World Transactions on Engineering and Technology Education
Vol.5, No.2, 2006

Design-build experiences and student safety

Geoffrey Cunningham, Perry Armstrong & Tony McNally

Queen's University Belfast
Belfast, Northern Ireland, United Kingdom

ABSTRACT: Design-build experiences (DBEs) are an essential element of any programme based on the CDIO (*Conceive – Design – Implement – Operate*) methodology. They enable students to develop practical hands-on skills, they enable the learning of theory by stealth and they provide a forum for developing professional skills such as teamworking and project management. However, the hands-on aspect of certain DBEs has significant risk associated with it that must be addressed through the formal evaluation of risks and the development of a methodology for controlling them. In this article, the authors consider the aspects of design-build experiences that may impact on student safety. In particular, it examines the risk associated with each of the four stages of CDIO and gives examples of risks that may commonly apply across various engineering disciplines. A system for assessing and controlling the risks in any particular DBE is presented and the article finishes with a discussion of the significance of health and safety in the educational environment.

INTRODUCTION

Design-build experiences (DBEs) are an essential element of the *Conceive – Design – Implement – Operate* (CDIO) programme and often serve to engender a new enthusiasm among both staff and students [1]. Indeed, the introduction of DBEs can be very rewarding, but can also be very time consuming.

However, finding the time to design, implement and operate a new DBE often leaves very little time to plan for the unexpected. Hands-on experiences are, by their very nature, more prone to unforeseen events than attending a lecture, yet, often little thought is given to this eventuality.

Safety in the workplace is primarily legislated in Northern Ireland by the Health and Safety at Work (NI) Order [2]. While generally applied in the employer-employee context, it also applies to the university-student relationship. In particular, the order states the following:

> *It shall be the duty of every employer to conduct his undertaking in such a way as to ensure, so far as is reasonably practicable, that persons not in his employment who may be affected thereby are not thereby exposed to risks to their health or safety* [2].

While this is taken from the legislation for Northern Ireland, the legislation for other parts of the United Kingdom is similar and expresses the same intent.

The foregoing has obvious implications for the implementation of DBEs in the UK curriculum. Hence, if a university is to maximise the obvious benefits for students of hands-on experiences without the disadvantages associated with lapses in safety, then it must adopt a proactive approach for the provision of a safe working environment.

A review of the literature has not provided any general information on the role of health and safety in the student experience. However, there are numerous publications available on health and safety in the workplace, for example refs [3][4], which provide useful guidance on current legislation and its implementation.

In this paper, the authors examine in more detail the safety issues surrounding DBEs and options for addressing these issues. They also discuss some more general issues, which, while not immediately relevant, also have an impact upon the control of risks in the project environment.

CDIO AND RISK

The CDIO Initiative stresses the concept of engineering education within the context of conceiving, designing, implementing and operating real-world systems and products. When applied to DBEs, the absolute risk associated with each of the four activities – C, D, I and O – will vary widely with the engineering discipline and project objective. For example, a typical microelectronics DBE would carry a much lower level of risk than a typical aerospace DBE. However, it is possible to assume a relative risk profile, as shown in Table 1.

Table 1: Risk profile of CDIO activities.

Activity	Relative Risk	Examples
Conceive	Low	Ideas generation, research, meetings, documenting
Design	Low/Medium	System modelling, computer-aided design, basic prototyping
Implement	Medium/High	Prototyping, manufacture, assembly
Operate	Medium/High	Testing, demonstrating

DESIGN-BUILD EXPERIENCES

CDIO Standard 5 addresses the need for two or more design-build experiences in the curriculum, including one at a basic level and one at an advanced level. Standard 5 is normally interpreted as one DBE in the first year and one in the final year of the degree programme.

A first-year DBE is often characterised by large numbers of inexperienced students operating in a new environment. It is probably not the best time to engage in dangerous activities and should normally concentrate more on the development of personal and professional skills, such as teamwork, communication, analysis, etc.

Final-year DBEs, in contrast, are likely to have a much wider remit and operate in a higher risk environment. Because of their diverse nature, it is difficult to provide a definitive list of risks, but experience from Queen's University Belfast (QUB) in Belfast, Northern Ireland, UK, can provide some general guidance, as shown in Table 2.

Table 2: Generic risks associated with higher level DBEs.

Hazard	Associated Risks
Workplace	Untidy work environment can lead to slips, trips and falls
Chemicals	Improper use can lead to skin contamination, inhalation and poisoning
Electrics	May lead to a range of minor and major injuries
Hand tools	Improper use can lead to minor injuries
Power tools	Improper use can lead to major injuries

CONTROLLING RISK

It is impossible to eliminate all risks, but they should be controlled as far as is reasonably practical. It is obvious from the aforementioned relative risk profile that the potential for risks lies mainly in the *implement* and *operate* phases of the CDIO chain. While, it is not adequate to focus solely on the I and O phases, these will usually require the most consideration.

The procedure for controlling risks is commonly known as risk assessment. Risk assessment is basically a five-stage process, as follows:

1. *Categorising activity*: divide all student activity into manageable categories;
2. *Identify hazards*: look for all non-trivial hazards associated with each student activity;
3. *Evaluate risks*: assess how likely it is that someone will be harmed by the hazard;
4. *Plan*: document how any risks that arise from the hazard will be controlled;
5. *Review*: keep the plan for controlling risks up-to-date.

Categorising Activity

Quite often the process of risk assessment can appear to be an overwhelming task; therefore, the first stage should be to break it down into a number of smaller groupings based on the patterns of activity in the department. Experience at the QUB, across a range of project types, has resulted in some general guidance on the categorisation of activity for the risk assessment process, as listed in Table 3.

Table 3: Categorising activity for risk assessment.

Category	Description
Individual	Where an individual student is undertaking a diverse range of activities in different areas as part of their project.
Project	Where a small group of students are undertake a diverse range of activities in different areas as part of their project; this is typical of a team-based DBE.
Activity	When an activity is carried out by a range of people on an *ad-hoc* basis during their project, for example, when using machine tools.
Area	When a diverse range of students have regular access to an area specifically designated for project activity. This is especially relevant to areas in which low-risk activities take place, for example, a studio or computer room.

Identify Hazards

Hazards, especially dangerous hazards, are normally straightforward to identify. The loud noises and fast motion of machine tools are an obvious hazard, high voltage electricity another, and chemicals with large warning signs are also to be treated with caution. The less obvious hazards are often less serious, such as back pain from poor computer configuration, tripping hazards from untidy workplaces, etc. When looking for hazards, it is not necessary to highlight the trivial, but it is best to instead concentrate on the hazards that may lead to genuine harm.

Evaluate Risks

There are a number of mechanisms for evaluating risks; however, the first distinction is between the formal (written evaluation) and informal (mental evaluation). The informal evaluation is only really suitable for the self-employed, very small companies or personnel who have undertaken thorough training programmes. The environment in which potentially inexperienced students undertake CDIO type activities should be the subject of a formal (written) procedure.

Once the decision to conduct a formal assessment of risks has been taken, the format of that written assessment is at the discretion of the assessor. A basic assessment, as shown in Figure 1, should list all the activities that are likely to pose a risk to the health or safety of students. It should list all the hazards associated with each activity and should then broadly categorise the level of risk associated with each hazard.

Activity	Hazard	Risk
Using circular saw	Wood dust Moving blade Noise	Medium Low Medium

Figure 1: Basic risk evaluation.

Plan

The outcome of a risk assessment should be a plan of action to minimise the hazards highlighted in the risk evaluation. The plan of action should list existing precautions, any additional precautions that may need to be required, the person(s) responsible for taking such action and when the additional precautions should be in place. An example of an action plan is shown in Figure 2.

Hazard	Existing Precaution	Additional Precaution	Action	Due
Wood dust	Dust masks provided but rarely worn	Fixed dust extraction system required	J. Smith	01/08/06

Figure 2: Example of an action plan.

It is possible – and often more convenient – to roll the process of risk evaluation and planning into one process and record the information in one document. This is the general approach at the QUB.

Review

Risk assessment is an ongoing process and should be subject to regular review for both changes in work patterns and to check on the successful implementation of additional safeguards. This is particularly important in student projects, which are often ill-defined at the outset and can easily diversify into new areas or activities during their course.

SAFE OPERATION OF DESIGN-BUILD EXPERIENCES

General Issues

A number of general issues should be addressed before students embark on any DBE. It is generally accepted that the provision of DBEs can be resource intensive; therefore, it is best to plan well ahead when developing policies and procedures to ensure that health and safety of students undertaking DBEs.

The foremost issue with regard to student health and safety is supervision. Student projects normally have an academic supervisor, who assumes overall responsibility for the project. However, DBEs often require more specific supervision and it may be useful to delegate the supervision of practical activities to a member of technical staff.

Closely associated with student supervision is the control of student access to workspaces. The rules governing student access to workspaces will be influenced by a number of factors. There may be university or departmental rules covering the subject. It may be influenced by the experience of the students, for example first-year students may require constant supervision in workspaces whereas fourth-year students require less direct supervision. The type of activity undertaken in a workspace may also influence them, for example a machine shop may require continuous supervision, whereas a studio would not. Access can be controlled by the appropriate timetabling of resources and may be backed up by physical systems, such as electronic locks.

Access control is also important for the provision of out-of-hours access. Students often prefer to work in the evening and weekends, when direct supervision is not normally available. The department must be certain that the risks associated with out-of-hours work do not outweigh the advantages. Conducting a thorough risk assessment will provide a clearer picture and enable a more informed decision to be made. The department must also ensure that all institutional and legislative requirements are met before granting out-of-hours access.

Many of the risks inherent in implementing and operating a product can be mitigated through appropriate student training, which may be formal or informal. Informal training may be more relevant where students have a working knowledge of a particular practical activity and only need minor guidance, while formal training will be more relevant for communicating important information, training for more dangerous activities or training larger groups.

Additional training is often cited in risk assessments as the most expedient method of introducing additional controls to an existing risk. Therefore, it should be considered as a method of imparting both general and specific information necessary for reducing risk in DBEs.

Implementing

Before allowing students to embark on any DBE, it is important to provide a short orientation talk, preferably in the workspace, on general health and safety issues. This should include the following:

- Procedure in the event of a fire;
- Procedure in the event of an accident;
- Rules governing the use of the workspace;
- Identity of any supervisors; etc.

The initial orientation may also include some basic training in the use of tools and the requirements for the use of personal protective equipment.

The most common problem associated with the implementation phase is untidiness and disorder within the student workspaces, and the associated risks of slips, trips, falls, falling objects, etc. Controlling the working environment is particularly difficult if there is no clear ownership of the area and/or large groups of students have access to the area for different purposes. Appropriate supervision and student training can alleviate this.

Hand tools are a basic requirement of most DBE projects. Hand tools are not normally associated with major injuries, although they must still be used with care. It is sometimes appropriate to assume a basic level of ability with hand tools and to offer assistance and informal training in their use where necessary. Certain hand tools may require specific controls, such as craft knives, but that should be decided on a case-by-case basis.

Advanced level DBEs often require the use of power tools, both portable and fixed. However, students should only be provided access to such resources after appropriate training and assessment of their competence. Not all students are able to – or want to – master the use of power tools, but there is generally at least one person in the group who is capable of fulfilling this role. There are obviously different levels of risk associated with power tools. There should be some relationship between the level of training and supervision, and the level of risk associated with a particular power tool.

Chemicals are an integral part of modern life and, in most cases, require some care and attention. The most common chemicals that students will encounter in DBEs are contained in paint and adhesives. Students should be encouraged to follow the manufacturers' guidelines for use and appropriate facilities for their use should be available.

Other hazards are present with electro-mechanical systems constructed by students. There are obvious dangers associated with electrical systems, but hydraulic and pneumatic systems also have inherent risks associated with them. It is difficult to provide any general guidance; therefore, it is particularly important that any projects involving electro-mechanical control systems be assessed individually for risks.

Operating

Operating self-built machines is often a leap-of-faith for both students and staff, and the results can be unpredictable. Many DBEs have no significant risk associated with their operation, for example, mechatronics projects, while others have significant potential for injury if they do not operate as expected. The potential for danger is closely related to the amount of energy associated with the operation of a product or system and the way in which that energy is dissipated. For example, a powered model aeroplane may have a relatively low mass, but a high velocity will lead to a large amount of energy dissipation during a crash.

Another contributing factor when assessing the risk of operating self-built machines is the necessity for direct human control. Most full-sized land, air and sea vehicles fall into this category. An excellent example among current student projects is Formula SAE/student projects that involve the direct operation of a self-built high-speed racing car. The potential risks associated with this particular DBE are significant and require extensive control measures to mitigate them.

As self-built machines are generally unique, it is again only possible to give general advice about their operation. Before operating a self-built machine, it should be thoroughly checked by an experienced engineer and, if appropriate, a safe operating procedure be agreed upon between staff and students. The operating procedure may be formal or informal, depending on the level of risk involved.

DISCUSSION

The spectre of heath and safety hangs over all aspect of personal and professional life in the UK and anecdotal evidence suggests the same is also true in most of the world's developed countries. The natural response to most health and safety issues is to complain about them and expend the minimum energy necessary to avoid the possibility of an unplanned courtroom appearance. Although, interestingly, if one is to discuss the issue with those responsible for health and safety in high risk industries, such as agriculture, petrochemicals and construction, they tend to take the issue very seriously. This is not only because they are worried about the legislative consequences, but also because they are concerned about the personal consequences to people in their care.

It is rare for students to engage in life-threatening activities as part of a DBE, but the risk of serious injury is always present, especially if student activity is carried out unchecked. In most cases, students will not have the experience to identify subtle risks, and it is often these that catch out students. The initial workload involved in reviewing the health and safety of students can be extremely onerous, but with appropriate delegation, it can become more manageable. Once the initial work has been completed and the procedures are in place, it is less time-consuming to retain the status quo.

Understanding the significance of health and safety is also a valuable aspect of an engineering education. It will certainly play a large role in students' future careers if they find themselves in a position of responsibility, or are responsible for designing products or systems that must be safe for the end user.

During the 4th year DBE at the QUB the risk assessment process has been exploited by running a trial in which one of the student teams was asked to complete their own risk assessment documentation. While the students' documentation required significant editing by the supervisor, the exercise did impress upon the students the nature of safety in the workplace and provided them with more incentive to follow the policies that they had jointly developed.

If design-build exercises are to form an ongoing part in the implementation of CDIO projects, then it is essential that issues, such as student safety, are properly addressed. There are doubtless many good practices already in place; therefore, it would be useful is these were brought to the attention of institutions involved in the provision of DBEs.

REFERENCES

1. Berggren, K-F., Brodeur, D., Crawley, E.F., Ingemarsson, I., Litant, W.T.G., Malmqvist, J. and Östlund, S., CDIO: an international initiative for reforming engineering education. *World Trans. on Engng. and Technology Educ.*, 2, **1**, 49-52 (2003).
2. Her Majesty's Stationary Office, Health and Safety at Work (Northern Ireland) Order 1978, 1978 No. 1039 (NI 9), 25 July (1978).
3. Health and Safety Executive Northern Ireland (HSENI), The Guide to Workplace Health and Safety. Belfast: HSENI 00 90 A (2000).
4. Health and Safety Executive Northern Ireland (HSENI), *Risk Assessment Simplified.* Belfast: HSENI 99 11 A (1999).