLE

A brief explanation of design and manufacture of the electric motorcycle follows because this report intends education and not development. As 3D-CAD exercise before the design starts, the manual winch [Design of Manual Winch, 1991; Creative Design Education Committee, 1998] was selected and proceeded.

3.1 Design of electric motorcycle

The size of the motorcycle is determined in the same manner as for the electric automobile [Sakamoto et al., 2001], which needs to be transported when batteries are dead or after an accident. If the vehicles are to be carried they should be no larger than 1,900 mm long and 1,200 mm wide, and the size chosen was similar to a gasoline-powered bicycle. Figure 2 shows the concept of the planned motorcycle which was developed using 3D-CAD software ProEngineer. The stress analysis for the main frame was performed using ProMechanica, and is shown in Figure 3.

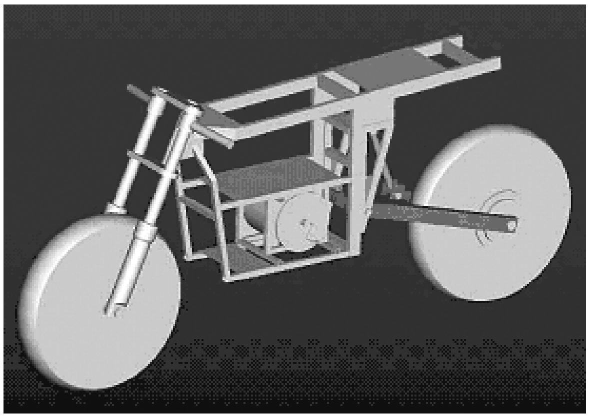

Fig. 2 3D-CAD image of the hand-made electric motorcycle

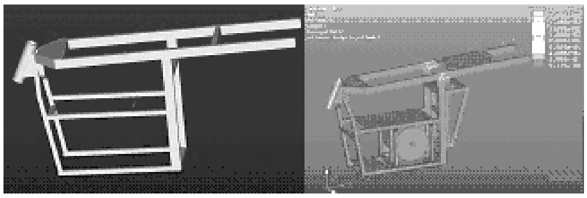

Fig. 3 Stress analysis of main frame

3.2 Manufacture of electric motorcycle

After the design was finished the motorcycle was manufactured. The welding equipment was available for use in our laboratory, and the motorcycle was produced mainly by welding. Figure 4 shows the appearance of the welded frame and the finished motorcycle.

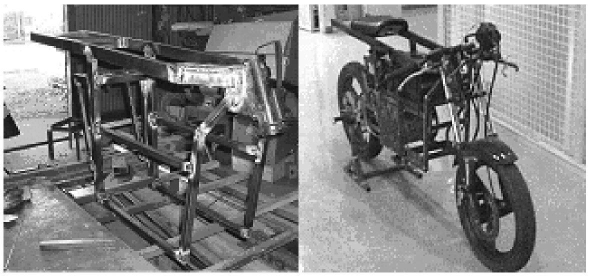

Fig. 4 Motorcycle welding and assembly

3.3 Running experiment

After the design and manufacture was completed the vehicle was test-run on a road that is 300m length and runs around a 1-story building on campus. The vehicles were run for 40 laps to give a total distance traveled of 12,000m. The items measured were the maximum speed obtained, voltage and battery temperature during continuous running. Lithium-ion batteries were used in the motorcycle. One lithium-ion battery contains four cells where one cell acts as a BMU (battery management unit) to control the voltage. The measured minimum voltage during the test was 42.6V against the permissible minimum voltage of not be less than 32.4V. Figure 5 shows the voltage reduction of one of the four batteries during the continuous running experiment. Figure 6 shows the increase in temperature during the experiment. 25°C was the maximum temperature measured for the batteries which is well below the permissible maximum temperature of 65°C. There were no problems with the batteries for the duration of the experiment, and the total distance able to be covered before recharging was estimated to be 20km. The motorcycle speed is controlled by the throttle, and the maximum velocity obtained was 23km/h (6.4m/s). This was slightly under an estimated maximum velocity of 25km/h (6.9m/s), but considering the friction between tire and road this was not a bad result.

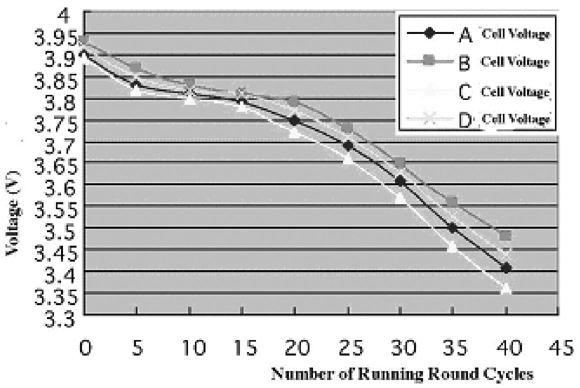

Fig. 5 Voltage against number of laps for battery No.2

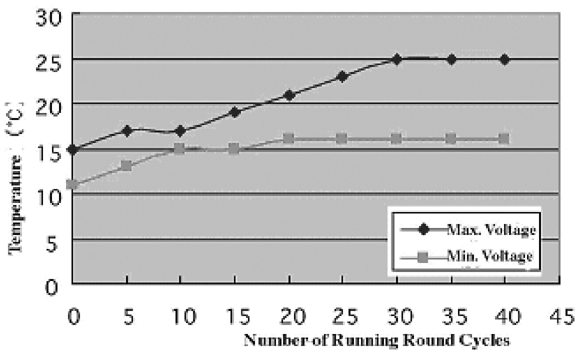

Fig. 6 Temperature of batteries against number of laps

4. MOTOR-ASSISTED TRICYCLE

In the Society of Electric Vehicle in Japan (SEV), there is a committee as the Association of Renewable Energy and Electric Vehicle, (AREEV) (http://www.areev.org). The committee developed the four-wheeled electric vehicle [Home page of AREEV] shown on the left of Figure 7. The vehicle has a good reputation, and many schools have purchased it as an educational tool. However, we thought that it might be hard to drive because of the low seat and the location of the pedal. Taking this stance we modified the vehicle as shown on the right of Figure 7. The seat was raised to about 1,000mm from 400mm above the wheel base. The wheel base width of 830mm was modified to 560mm, to enable it to run on pavements (if regulations permit). However, after the search of traffic regulations we found that the four wheeled vehicles cannot run on pavements or roads used by bicycles.

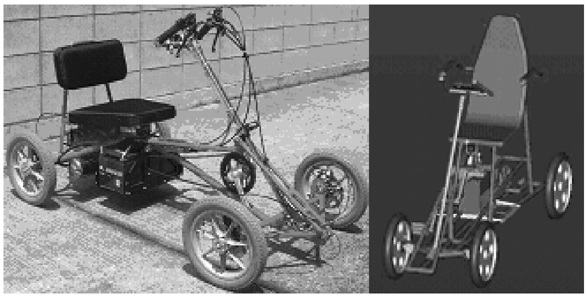

Fig. 7 Four-wheels electric vehicle by SEV and modified vehicle by students

4.1 Target and design of motor-assisted tricycle

After the survey of the traffic regulations and discussion in the laboratory we decided the target for development should be a motor-assisted tricycle incorporate the following considerations:

(1) A bicycle with motive power can not be registered as a light weight vehicle and cannot run on pavements regardless of the traffic sign on the pavement.
(2) The light-weight vehicle with motive power such as a bicycle or even a mini-car are not permitted to run on the roads for conventional bicycles. Even in if the batteries are dead, the vehicle must have lights on.
(3) The traffic law in Japan states that light weight vehicles such as bicycles have to run on bicycle pavements or the roadway as described in Item 17 of Chapter 1. Using a bicycle on the roadway can be dangerous, if the roadway is not wide enough. Most roadways in the country-side and local areas are narrow and bicycles on the roadway is unsafe in such areas.
(4) The same law prohibits vehicles less than 4 wheels to run on roadways. Therefore, the aimed vehicle needs to be 2 or 3 wheels and able to run on pavements for bicycles.
(5) For elderly people to use the vehicles, we need to consider one that doesn't require licenses and runs at a low speed.

Using this criteria, the motor-assisted tricycle was designed using ProEngineer. Based on the specification and rough drawings, the 3D-CAD image was made. The left side of Figure 8 shows the first version of 3D-CAD. By using the 3D-CAD software, the dimensions and configuration was cleared. The rear frame configuration and the location of the battery needed to be changed. The seat was to be reconsidered because the vehicle size is outside the limitation. The handle angle adjustment was found not to be necessary because the vehicle size is smaller than expected. The design which takes elderly drivers into consideration is shown on the right of Figure 8. After the first version of 3D-CAD was completed the modification was accepted. The design and manufacture was conducted by the cooperation of Daioh Machinery Co. in Kochi and the Kochi University of Technology. About forty parts were designed, excluding those from Daioh Machinery Co.

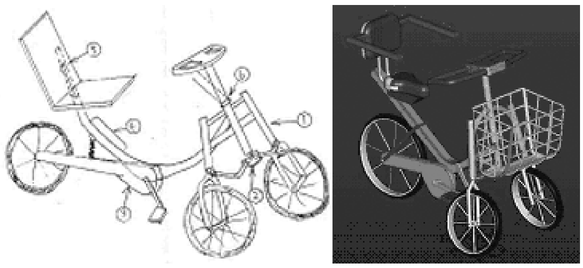

Fig. 8 Image and design of motor-assisted tricycle

4.2 Manufacture of motor-assisted tricycle

After the final design was decided the 3D-CAD was completed for the rear portion. The front portion of the vehicle was purchased from Avantec Co. The whole assembly (without the purchased front section) is shown as a 3D-CAD assembly in Figure 8. We put a different backrest on the seat. Twenty-three parts in total were designed. Figure 9 shows the fabricated tricycle.

Fig. 9 Fabricated motor-assisted tricycle

4.3 Control for motor-only drive

To enable the dual-function of motor-only driving under 6km/h and motor-assisted driving in the range of 6-25km/h, we needed to add a control function for motor-only drive. This requirement came from was a request from the police when we asked about the possibility of allowing motor-assisted tricycles on pavements. The police requested that the vehicle should be able to run at a low speed (less than 6km/h) by motor-only when driving on pavements. The motor-assisted drive is provided by the motor unit purchased from a trading company in Kochi. Therefore, we needed to consider a special control device for the motor-only drive. We also needed to consider the explicit switching device for changing the function between motor-only driving and motor-assisted driving.

According to the specifications in the catalog received from the manufacturer, the motor characteristics are as follows. The motor itself is brush-less DC, 240W of power, motor-assisted drive control is by pedal force proportional method. The battery is lithium-ion or lithium-hydrogen with 24-26V and 2.8-3.6A. The motor unit consists of torque sensor, microprocessor, and the brush-less DC motor. In order to add the function of motor-only drive to the motor for the motor-assisted tricycle, we decided to use a wire for the signal in the torque sensor. Firstly we needed to be able to switch from motor-assisted drive to motor-only drive and added a button beside the start switch. The button was placed here to stop the vehicle from running immediately after switching. Using a wire of torque sensor signal, we made a H8 microprocessor (AKI-H8/3048F) circuit. Since this circuit is only used for the experiment of motor-only drive it was hand made.

The circuit contains a LED for displaying power-on, the switch to change between motor-only and motor-assist drive, a button for the motor-only drive start, and a control circuit. A battery of 9.6V and 600mA for the H8 microprocessor is used. After we confirmed the circuit action we added a relay to control by H8 processor. The experimental set-up and the final manufactured circuit is shown in Figure 10.

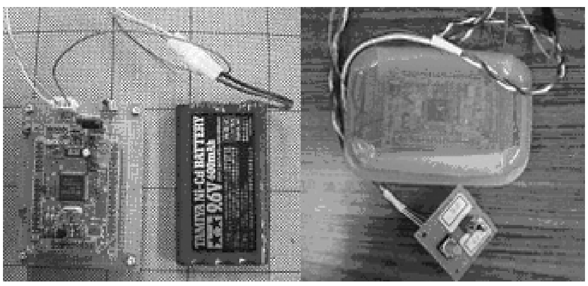

Fig. 10 Experimental set-up and circuit

5. PLANET PROBE ROBOT

5.1 Target and design of planet probe robot

Planet probe vehicles must be able to move over a relatively smooth surface and climb over rough terrain. When on a fairly smooth surface it needs to move quickly, but on rough terrain it needs to climb and move at low speeds. Figure 11 shows possible planet surface conditions. In order to design the vehicle capable of moving in each type of surface condition two motor functions are needed.

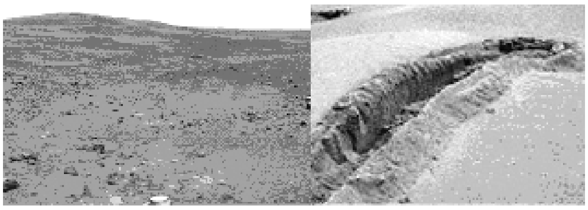

Fig. 11 Surface conditions on planets

For designing such a vehicle for the two functions, the student considered the system shown in Figure 12. However, the vehicle needs to solve a lot of issues and at the first stage of development the student started to design the vehicle which runs on wheels as shown in Figure 13. The function of climbing will be planned in the second step. ProEngineer software was used to design the wheel-running vehicle. Figure 14 shows the assembly and the result of stress analysis for the main frame using ProMechanica.

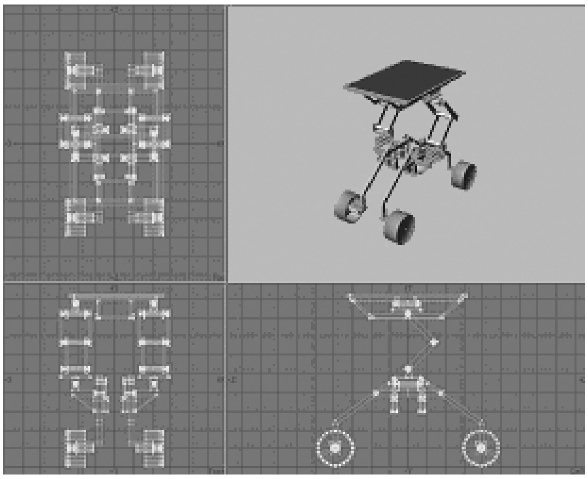

Fig. 12 Image of vehicle for wheel and gear movements

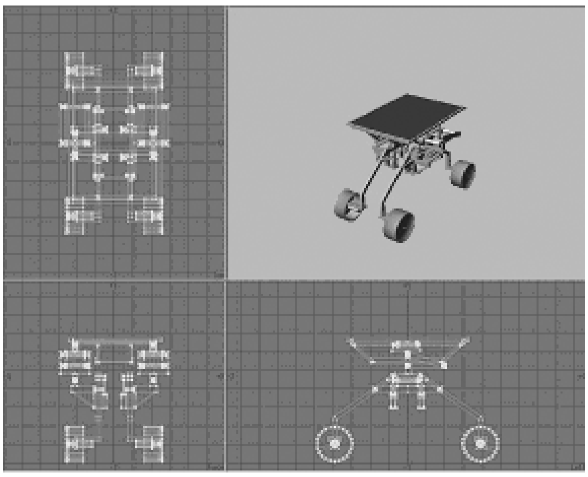

Fig. 13 CG image for wheel running in first stage

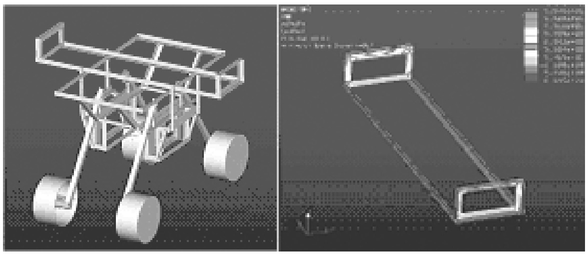

Fig. 14 Assembly of wheel running vehicle and stress analysis

5.2 Manufacture and experiment of planet probe robot

After the design was completed, a trial of manufacture and assembly was begun. A solar panel of 126W and 24V output was used. Figure 15 shows the assembly with the solar panel on board. The target for the first test run was to move up a slope of 50mm high and to climb a 50mm high obstacle. This experiment was successfully completed.

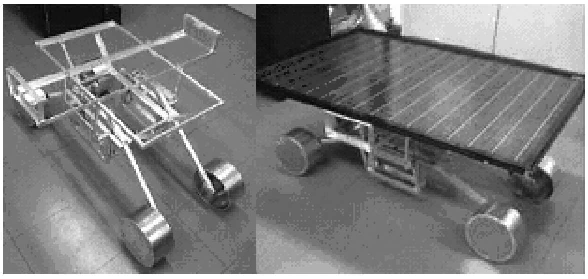

Fig. 15 Assembled vehicle

6. DISCUSSION

6.1 Capstone design and manufacturing project

As a project for 4th year students, manufacturing as well as design skill was required. And practical experience of manufacturing is of great importance in mechanical engineering. It was up to the students themselves to work out the theme and target vehicle. One view is that the project outcome should not be constrained by those in the research field as the faculty discipline is normally only in a small area of the academic research. The project should be aimed at the real world.

The students who selected the projects of a hand-made small-sized electric motorcycle, motor-assisted tricycle, and a for planet probe vehicle, all demonstrated design and manufacturing skill as well as knowledge of automobile technology and vehicle assembly. The faculty played the role of supporter as it does not teach automobile technology. The students needed to locate the related parts and materials and to learn how to design and manufacture certain parts themselves. The students needed to negotiate with the people from the welding shop and parts makers.

Although the completed vehicles were not exactly what they intended (the weight, power, and control still needed modification) the students succeeded in producing a real product. The project theme was considered to be an appropriate form of study for 4th year students in mechanical engineering.

6.2 Team work

The project for the motor-assisted tricycle was completed by a team of three seniors but the other two projects (electric motorcycle and vehicle for planet probe) were completed by the individuals. The students for the electric motorcycle performed the design, manufacture, and experiment including the welding for the main frame. The two individual students are considered to have performed their intended design and manufacture, even though they produced one vehicle that was not perfect. However, the team of three students is not considered to be even contribution for three students. This is the issue that how the team work should be inside the team. The instructor should not distribute the work. Instead, each member of the team needs to consider.

6.3 ABET (Accreditation Board for Engineering and Technology) Requirements for Academic Engineering Program

The Accrediting Engineering Program [ABET, 2000] states the criteria for accreditation is that engineering programs must demonstrate that their graduates have in the following,

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs
(d) an ability to function on multi-disciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global/social context
(i) a recognition of the need for and an ability to engage life-long learning
(j) a knowledge of contemporary issues
(k) and an ability to use techniques, skills, and modern engineering tools necessary for engineering practice

From the capstone projects, students can learn some of the above requirements. Also, both students and engineering professionals need to learn about and experience related issues such as economics and management. The issue is determining how this can be done. Although it is considered that design is the synthesis of engineering [Fargason, 1995], we need continue to consider in the future.

7. CONCLUDING REMARKS

One of the authors thinks that 1st-3rd undergraduate years are educational ones by mainly faculties, and 4th year is the one for them to educate themselves by having faculties support. In such a sense, capstone projects are the learning opportunity for them to learn the synthetic engineering from their ideas. As a capstone project, the 4th year students were challenged to design and manufacture a hand-made small-sized electric motorcycle, motor-assisted tricycle, and a vehicle for planet probe with the following results.

(1)The hand-made electric motorcycle, motor-assisted tricycle, and a vehicle for planet probe were completed although some technical issues such weight, speed, and control still need to be addressed.

(2)As a project, each team considered their theme and target. The faculty was a supporter for this project from the viewpoints of funding and suggestions. The teams completed the vehicles by themselves.

(3)The project theme aimed at manufacturing as well as design. In the design process computer graphics were effective for the group discussion. Although the design detail was not sufficient for manufacturing due to students' inexperience in design ability, the team obtained experience on how to produce a product with their own drawings.

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References

American Board of Engineering and Technology, *Accrediting Engineering Program*, 2000.

Creative Design Education Committee, *Machine Design*,

1998.
Design of Manual Winch, *Technical Education Committee*, Power, 1991.
Fargason, E. S, translated by Fujiwara and Sunada, *Gijutsusha no Shingan*, Heibon, 1995.
Greene, D., "LATCH: a syllabus design for EFL instruction in CALL" in Computer Assisted Language Learning, *Lisse*, Vol. 11, No. 4, 381-396, 1998.
Home page of the Association of Renewable Energy and Electric Vehicle, (AREEV) in Japanese, http://www.areev.org.
Hunter, L., "Text nouveau: visible structure in text presentation" in Computer Assisted Language Learning, *Lisse*, Vol. 11,No. 4, 363-379, 1998.
Sakamoto, H., Extracurricular Education and Experimental Course Using Electric Vehicles, *Proceedings of American Society of Engineering Education Annual Conference*, Session 2302, 2001.
Sakamoto, H., K. Kusukawa, and Jorgensen, Mechanical Engineering Education for 1st Year Seminar Using Real Products, Proceedings of *American Society of Mechanical Engineering*, DE-Vol.102, 13-17, 1999.
Sakamoto, H., T. Uchino, T. Kaino, T. Sawada, and M. Yokoyama, Capstone Design and Manufacture of Hand-Made Small-Sized Electric Vehicle, *Proceedings of American Society of Mechanical Engineering*, IDECE, DETC2001/IED-21220, 2001.

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