

# ECO-CAR: A PERFECT VEHICLE FOR TECHNICAL DESIGN TEACHING?

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## ABSTRACT

Design methods and tools are generally best learned and developed experientially [1]. Finding appropriate vehicles for delivering these to students is becoming increasingly challenging, especially when considering only those that will enthuse, intrigue and inspire. This paper traces the development of different eco-car design and build projects which competed in the Shell Eco-Marathon. The cars provided opportunities for experiential learning through a formal learning cycle of CDIO (Conceive, Design, Implement, Operate) or the more traditional understand, explore, create, validate, with both teams developing a functional finished prototype. Lessons learned were applied through the design of a third and fourth eco-car using experimental techniques with bio-composites, combining the knowledge of fibre reinforced composite materials and adhesives with the plywood construction techniques of the two teams. The paper discusses the importance of applying materials and techniques to a real world problem. It will also explore how eco-car and comparing traditional materials and construction techniques with high tech composite materials is an ideal teaching, learning and assessment vehicle for technical design techniques.

*Keywords: CDIO, curriculum alignment, collaborative working, experiential learning*

## 1 INTRODUCTION

The Shell Eco-Marathon, now organised by Shell Global Solutions, dates from 1939 when Shell employees made a wager over who could travel furthest on the same amount of fuel [2]. Since then it has expanded to three continents, includes energy types ranging from biofuels to electricity, and sparks debate around the future of energy and mobility. Technical and practical skills developed through design and engineering undergraduate courses are applied to create ultra-energy efficient cars in the Shell eco marathon competition - with some reaching 10000mpg. It is an ideal learning vehicle around which students can showcase their analytical skills, engineering theory, design and materials knowledge by applying them to a sustainable design problem. A TLA strategy has been developed so that students can take full advantage of this project (Figure 1).

## 2 ECO-PRO

Eco-Pro was designed in 2010 by two Mechanical Engineering Design students using a traditional 'final year project' format - the culmination of taught theory, put into practice by completing an engineering challenge. Eco-Pro was entered into the energy efficient prototype category of the Shell eco marathon, as such, it was designed with a 23.5kg carbon fibre and paper honeycomb monocoque chassis, 35cc four stroke Honda engine and a weight of 42kg. It was developed using a 1/10 scale model through wind tunnel test and computational fluid dynamics (CFD) modeling, the  $C_d$  of 0.16 at the top speed of  $10\text{ms}^{-1}$ . The vehicle achieved 900mpg in initial trials and then over 1000mpg when fitted with covers and a redesigned exhaust manifold. Fuel efficiency was achieved through a combination of CFD and FEA analysis, and lightweight materials. The strategy for reducing fuel consumption was to reduce the power required to propel the vehicle, through light weight, low friction and aerodynamics, and to produce the power more efficiently.

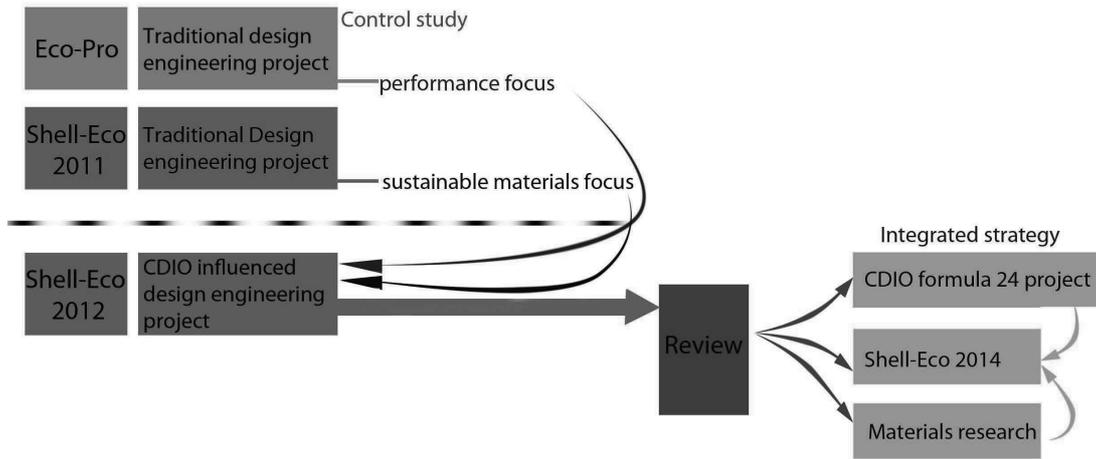


Figure 1. Teaching and learning strategy proposed for the eco-car project



Figure 2. Establishment 1 - Eco-Pro (without covers, showing driver and engine)

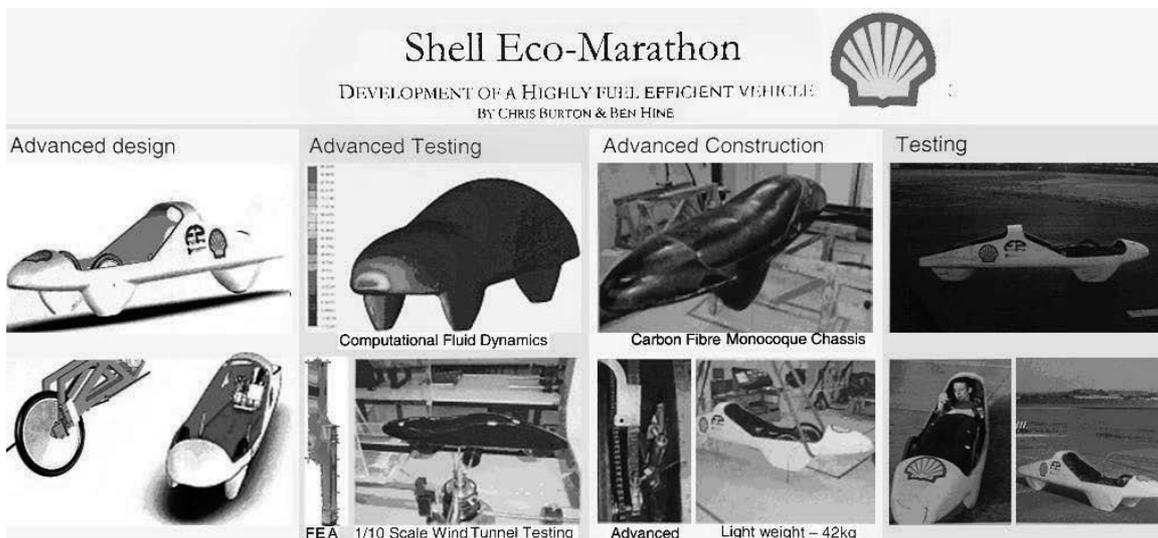


Figure 3. Eco-Pro promo poster showing stages of design, construction and testing

### 3 SHELL URBAN CONCEPT CAR

Vehicle two was designed in 2011 by a team of final year BSc Product and Automotive Design and BEng Mechanical Engineering students at establishment two and was powered by a hydrogen fuel cell. This car competed in the Shell Urban Concept category, offering a vision of a more sustainable city car. Students worked on a single aspect of the vehicle, gradually applying collaborative co-design techniques, reflecting and analysing, and developing into a cohesive team.



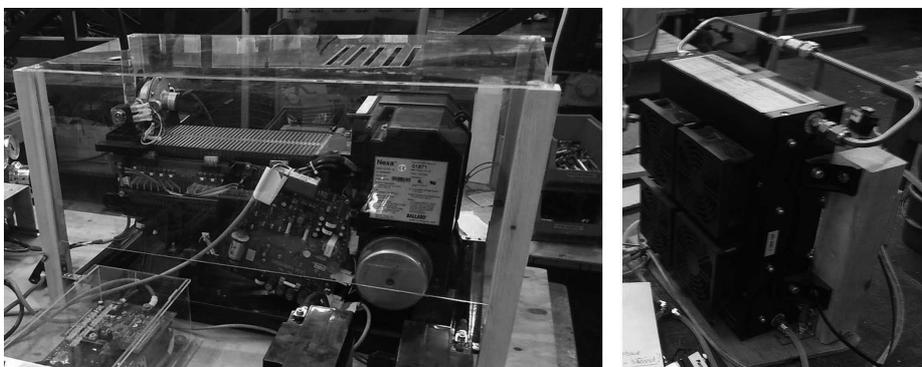
*Figure 4. Eco marathon sustainable city car with hydrogen fuel cell 2011*

In 2012, the project developed further with a team encouraged to utilise a learning approach based on the CDIO principles developed in 2000 by MIT (Figure 10) and saw the team develop a plywood chassis using cardboard composite and wood panels for a more sustainable structure. For continuity, a similar concept to the 2011 car was used for 2012. Instead of each student focus on separate individual projects, a cohesive project management approach was taken, encouraging team members to collaborate - sharing ideas and discussing problems amongst the group. This cohesive approach led to significant improvements in the design and materials used, with a more technically advanced flat-pack chassis which was commended by judges. Students' learning and comprehension was far greater using the shared and collaborative learning strategy, and the results were greatly improved - team went on to win the Shell Eco Design Award in Rotterdam 2012 [3].



*Figure 5. Shell Eco Marathon car 2012, and competition prize giving event*

Establishment 2 has since invested in a new, more advanced hydrogen fuel cell. The original fuel cell used in the 2011 car is used as a bench testing unit for educating students on this emerging and rapidly developing technology. This provides students with relevant practical knowledge, then challenges them to apply what they have learned to a real engineering problem using the latest technologies, with the later fuel cell showing great improvements in size, weight and efficiency.



*Figure 6. 1KW Original 2011 Ballard Nexa fuel cell set up for bench testing (left), smaller and more efficient 1KW Horizon fuel cell set up for the Shell car 2014 (right)*

The successful development of the Shell project has influenced the strategy for the design and engineering school's undergraduate CDIO program and also with the individual course strategies.

#### **4 DEVELOPMENT OF LEARNING - CDIO**

The teaching and learning principles developed across the two initial case studies have been applied to the undergraduate learning experience. A distinctive element of the previous Shell and Eco-Pro projects was the team composition, being made up of both engineering and design students. This has been introduced in a three month, first year undergraduate project. Mixed teams of BEng Mechanical Engineering and BSc Product and Automotive Design students work together to design and build components for Formula 24 electric cars. The design challenge has allows students some freedom whilst also providing a structure to ensure teams can cope with the challenge at this level. Students are introduced to practical skills of manufacturing and assembly with a standard front suspension design for each car. This facilitates students' understanding and interpretation of engineering drawings, which then they take into the machine shop and make, again and integrating connecting theory with practice to broaden and deepen their learning [4].



*Figure 7. Formula 24 First year CDIO design & make project, construction 2013*

This challenge gives students a standard rear subsection to ensure some consistency and to allow teams to concentrate on the design and manufacture of their own main chassis. CDIO encourages teams to develop their own solutions and either wood or steel were permitted chassis materials, all with specific cost constraints to bring a realistic parameter to the work. Teams were encouraged to experiment and take risks while considering the issues of weight, strength and sustainable design.



*Figure 8. Formula 24 First year project, final testing and timed race event 2014*

Teams tested the cars in the final week of the module and were awarded marks for cost, design, construction and assembly. Feedback from students showed excellent engagement in the project with students enjoying the combination of theory and applied practical experimentation. The skills developed through CDIO projects such as this will feed into the Shell project in their final year, allowing the students to build on previous knowledge while also challenging them further.

#### **5 PEDAGOGY APPROACH – EXPERIENCING THE CDIO CYCLE**

The CDIO initiative aims to provide students with an education that stresses engineering fundamentals set in the context of Conceiving - Designing - Implementing - Operating real world systems and products. CDIO has 12 published standards which prescribe improvements in 4 areas:

- Increase in active and hands-on learning (programme philosophy, standard 1)
- Emphasis on problem formulation (curriculum development, standards 2, 3 and 4)

- Emphasis on concept learning (design-build experiences and workspaces, standards 5 and 6, and new methods of teaching and learning, standards 7 and 8)
- Enhancement of learning feedback mechanisms (assessment & evaluation, standards 11 and 12) (the remaining standards 9 and 10 provide guidance on faculty development).

These standards therefore cover all 3 of the major processes in education – curriculum, pedagogy and assessment. By addressing these simultaneously, and aligning in support of each other, the CDIO concept promotes the notion that learning activities can be crafted to support explicit pre-professional behaviours [5]. By applying CDIO through eco-car, ie a motivational and aspiration activity which encompassing technical aspects, a successful learning vehicle has been established.

## 6 CONCLUSIONS AND FURTHER WORK

The Eco-Pro and Shell Eco Marathon cars show the potential for large, complex group based practical projects in a students' learning. They could be seen as collaborative major projects at a final year degree level, or as part of a compulsory postgraduate group module. Their complexity and level of sophistication is clearly demonstrated with the final vehicles, both being advanced and well developed prototype vehicles. On reflection, the project contained a number of features that made a huge impact on the teaching and learning from the students' and staff perspective:

- The mixed teams of engineers and designers proved very favourable in a sharing of knowledge within the group and breaking down the boundaries between disciplines, a co-design approach.
- The practical nature of the learning allowed a broadening and deepening understanding of theory, seen through the application of principles in an enjoyable and cooperative environment.
- The projects themselves became effective learning vehicles to explain engineering and material principles, in particular sustainability, material selection, and technical issues such as fuel cells.
- The Shell competition presents an opportunity for final year students to take part in a high profile realistic project, relevant to the many and various challenges they will face in industry.

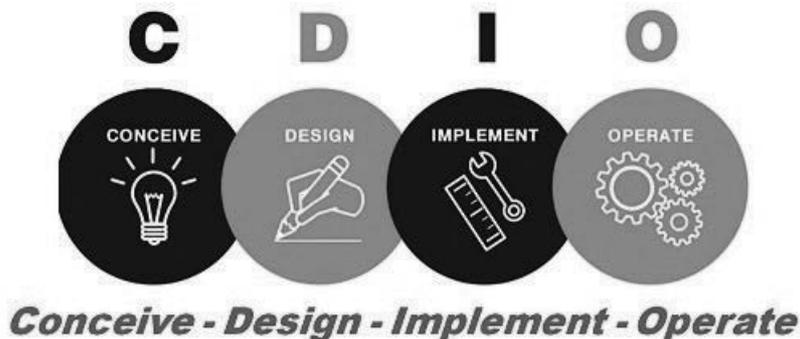


Figure 9. The CDIO engineering education principle [6]

The CDIO initiative was developed with input from academics, industry, engineers, and students. It is universally adaptable for engineering schools and is being adopted by a growing number of engineering educational institutions around the world. CDIO is currently in use in aerospace, applied physics, electrical engineering, and mechanical engineering departments, and a growing number of design courses. CDIO is based on a premise that engineering graduates should be able to: Conceive - Design - Implement - Operate complex value-added engineering systems in a team based engineering environment to create systems and products. The goals are to educate students to master a *deeper working knowledge* of the technical fundamentals; to educate engineers to lead in the *creation and operation* of new products and systems; and to educate future researchers to understand the importance and *strategic value* of their work; students report very positive results.

Project outcomes were disseminated through delivery of a first year module using the CDIO model. Feedback shows a positive experience for students with increased confidence about the manufacturing process, team working and the link between design process and final outcome. The planning and coordination of first year learning is critical for success - while final year students can at times be expected to be self sufficient, first year students need a much more structured learning journey. Detailed planning is required, with careful consideration of the learning aims and objectives to ensure

the balance of challenge and achievable practice are met [7]. It is this alignment of curriculum, pedagogy and assessment that the CDIO programme appears to help.

The 2014 Shell Eco Marathon team were the first students to have completed a CDIO programme. While the current team are still working towards final competition, observation can be made when comparing the team to previous years. Initial observations at the time of writing show that:

1. Students show greater initiative in tackling problems, and look for deeper understanding of technical issues such as fuel cell technologies, complex manufacturing and materials issues
2. Practical workshop abilities, materials handling and understanding have greatly improved, as have a desire to experience and resolve issues first hand, and in a cooperative, timely manner
3. Sketching, sketch modelling and informal impromptu design reviews and crits are used to communicate among the team much more than with previous cohorts or non CDIO groups
4. Problems and set backs are met with a positive desire to overcome and a 'can do' attitude.

The impact of the CDIO programme on student progression into the workplace is a key indicator of success, and a reason for implementation into programmes [8]. Several students working on the current car have secured jobs in prestigious companies before graduation, such as Siemens and Dyson. Anecdotal evidence suggests that the CDIO programme was of great interest to the employers, indeed many now run practical assessment design and make type challenges, very like short open brief CDIO projects. All noted their contribution on the Shell team as a benefit in their job success, through a general increase in self confidence, efficacy, and sense of achievement.

By focusing on curriculum, pedagogy and assessment simultaneously, and aligning these together by providing a stimulating learning opportunity, the CDIO approach has provided the students with improved competency in professional skills such as problem solving, critical thinking and interpersonal communication skills. It has also promoted the emergence of a cooperative learning environment for the achievement of learning outcomes, which was certainly aided by the use of the eco-car model as an aspirational subject matter, a perfect learning vehicle.

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