Implement and Operate in Civil Engineering CDIO

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Abstract

This paper will describe an exciting new initiative in the UK focusing on "Implement" and "Operate" of CDIO for a **Civil Engineering** programme at the University of Liverpool. Facilitating the experience of carrying out a real civil engineering project poses much more of a challenge than the other engineering disciplines because of the large scale requirements. The Constructionarium provides students with a real-life construction experience, working with a Contractor and a Consultant to build realistically scaled structures.

Students work in teams of 20-24 for a week on a real construction site. Each team works as a "mini-company" and is responsible for planning, costing, understanding drawings, human resources, quality control, procurement, setting out, fabrication and construction, health and safety and many other realistic professional roles required for construction of a real scale civil engineering structure. Examples such as a steel bridge spanning 20m and over 7m tall or a floating concrete oil rig (scale 1:20) are used to provide students with a practical exposure to engineering construction.

The presentation will focus on delivery and assessment of this interactive initiative and on the student perception of the experience. Participants in this session will have the opportunity to provide feedback and experience of their own "I and O" implementation.

Keywords: implement, operate, civil engineering, construction, active learning

Introduction

The guiding principles of CDIO aim to motivate engineering undergraduate students and to help them develop their technical and professional skills within an overarching educational framework of ***active learning***. This can be achieved by encouraging students to become more responsible for their own education rather than allowing them to become passively disconnected in a conventional lecture room environment. Motivation can be achieved by showing them the relevance of their studies to "what engineers do" in a realistic context with direct application to their future profession.

12 CDIO standards [(1)] have been developed in response to stakeholder feedback from industry as to what they seek from new graduate intake. These standards address:

- Curriculum development
- Design-build experiences and workspaces
- New methods of teaching and learning
- Faculty development
- Assessment and evaluation

These standards are implemented by encouraging students to learn about the whole-life development of an engineering solution of a particular problem from conception right through to eventual decommissioning or recycling. The four principal stages in this solution process are characterised by the words: Conceive, Design, Implement and Operate, hence CDIO.

Since the CDIO initiative was launched in 2004 there have been some 27 different University engineering departments worldwide who have adopted the governing aims and principles. The majority of these departments offer professional degree courses in

- Mechanical Engineering,
- Aerospace Engineering,
- Materials Engineering and
- Manufacturing Engineering

Design and build projects in these areas can be relatively straightforward to develop for teaching purposes because of the scale can be kept relatively small and yet remain relevant to projects in the "real world". Examples of these are the Formula Student racing car, Heavy-lift model aircraft, water bike and solar powered model aircraft.

In 2006 the University of Liverpool, Department of Engineering took the bold step to embrace CDIO as part of the ***Liverpool Engineer*** [(2)] initiative right across the full range of engineering disciplines, including Civil Engineering. This causes some practical difficulties with incorporating practical learning of Implement and Operate into the curriculum of a CDIO compliant course. Civil Engineering projects are by their very nature large-scale. It is difficult to incorporate the building and testing of a project such as a dam, a water treatment system, a bridge, a highway scheme, a harbour etc into an undergraduate course at small-scale while still retaining practical relevance to the full size project. While some lessons can be learnt at small-scale, the appreciation of real engineering practicalities can only be realised working with a scale approaching that of a real project in the outside world, Figure 1.

Figure 1 Real life civil engineering projects

This dilemma was addressed by the incorporation of a new construction teaching and learning initiative the "Constructionarium" into the Liverpool Engineer project.

The Constructionarium

The concept of the Constructionarium was first developed [3] by Imperial College in 2003, in conjunction with civil engineering contractor John Doyle Ltd and design consultants Expedition Engineering. The University of Leeds was the second to participate in the Constructionarium in 2005, with the University of Liverpool joining in 2006. There are now some 11 universities in the United Kingdom participating, with several more waiting to join up in 2009.

The Constructionarium is held at the National Construction College in East Anglia, where a 6 hectare site has been specially designed and built to accommodate a series of construction projects, giving a range of challenging learning and teaching conditions. There are a total of 17 work areas incorporating several lakes, a river gorge, a mountainous area and a swamp. Students are involved in a full-time construction project working with a Contractor and a Design Consultant to build a real civil engineering project. Each student team will comprise typically 16-20 members and will make up a mini-company. Students are responsible for

- Planning
- Costing
- Setting out
- Construction
- Health and safety
- a range of other practical and professional skills activities

Each team of students make their own decision regarding allocation of professional roles. A Management Team comprises: *Project Manager, Cost and Planning Manager, Safety Manager, Site Manager, Operational and Portfolio Manager* and *Liaison Officer.* Five of the team would receive training in the use of powered hand tools and these would be the only students permitted to use power tools at any time during the Constructionarium. The role of *Setting-out Engineer* was an important one to ensure that structures were built to the right size, in the right position and with appropriate tolerances.

Constructionarium projects

A range of different construction projects have been developed [4] by the participating universities in conjunction with their collaborating Design Consultant and Contractor. All of these projects are designed to be completed in 4.5 days, with students arriving on site on Monday morning and departing Friday afternoon. These projects exposed students to a range of construction challenges including working in bad ground, working over water, working at height, working with construction plant and so on. The Constructionarium site, Figure 2 has been designed to accommodate the varied project types. Each of the projects represents a scale down version of a real civil engineering structure. The scale is sufficiently large such that realistic construction challenges must be overcome by the students.

Some of the projects currently available are:

- London Gherkin Building
- Millau viaduct
- Ravenspurn concrete gravity oil rig

- East Reef pier
- Barcelona Tower
- Johannesburg Stadium
- Canary Wharf underground station
- Kingsgate Swingbridge
- Brewery Wharf cable stayed bridge

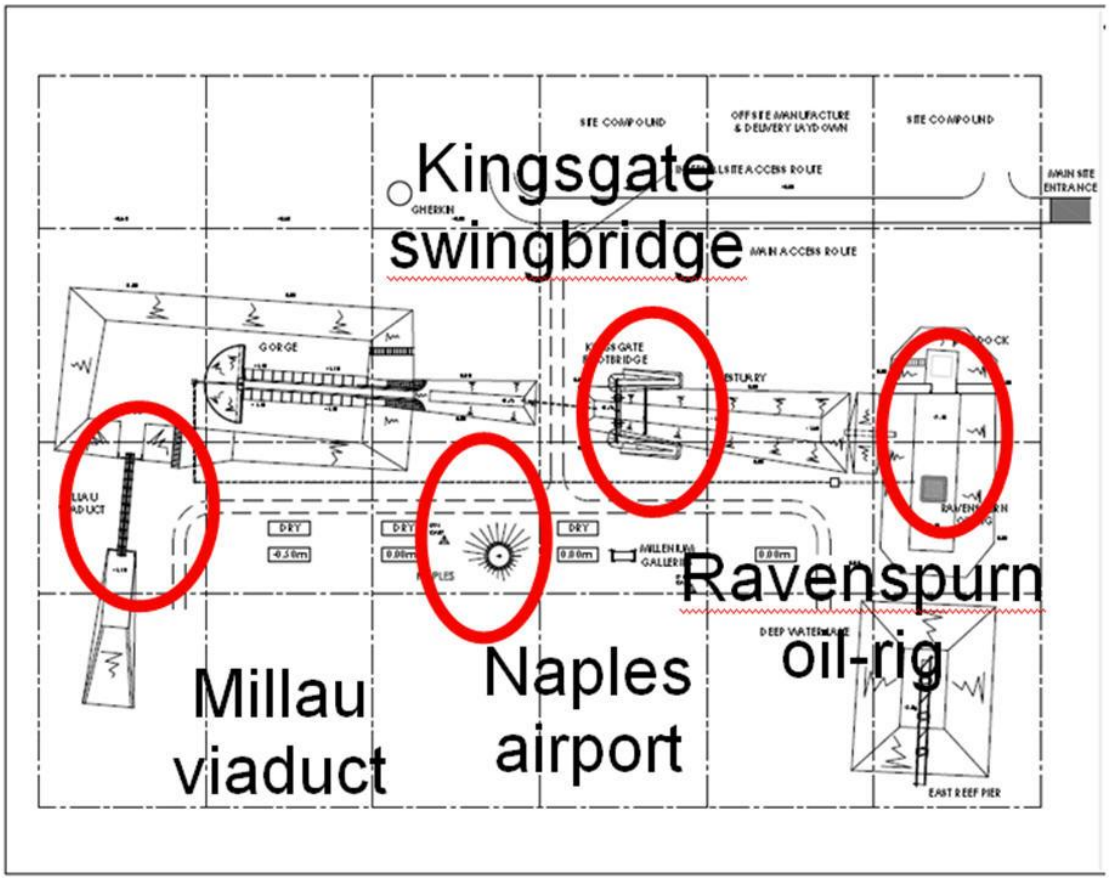

Figure 2 Constructionarium site

Project briefing

Several weeks before the start of the Constructionarium project week, students were introduced to their respective projects and required to allocate project roles within the team. Student team members were carefully preselected to ensure a representative distribution of previous construction experience, academic ability, gender and ethnicity. Each student was required to research their particular project in real life and to prepare a brief pre-Constructionarium report. This report contained details of the project itself, details of the Contractor/Design Consultant/Architect and the project cost and duration. In addition students were required to research how the real-life project was constructed and comment on any special health and safety considerations during its construction.

Students were introduced to the Contractor and Design Consultant team and were given guidance on how construction sites are managed efficiently, within an overarching culture of health and safely. Guidance was also given on project planning and project costing. Each team was required to develop an overall construction plan for the Constructionarium week and each team member drew up a

Method Statement and a Risk Assessment for one particular construction activity from their project.
A student information pack was distributed to students three weeks before the Constructionarium week. This contained project details, site information, examples and blank forms for the Method Statement, Risk Assessment, Weekly Programme, Project Management Plan, etc.

Setting out: Computer aided learning

Setting out was seen as a particular challenge to be addressed. All Civil Engineering students receive training in Surveying, i.e. creating a map from a series of measurements of specific features on the ground using standard surveying equipment. Relatively few civil engineering degree courses focus on setting out, i.e. extracting information from a drawing to locate the position of construction features on the ground. This process has been greatly simplified utilising new digital technology. A ruggedised and waterproof/shockproof Pocket PC computer (Trimble LM 80 Layout Manager) is commercially available to interface with a Total Station, Figure 3. Information can be downloaded from an AutoCAD drawing and uploaded to the LM 80. On site this facility removes the need for hardcopy paper drawings and greatly facilitates use of a Total Station for setting out.

Figure 3 Setting out using LM 80

A computer aided learning package was developed in-house to help students gain experience and knowledge concerning setting up procedures, use of offsets, acceptable tolerances and use of the LM 80. This package focused specifically on the Constructionarium projects which the Liverpool students were allocated. The package had an interactive capability to develop skills in setting out and use of a Total Station mini-prism, Figure 4.

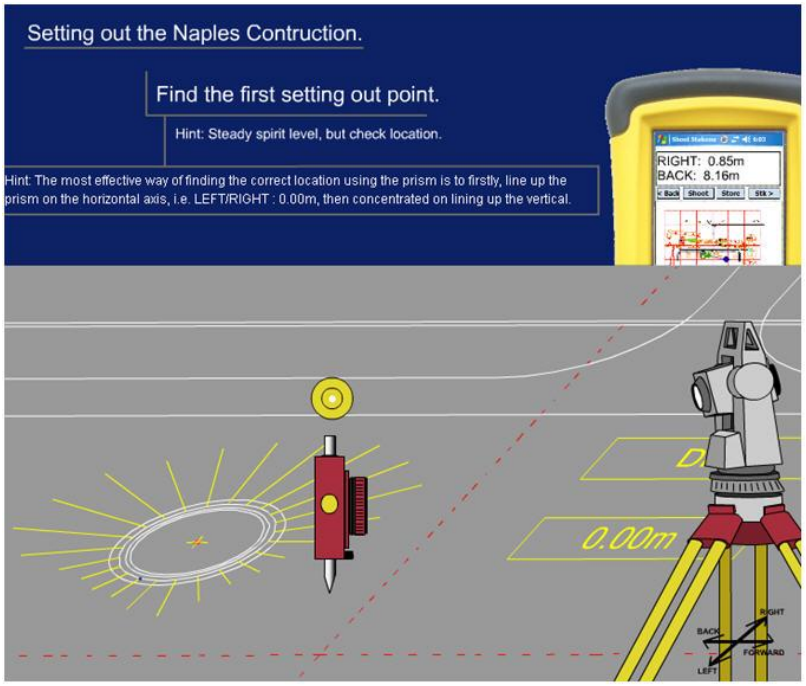

Figure 4 Interactive setting out CAL package

Liverpool 2007 Experiences

In 2007 the University of Liverpool worked with Contractor, Edmund Nuttall Ltd and Design Consultant, Mott MacDonald for their first Constructionarium experience. A total of 82 students were divided into four teams to work on the following projects.

- **Ravenspurn concrete gravity oil rig**: A scaled-down reinforced concrete box, 4m x 4m x 2m is constructed in a dry dock. A steelwork superstructure is erected. The dry dock is flooded and the 20 tonne floating structure is then moved into the lake and sunk in the required position.

- **Naples subway entrance/canopy:** Precast concrete caisson segments are sunk 2m into the ground to create an entrance shaft. A ring of short reinforced concrete circular columns are cast into a ground ring beam. A series of radial timber ribs are erected on these columns and interconnecting steelwork bracing is assembled to make a stressed toriodal canopy.

- **Millau viaduct**: Two reinforced concrete pad foundations and columns are constructed. Cable stayed steelwork bridge sections are then assembled and launched onto the columns to make a 20 m long footbridge.

- **Kingsgate swingbridge**: 2 foundation pads, each incorporating a swivel base plate, are cast into the sides of a lake using temporary cofferdams to hold back the water. Two reinforced concrete bridge deck sections are constructed on to a supporting steel substructure. The deck sections are positioned on to the base plates and the bridge is swung into position.

For each project the Management Team was required to meet with Contractor/Consultant staff and also with academic staff each evening to review progress and discuss plans for the following day. Technical and health and safety

issues were addressed by the contractor/consultant staff. Learning outcomes and other issues were discussed with academic staff.

The weather conditions for March in 2007 were exceptionally good. Rain and cold weather were the expected conditions for this time of year but the weather was very sunny and dry. All of the projects were successfully completed on time, Figure 5.

(a) Ravenspurn oil rig

(b) Kingsgate swingbridge

(c) Naples subway station

(d) Millau viaduct

Figure 5 Completion of 2007 projects.

Liverpool 2008 Experiences

The weather in 2008 was seasonally inclement and some rain/hail was experienced on most days. This caused some motivational challenges and difficulties with working on a muddy site, Figure 7. Due to organisational difficulties, this year's Constructionarium was carried out with a new Contractor, Morrisroe Ltd, but retaining Design Consultant, Mott MacDonald. Due to the lack of continuity it was decided to retain the same projects as the previous year but replacing the Kingsgate swingbridge with a new project:

Brewery Wharf cable stayed bridge: A foundation plinth and a support A-frame are constructed from reinforced concrete. Two reinforced concrete bridge sections are also precast. The A-frame is then erected and anchored using high tension steel cables. The two bridge sections are then positioned and supported by the A-frame using additional steel cables, Figure 6.

The students however rose to the challenge of the British weather and all four projects were again successfully completed in time.

Figure 6 Muddy 2008 site conditions

Figure 7 Brewery Wharf bridge

Learning outcomes and student feedback

Students gained valuable hands-on experience of construction practice through the one-week Constructionarium activities and the learning curve is very steep. This is particularly true for those students having no previous construction site experience. Specifically the Constructionarium offers unique opportunities for overseas students to experience high standard UK construction practices.

The learning outcomes include:

- Appropriate use of PPE
- Health and Safety awareness, including environmental hazards
- Effective use of method statements, risk assessments, work planning and costing.
- Specific construction techniques
- Ability to read technical drawings and implement them
- Apply theories into practice
- Skills of negotiation and communication with industrial partners
- Leadership ability, interpersonal communication, coordination and organisation
- Time management skills and ability to work under pressure
- Professionalism

Most of the students had little previous knowledge of planning and implementation of activities on a real construction site. After this intensive learning week everyone had a much better idea of construction site work, which will have a positive impact on their future career. A post-Constructionarium questionnaire was carried out, which shows very positive student feedback as shown in Figure 8.

Health and safety considerations

The most important objective for the Constructionarium initiative is not project completion but to ensure that no student gets hurt. Allowing a large number of students to become involved with construction activities, most with no experience of the culture of health and safety expected on a modern construction site, has its own risk. This was effectively dealt with by the Contractor insisting on written and approved Method Statements and associated Risk Assessments for every site activity.

A number of minor cuts, bruises and scratches were recorded but there were no major accidents or injuries throughout both of the Liverpool Constructionarium weeks.

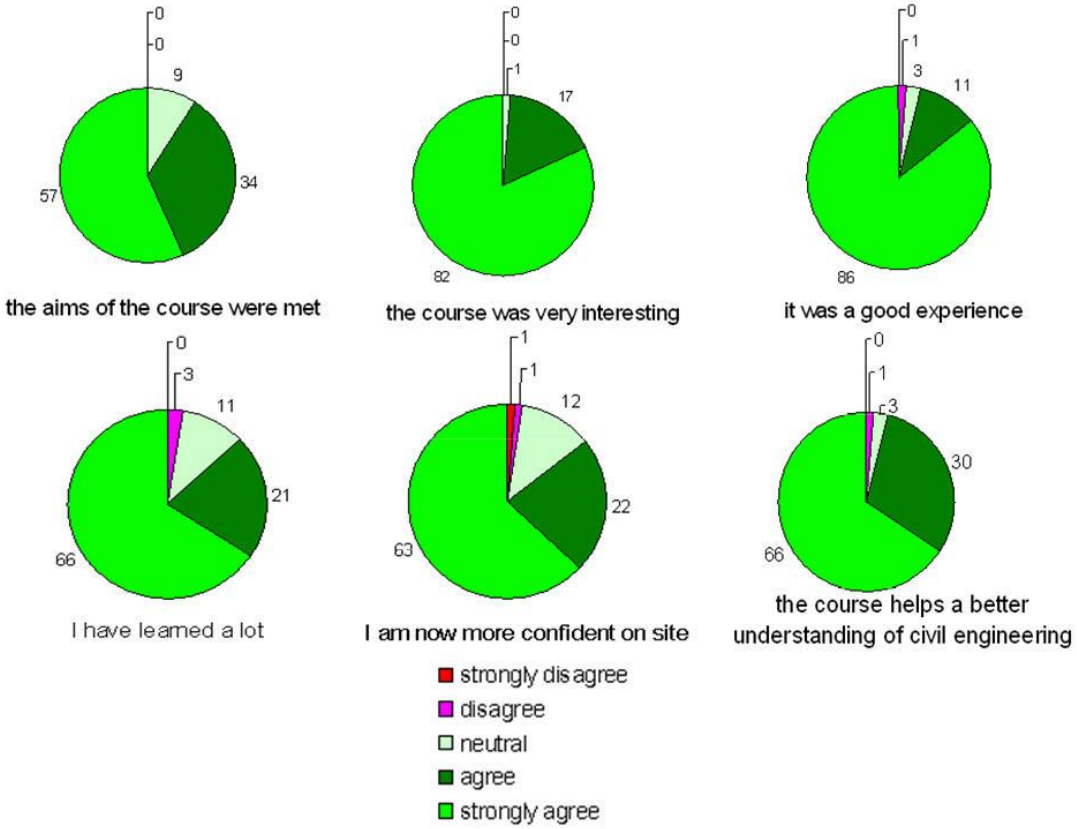

Figure 8. Students' feedback of post-Constructionarium questionnaire.

Conclusions

The Constructionarium experience has proven to be an invaluable site activity for civil engineering students, which fits well into the CDIO learning and teaching methodology. In the UK it is very difficult for all civil engineering students to take part in a relevant summer vocational experience. The Constructionarium provides an alternative way of giving students valuable pre-career practical experience and to inspire enough confidence to carry out future civil engineering work. The Liverpool Constructionarium has demonstrated a successful site learning practice, from which all of the students participating benefited.

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