Construction of ecocars and windturbine cars following the CDIO principle

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Abstract

This paper describes the process of active learning in connection with the construction of concept cars by the students at the Technical University of Denmark (DTU). The concept of the ecocars is to develop a car where the top priority is energy efficient solutions in order to make the car run as far as possible on one litre of gasoline energy equivalent. In parallel the idea of the wind turbine cars is to design-build vehicles for driving directly against the wind, powered by a wind turbine. The projects are applied in an elective course for bachelor students with approximately 2 years of experience. However, students are also associated from other student activities like bachelor and master projects. In order to carry over know-how from previous years, which is essential to the success of the whole process, some "older" students are encouraged to participate in the activities for more than one year. This also gives the students a possibility to evaluate new ideas that was generated during testing and operation of the developed cars.

The projects is carried out over 2 semesters (1 year) for the ecocar and 1 semester for the wind turbine car giving a basis for a detailed comparison between two projects containing similar teaching elements although with different origin. Both projects contains all 4 elements of the CDIO[1] principle in one teaching project, i.e. conceiving the engineering elements of the cars, the design-build phase and finalizing at internationally organized races with the cars. The project has been running repeatedly for 6 years and has been implemented more and more smoothly in the teaching program at DTU. The organization of the projects is a very essential task for a successful outcome and a very important learning process in itself. Experiences from the projects will be compared and described in details in the paper focusing on the development and evaluation of the teaching and active learning processes observed over the years.

1. Introduction

Future engineers are expected to work in a very dynamic environment where facts will change, be questioned and discussed. The education of engineers will therefore have to change according to these trends and focus more on the necessary competences in this environment. More specific communication and collaboration are strongly needed skills. Traditional teaching in engineering has been organized primarily as one-way communication, where the students are mainly passively following the teacher's speech. This is indeed very sensible and applicable for basic courses in mathematics, physics etc. with many students. In this type of courses predefined exercises or problem solving in smaller groups is typically an additional option for the students. Finally, assessment has usually been based on a written exam. These type of courses are, however, rather uninspiring for late years students and do not appeal at all to many students. Education in fairly narrow fields as in typical courses trains skill towards analysis aspects of problems rather than synthesis, which real engineering typically is about (Gustafsson[2]). Using CDIO in design-build projects opens to multi disciplinary aspect engineering, however, a good setup for a design-build project has to be well prepared since it does require a large number of factors to be taken into account which traditional courses generally not include (Malmqvist et al.[3]). In the Internal Combustion Engine Group (ICEG) we have implemented CDIO[4] course activities in order to address the above mentioned remarks.

In the following the two CDIO activities are described individually. Later on the experiences from the activities are compared and evaluated.

2. Ecocars

The course is running over 2 semesters (1 year). The activities contain all 4 elements of the CDIO principle in one teaching project, i.e. conceiving the engineering elements of the cars, the design-build phase and finalizing at internationally organized races with the cars. The project has been running repeatedly for 6 years and has been implemented more and more smoothly in the teaching programme at DTU. The organization of the projects is a very essential task for a successful outcome and a very important learning process in itself.

The general course objectives are: To let the students work on practical construction tasks, based on theory. The idea is to construct a fuel economic vehicle. This vehicle should be able to participate in an international university competition like "The Shell Eco-Marathon".

The learning objectives of the course are defined as:

A student who has met the objectives of the course will be able to:

- Work creatively with a given problem
- Design a functional solution based on a theoretical idea
- Carry out an overall energy evaluation of a vehicle
- Carry out an analysis of the existing knowledge about a certain topic
- Apply engineering measurement principles as an assisting tool.
- Put up a working plan for the practical carrying-out of an engineering problem

- Work responsible in a team
- Write a technical report

CDIO activities

In the following text the different elements of the CDIO principle is described in relation to the activities. An overview of typical overall process elements is given in Table 1.

Conceive

The basic idea is to have an inspiring goal to work towards. Therefore, a car is chosen as the goal, since this is a product we can all relate to in our daily life. This is predefined from the start and cannot be influenced by the students. Some basic ideas about the concept, in order to improve the performance of the car are retrieved from experiences the previous year and cannot either be influenced by the “new” students. These ideas are, however, a product of the overall learning process that the “old” student have undergone and carries over to the new team. With these predefinitions of the product the students start to conceive their own ideas which are discussed and evaluated before the next step.

Design

Based on the ideas generated, the project is organized in smaller groups where the students are discussing the design of the individual parts of the car. This process is followed by production of, f. ex., drawings for a certain part of the car. It could also be setting up specifications for a calculation tool, needed for simulation of the energy consumption for the vehicle at variable conditions.

Implementation

After receiving the vehicle part from the workshop the students are supposed to build the vehicles from the individual parts, which could be engine, frame, wheels, carbon fiber body, electronic control system etc. This requires strict collaboration between the individual groups and an early agreement on the time schedule (Gantt Schedule) for the whole project. The individual components and part systems, like the drive train, are tested before integration in the vehicle.

Operate

After assembling of the car the product is tested, in the end at an international fuel economy race (Shell Eco Marathon).

The students

The “team” consists of students with skills from all over the university. The most represented expertise comes from the mechanical engineering department, the electronic engineering department and the design engineering department.

Element	Example: Ethanol car
Conceive	• Overall concept (not optional) • Selection of o Engine type o Transmission type o Steering principle o Body design (roughly) o Materials
Design	• Engine design • Engine operation • Engine control system • Aerodynamic design • Individual part drawings • Proper dimensions of vehicle • Energy analysis of vehicle
Implement	• Gantt schedule • Testing of component function • Testing of integrated subsystems • Assembling of vehicle
Operate	• Operation and evaluation of the vehicle in an international competition

Table 1. Overview of the individual CDIO elements.

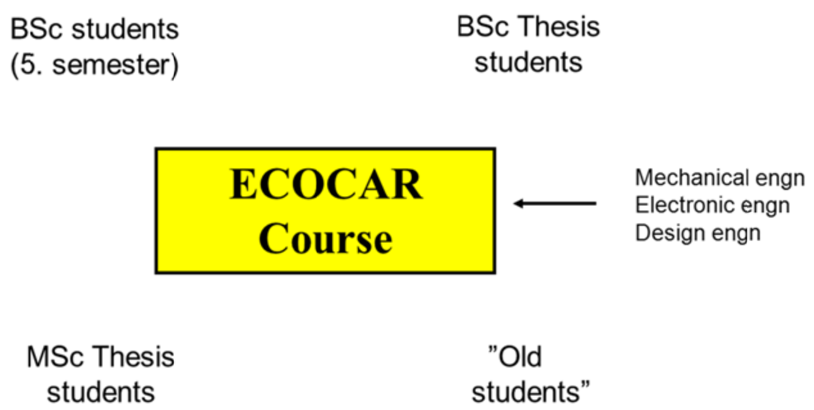

Figure 1. Overview of the students participating in the ecocar activities.

The kernel element in the teaching project is a 10 ECTS point course which runs over two semesters, i.e. 1 year in total. The participants of this course are the new students that have not participated before. Some of the students decide to carry out their bachelor or master project later, or they sign up for an individual project course of 5-10 ECTS points to follow up on ideas they have obtained during their previous participation. This is a strong feature because in this way know-how is transferred from the previous years, making the activities more and more advanced.

An overview of the students are given in Figure 1.

Organization

The project is organized like shown in Figure 2.

As mentioned earlier the overall concept is defined by the supervisors and the old students. In this way the know-how from previous years is used to secure a proper definition of the frames of the teaching project. This prevents the project from running into problems that can be foreseen, and put forward a realistic goal that can be achieved with the available manpower.

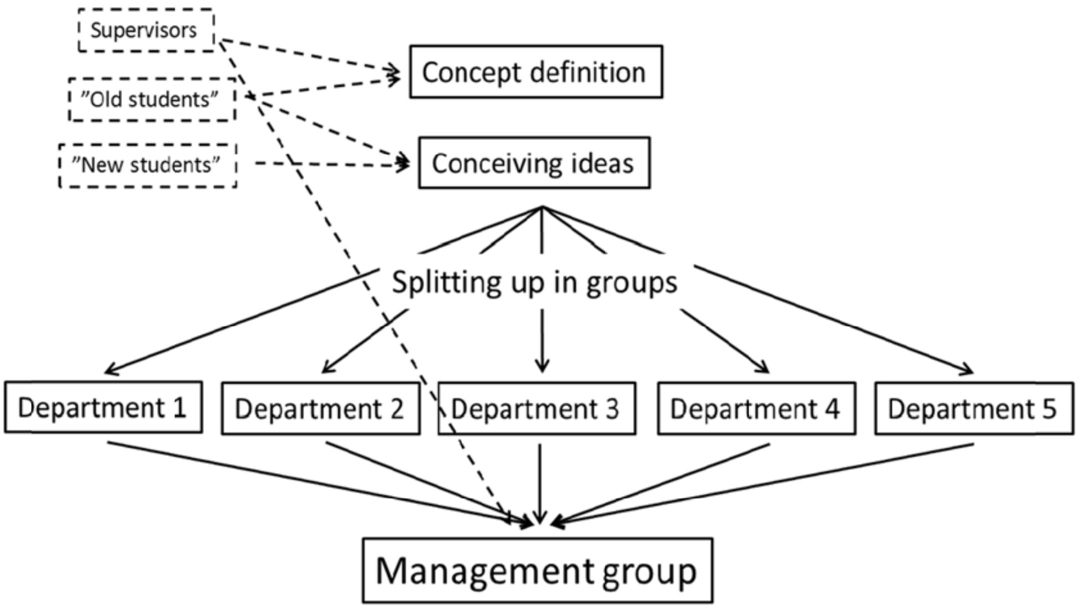

Figure 2. Organization of the ecocar activities.

Once a more detailed plan of the ideas for the new car has been established by the students, a split up into different working groups is decided. From now on the work is carried out like in a small production company, where the groups are similar to different departments in the company. The departments elect a candidate to be the representative in a management group which will take care of the progress of the project on behalf of the “company” from now on.

Evaluation

The evaluation of the project is done in two ways. If the students have actually produced a car, this is seen as a successful outcome, because this is an evidence of completion of the practical work, setting up a realistic goal and good teamwork.

The second evaluation is based on a questionnaire that the students have to fill in at the end of the course. This evaluates the outcome of qualifications for the students.

Product

The first evaluation is based on whether the car is finished in time to the public presentation or not, at the public presentation, which is held at the end of the second semester, the car should be able to move around at a moderate speed and show satisfactory driveability with respect to starting, steering, braking, low emissions etc. This evaluation has been fulfilled satisfactorily in 6 out of 7 events. This is a clear measure of responsibility and commitment from the students.

The second evaluation is based on the actual measured performance of the car at the fuel economy race – Shell Eco Marathon. The evaluation is based on three criteria’s: innovation, ranking in race, actual fuel economy. An example of the evaluation scheme for the prototype car “DTU Innovator” is seen in Table 2.

Year	Innovation	Ranking in Shell Eco Marathon	Fuel consumption
2004	New concept • New frame and body • New alternative fuel • New combustion engine based drive train	69.	571 km/l
2005	New engine developed New frame and body	No result	No result
2006		No result	No result
2007	New concept • New fuel cell based drive train • New frame and body Telemetric system developed	14.	1633 km/l
2008	New body New technique for body production Miscellaneous improvements on fuel cell	8.	2328 km/l
2009	New body Aerodynamic measurements Miscellaneous improvements on fuel cell	2.	3549 km/l
2010	Optimization of vehicle in general	No result	No result

Table 2. Evaluation scheme for the prototype car “DTU Innovator”

Generally the students challenge themselves with new innovations every year to the outmost satisfaction. These challenges are results of ideas from the students of the previous year and a clear measure of engagement and commitment.

The results are clearly improving over the years with respect to both ranking and fuel economy. This is a product of the learning process from every year. In 2010 the result was disappointing and a result of too few “old students” to carry over experiences from previous years. This resulted in technical problems, but primarily in a bad timing of work from the different groups. In the end, due to lack of time, the car was not tested properly ahead of the competition, so a lot of unexpected problems occurred at the race.

Student qualifications

The students had to fill in a questionnaire at the end of the course. There were to major questions to be answered:

- Have you learned much during the course? (learning)
- Do you think the course is good? (CDIO form)

The first question gives an answer to the quality of the learning process, and the second gives an answer to the CDIO teaching form. In order to compare the CDIO teaching form with other traditional teaching forms, the answers from this course are compared with answers to these questions from 2 other courses, as shown in Figure 3-4. The other two courses are typically taken by the same kind of students with respect to semester no. and interests. Course 1 is the present course, course 2 is a course including lectures and problems solving in classroom and course 3 is a course including lectures and exercises in laboratory. The answers are ranking from 1 (completely disagree) to 5 (completely agree).

From the results it is seen that the learning process is improved in the CDIO course and particularly the students like the CDIO form of teaching better.

3. Wind turbine cars

In parallel to the ecocars the wind energy group at has considered ways to practically activate students in engineering aspect of wind turbine design. Modern wind turbines today are very large machines and keeping a realistic level of complexity is found in a design-build project making a wind turbine car of limited size that carries a person against the wind. The teaching project may easily contain all 4 elements of the CDIO principle, since at first the student needs to conceive that it is actually possible and next, to design, build and race with the cars.

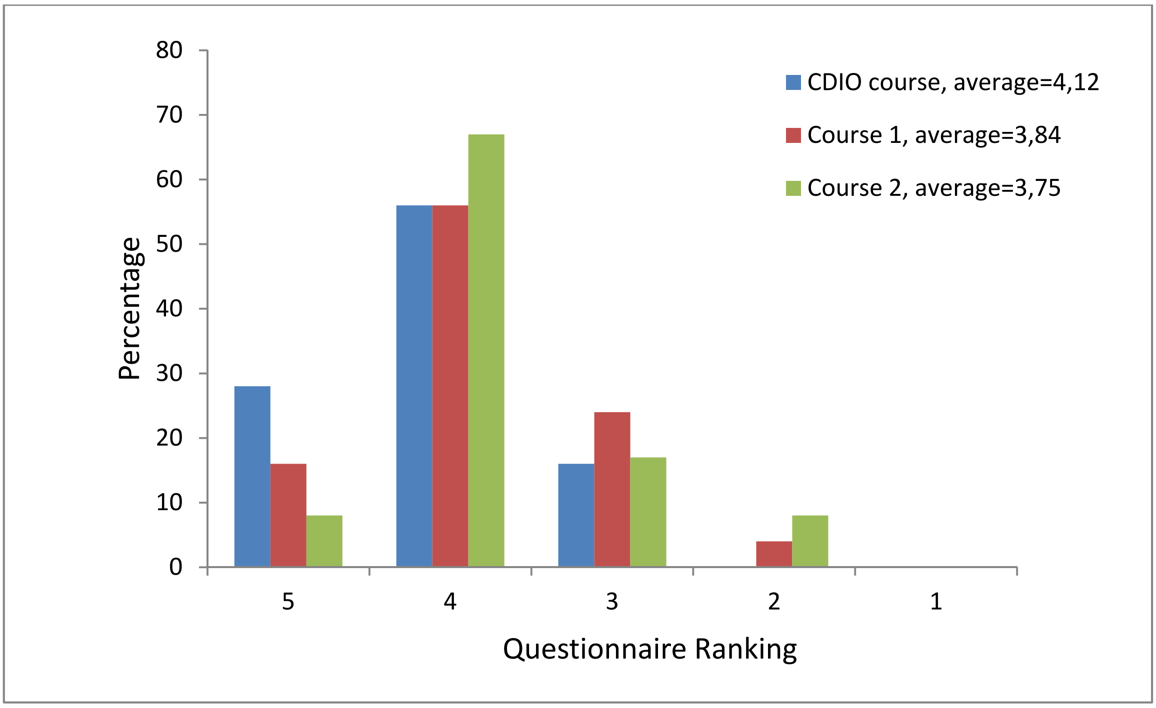

Figure 3. Ranking of learning process during the course

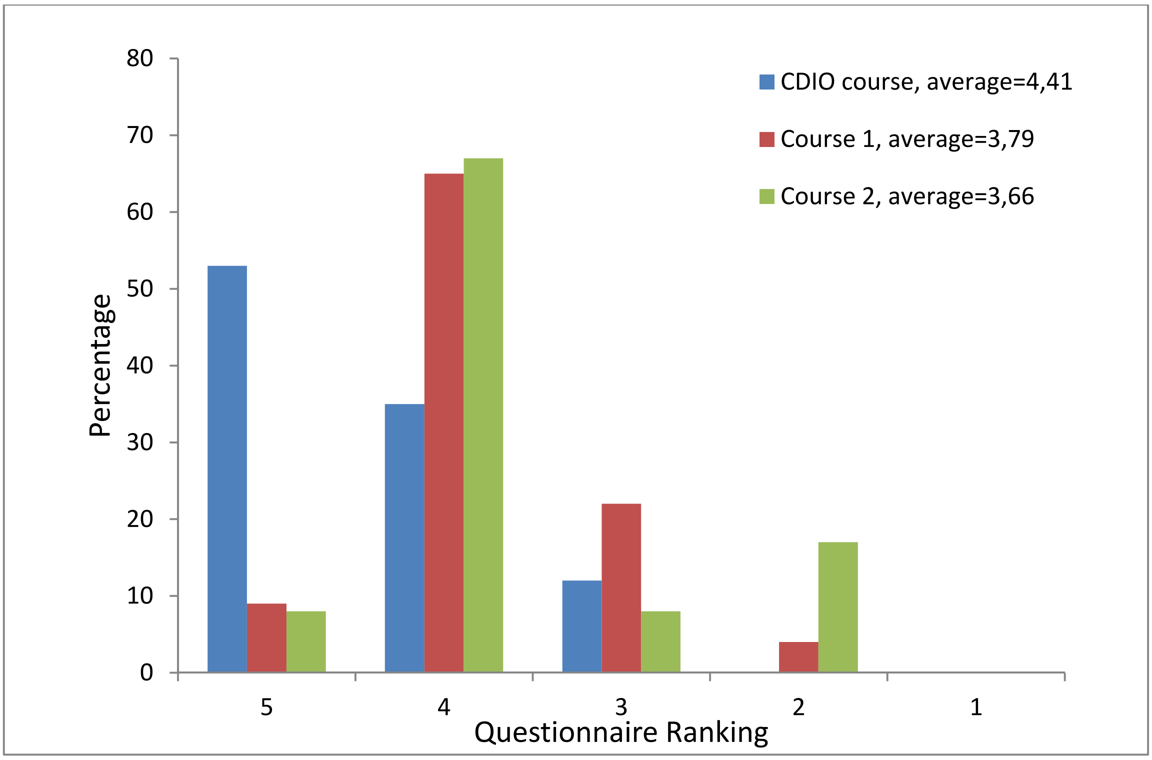

Figure 4. Ranking of teaching form during the course

Implementation

As parts are produced in the workshop the shape and functionality of the vehicle becomes clearer. Typically some elements have to be redesigned / remade in an iterative manner or may event not be possible to produce. This strengthens interaction with the workshop and their experienced knowledge on feasible solutions. The assembled car requires windy conditions for testing which may not be trivial to find. Low winds are nearly always present nearby and the main functionally (turning of rotor, transmission, etc.) can be tested at these conditions. Real racing conditions (straight road into the wind, airstrip) may be challenging to find nearby.

Operate

The assembled wind turbine car races at international event (Wind Turbine Race, Aeolus Race) as match races for a given distance between competitors.

Element	Example: Wind turbine car

Conceive	• Overall concept (not optional)
	  o Turbine type
	  o Mechanical transmission
	• Selection of
	  o Transmission type
	  o Suspension, steering
	  o Control aspect

Design	• Rotor blade design • Shroud design • Control, blade pitch, rotor yaw • Upper, lower transmission • Individual part drawings
Implement	• Gantt schedule • Testing of component function • Testing of integrated subsystems • Assembling of vehicle
Operate	• Operation and evaluation of the vehicle in an international competition

Table 3. Individual CDIO elements of wind turbine car project

The students

Mainly student from the mechanical engineering department and the design engineering department participate in the project, receiving 10 ECTS credits during one (spring) semester, i.e. ½ year in total. The students are typically 4th semester, generally categorized as with very limited 'design-build' experience. The transfer of knowledge to each new team of students is conducted through lectures, access to previous team reports and the wind cars themselves. Previously participating students have so far not been included as a resource.

Project success

As for the ecocar, having an operational wind car ready for presentation is the first part of a successful project. Next, the parameters evaluated at the wind car race, are on innovation, ranking and max windcar/windspeed ratio. Table 2 sums up the merits of the winDTUbineracer projects through 2008-2010.

Year	Innovation	Ranking	Speed ratio
2008	New concept • New frame and body • New rotor • New drive train	2.	53%
2009	• New suspension • New rotor • New body	2 and 3	42%
2010	• New shroud • New pitch hub • New transmission	5 and 7	43%

Table 4. Evaluation scheme for the winDTUbineracer

The table shows an overall trend of decreasing results over the years. This is, however, not entirely fair to the later participating windcars. The success of the event is completely dependent on the windy condition on location and the 2009-2010 events was, unfortunately, struck by very low winds (<6m/s) during the three days of competition. This was not to the advantages of the chosen design outline.

Timing

The timing of the project has been a challenge for the windcar. The continuation of the project from start until race event has suffered from the course period (Feb-Jun) ending prior to the event (Aug-Sep) with students engaging themselves in new activities/travel abroad after the summer vacation. This effect has reduced some student's willingness to see the project through and to some degree influenced the final evaluation of the project.

4. Discussion and conclusions

The ecocar and windcar projects shear similar CDIO elements as students have to conceive the functionality of the concept cars, design-build a new vehicle and operate it at international races. The parallel projects have although clear difference e.g.

- Two semesters vs. one semester
- Transfer of knowledge through older students to new ones
- Volume
- Organization

The first three elements are all related to the differences in the volume of the projects. The ecocar project has been running for more years and has furthermore been set up as a larger project from the start. Therefore, it is possible to have a more dedicated education plan within the topic. This seems to be important for the students. The project becomes more visible and attracts more students. The increased volume of students naturally leads to a strong demand for a strict organization, which is a very important learning process and close to real life, working in a company as an educated engineer.

The ecocar project has been most successful, both with regard to results obtained, and in attracting and satisfying the students. This is obviously a result of the larger aim from the start. The evaluation of the activities from the students has shown positive feedback regarding the learning process and the teaching form in both cases. Even though only the ecocar project has been evaluated in a questionnaire, it is the authors feeling that the student in both cases appreciate both of the new teaching activities.

5. References

[1] http://www.cdio.org/framework-benefits/cdio-syllabus

[2] Gustafsson G. Experiences from the transformation of an engineering education introductory project design course into a project design-build-test course. 2004.

[3] Malmquist J, Young PW, Hallstrøm S, Kuttenkeuler J, Svensson T. Lessons learned from design-build-test-based projects. 2004.

[4] The CDIO Syllabus: A comparative study of expected student proficiency. Bankel J, Berggren KF, Blom K,Crawley EF, I, Östlund S. 2002.