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DESIGN BUILD EXPERIENCES AND STUDENT SAFETY

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ABSTRACT

Design-build experiences (DBEs) are an essential element of any programme based on the CDIO 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 team working and project management. The hands-on aspect of certain DBEs has significant risk associated with it which must be addressed through the formal evaluation of risks and the development of a methodology for controlling risks.

This paper considers 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 which may commonly apply across engineering disciplines. Two particular aspects of DBEs, operating off-campus and high-risk DBEs, are also discussed. A system for assessing and controlling the risks in any particular DBE is presented and the paper finishes by discussing the significance of health of safety in the educational environment.

NOMENCLATURE

DBE(s)	design-build experience(s)
QUB	Queen’s University Belfast

INTRODUCTION

Design-build experiences are an essential element of the CDIO [1] programme and often serve to engender a new enthusiasm among both staff and students. The introduction of DBEs can be very rewarding, but can also be very time consuming. Finding 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 though 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], which, while generally applied in the employer-employee context, also applies to the university-student relationship. In particular, the order states that ‘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’. While this is taken from the legislation for Northern Ireland, the legislation for other parts of the United Kingdom are similar and will express 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 experience without the disadvantages associated with lapses in safety it must adopt a proactive approach to 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 [3, 4], which provide useful guidance on legislation and its implementation. This paper will examine in more detail the safety issues surrounding DBEs and options for addressing these issues. It will also discuss some more general issues, which, while not immediately relevant, also have an impact on 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 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	Description
Conceive	Low	Activities generally involve ideas generation, research, writing a product design specification, meetings, etc. These activities normally occur in a meeting room style environment and have no significant risks associated with them.
Design	Low/Medium	Design work is generally low risk. It normally revolves around office type activities such as system modelling, computer-aided design, calculations, etc. Design can, however, extend into the production of models or basic prototypes to test theories or ideas, which can be a potential source of risk.
Implement	Medium/High	Implementing products or systems can span a wide range of risk. For example, computer simulations would have a very low risk, whereas the manufacture of a complex machine, such as a hovercraft could involve substantial risk. Nonetheless, the average level of risk will be medium to high.
Operate	Medium/High	Operating products or systems carries a similar risk profile to implement activities. It can span a wide range from low to high. The current popularity surrounding the Formula SAE/Student is a prime example of a high risk activity; however, there are many other examples of student-build and operated machines that are equally risk sensitive.

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 first year and one in the final year of the degree programme. At Queen's University Belfast, the students are given the opportunity to participate in a DBE during the 1st, 2nd, 3rd and 4th years of the programme, as shown in Table 2. To highlight the issues surrounding DBEs the 1st and 4th year projects are examined in more detail.

Table 2: DBEs at Queen's University Belfast

1st Year	Model Racing Car
2nd Year	Structural Beam
3rd Year	Formula Student
4th Year	New Product Development

Model Racing Car

This project requires teams of students to build a model racing car, from a kit of parts, that will compete against other teams' cars over a sprint and hillclimb course. The cars are approximately 200 mm long and 100 mm wide, and are constructed from 4 mm wooden sheet, wheels, gears and a battery powered motor. The students have to make choices about the gearing, number of wheels and layout (for stability).

The only significant hazards during the build phase is cutting the wooden axles to length and cutting the supplied wooden sheet into the desired shape. Cutting the wooden axles to length has been assessed as low risk and the students are provided with a junior hacksaw for that task. Cutting the wooden sheet to form the car's chassis is a more complex task and it is completed by one of the technicians – the students mark the chassis profile on the sheet and pass it to the technician for cutting. The remaining parts of the cars are assembled by the students using adhesive pads.

The competition between the teams' completed cars requires approximately 30 m of indoor floor space. The cars are raced in pairs in a knockout format over a period of about three hours. There are no significant risks associated with the operation aspect of the project.

Design-build experiences are intentionally multi-faceted and serve to support learning outcomes other than practical skills. As a result of large student numbers QUB have decide to make the practical side of the DBE relatively risk free. The requisite skill levels are low and this enables the students to concentrate on developing analysis, team-work skills, etc.

Table 3: Generic risks associate 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, 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

New Product Development

Fourth year students undertake a team-based project which spans the complete CDIO process - they must conceive, design, build and operate a innovative new product. Because of the diverse nature of these projects the hazards are less well defined and they will consequently require closer levels of supervision and control. It is impossible to give a definitive list of risks associate with a higher level project, however, a number of examples are provided in Table 3.

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 phase 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:

1. Categorising activity – divide all student activity into manageable categories
2. Identify hazards – look for all non-trivial hazards within the categories identified in step 1
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. For example, if a production company were to categorise its activity, it may decide to categorise it based on area, e.g. production line 1, production line 2, etc. Whereas, a small workshop may decide to categorise activity based on individual members of staff, e.g. employee 1, employee 2, etc. Experience at QUB, across a range of project types, has resulted in some general guidance, as shown in Table 4, on the categorisation of activity for the risk assessment process.

Table 4: Categorising Activity for Risk Assessment

Category	Description
Individual	Appropriate where an individual student is undertaking a diverse range of activities in different areas as part of their project. For example, a research project that involves both theoretical and applied work.
Project	Appropriate where a small group of students are undertaking a diverse range of activities in different areas as part of their project. 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, using machine tools.
Area	When a large group 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.

Once the activities have been categorised, it may be prudent to delegate the responsibility of identifying and assessing the risks to personnel that function wholly or partly within that category. For example, a technician that is responsible for a particular laboratory may be in the best position to identify and assess hazards in that particular laboratory.

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 is best to instead concentrate on the hazards which may lead to genuine harm.

Evaluate Risks

There are a number of mechanisms for evaluating risks, however, the first distinction in 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 that have undertaken thorough training programmes. The environment in which, potentially inexperienced, students are undertaking 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. More sophisticated systems are available, as shown in Appendix 1.

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, additional precautions required, person responsible for taking 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: Action Plan

The person responsible for implementing any additional precautions would normally be in a supervisory role, such as the project supervisor, laboratory supervisor, etc.

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 QUB, although the level of detail in the document may vary from area-to-area. A section of the current risk assessment for the Formula Student workspace in provided in Appendix 2 as an example of this approach.

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 the he provision of DBEs can be resource intensive therefore it is best to plan well ahead when developing policies and procedures to ensure the 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, although, DBEs often require more specific supervision and it may be useful to delegate the supervision of practical activities to a member of technical staff. Irrespective of the supervisory structure, it is important to have an appropriately qualified person available to provide assistance when necessary, to oversee student activities and to watch for potential dangers.

Closely associated with student supervision is the control of student access to workspaces. The rules governing student access to workspace 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 1st year students may require constant supervision in workspaces whereas 4th year students require less direct supervision. It may also be influenced by the type of activity undertaken in a workspace, for example a machine shop may require continuous supervision, whereas a studio would not.

Integral to the policy regulating access to workspaces is the physical systems in place to enforce the policy. At a basic level, the workspaces can be unlocked and locked at the appropriate times, although without direct supervision this will not exercise any control over individuals gaining access to a room. The next step is the use of a mechanical combination lock with a single shared access code to gain entry. These are also prone to misuse as the number can be freely distributed among students and they provide no control over the time period during which entry is acceptable. The most appropriate, and costly, solution for controlling access is the electronic lock, which can accommodate individual access by number or card and can also control access with respect to time-of-day. Card access is preferred to number access as personal identification numbers are more readily distributed among unauthorised students.

Access control is also important for the provision of out-of-hours access. Students often prefer to work in the evening and weekend, when direct supervision is not normally available. It is certainly possible to provide access using electronic locks; however, there are more significant factors in the decision to providing out-of-hours access. The department must be certain that the risks associated with out-of-hours working do not outweigh the advantages. Conducting a thorough risk assessment will provide a clearer picture and enable a more informed decision to be made. For example, access to a computer lab may be provided, while access to a machine shop would not. The department must also ensure that all institutional and legislative requirements are met before granting out-of-hours access. In particular, the university's insurance company must be aware of the proposed arrangement.

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 or introducing additional controls to an existing risk. It should therefore 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: 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. It is a problem that requires constant attention and can be alleviated by the following means: allocate a member of staff (preferably technical) responsibility for the area; provide adequate storage for student project work; store tools in an organised manner; train students to clean up after periods of work.

Hand tools are a basic requirement of most DBE projects. At a basic level the students may be required to use screwdrivers and pliers for dismantling consumer products, while they may be required to use a full range of hand tools in an advanced DBE. Hand tools are not normally associated with major injuries, although 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 DBEs will 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 that is capable of fulfilling the role. There are obviously different levels of risk associated with power tools. For example an electric hand drill, while dangerous, is not as much of a risk as a lathe or power guillotine. There should be some relationship between the level of training and the level of risk associated with a particular power tool. The level of supervision should also be appropriate to the assessed risk of a particular tool.

Chemicals are an integral part of modern life and in most cases require some care and attention. Very dangerous chemicals are unlikely to play a part in DBEs, although cumulative exposure to lower level toxins is a more likely threat. The most common chemicals that students will encounter in DBEs are contained in paint and adhesives. Students have a particular habit of using aerosol paint in enclosed un-vented areas. The optimum solution to this problem is to provide a paint booth in the immediate vicinity, although lesser solutions may be appropriate depending on the manufacturer’s instructions on usage. Adhesive are less of a problem, but it is still important to be familiar with the manufacturer’s directions on correct use before supplying to students.

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. Electro-mechanical control systems are more often present in higher level DBEs and their designs will be very diverse. It is difficult to provide any general guidance, except to say that students should not be allowed to work on any high voltage/current systems or high pressure hydraulic/pneumatic systems. Notwithstanding this general guidance, it is particularly important that any projects involving electro-mechanical control systems should be assessed individually for risks.

Operating

Operating self-built machines is often a leap-of-faith for both students and staff – the results are often 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 size land, air and sea vehicles fall into this category. An excellent example among current student projects is Formula SAE/Student projects which involve the direct operation of a self-built high-speed racing car. The potential risks associated with this particular DBE are significant and require significant 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 out by an experienced engineer and, if appropriate, a safe operating procedure agreed between staff and students. The operating procedure may be formal or informal, depending on the level of risk involved.

Off-Campus Activities

The operation of some DBEs requires large amounts of space and can only be conducted safely off-campus. There are a number of safety issues associated with operation off-campus which should be addressed before engaging in any such activity. This is particularly important if the off-campus location is not owned by the university where issues of liability and insurance cover become important.

The first issue is transportation of both the students and the product of the DBE to the external location. It may not be appropriate for a student to transport the DBE in his private car as adequate insurance cover may not be in place and it would be unadvisable for a student to tow a trailer with his private car, again for insurance reasons, but also due to lack of experience of towing trailers. It is generally more appropriate in all cases to arrange for the transportation of the DBE by university transport and staff. The students are then free to walk, drive, use public transport, etc. to the off-campus location.

As previously stated, the reason for going off-campus is normally to gain extra space for safe operation. The obvious implication of this need is that the operation may be potentially unsafe otherwise it would not need large amounts of space. This is not true in all cases, but is in some. Irrespective of the level of risk for off-campus endeavours, it is important to conduct a risk assessment of the likely activities and address any additional precautions that may be necessary. One particular problem with off-campus activities is keeping members of the public safe if the location has public access.

If there is any significant risk associated with off-campus operation it is good practice to have a defined operating procedure, which minimises the risks that staff, students and public are exposed to. As before, this can be formal or informal, depending on the level of risk associated with the activity.

High Risk DBEs

A number of universities are involved in high risk DBEs, of which the most popular is currently Formula SAE/Student. This project involves teams of students conceiving, designing, building and competing in a small single-seater racing car. There are currently in excess of 300 universities across the world involved in a number of national competitions. QUB have been involved in the UK competition since 1999 and have developed a number of systems for managing this particular DBE.

The cars have a very high power-to-weight ratio and have performance level similar to high performance sports cars. They are however very small and have significant potential for injury if not used correctly. The design of the cars is relatively free, but the safety aspects are well controlled by the rules of the competition for which they are intended. Operation of the car at the competition is also well controlled by the organisers and the level of risk is relatively low. The main risks associated with Formula SAE/Student are present during the build and test phase at the host university. The cars are very complex machines and require the full range of resources, already highlighted as risks, during the implementation stage. Time permitting, they also require extensive testing prior to the competition, which requires both direct student operation and normally an off-campus location.

Controlling all pre-competition activities is a major task, which is important to maintain the safety of all students involved. A number of documents have been developed and procedures implemented at QUB to control all Formula Student activity. This currently includes: a risk assessment for the Formula Student build area (6 pages); a risk assessment for the Formula Student office (3 pages); a risk assessment for engine testing (4 pages); a written procedure for testing the car off-campus (6 pages); a risk assessment for testing the car off-campus (4 pages). This may be considered to be an excessive assessment of the situation, but it is often only by formally reviewing a process and documenting the results that issues become apparent. All involved in Formula Student at QUB are briefed on documentation at the start of the academic year. The documentation is reviewed informally throughout the year and formally at the end of the year in preparation for the intake of new students.

Formula Student is only one of many high risk DBEs currently undertaken by universities. There does seem to be a direct correlation between the students' enthusiasm and the risk involved, so if these DBEs are to remain on the curriculum they need to be properly controlled by the supervisors.

DISCUSSION

The spectre of heath and safety hangs over all aspect of personal and professional life in the United Kingdom 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 gripe about them and expend the minimum energy necessary to avoid the possibility of an unplanned courtroom appearance. Although, interestingly if you are 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. Not only because they are worried about the legislative consequences, but also because they are concerned about the personal consequences to anyone in their care that may sustain serious injury.

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 on unchecked. In most cases, students will not have the experience to identify subtle risks, and it is often these which catch out the students. The initial workload involved in reviewing the health and safety of students can be extremely onerous, but by 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 the students' future career 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 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. And while the students' documentation required significant review by the supervisor, the exercise did impress on the students the nature of safety in the workplace and provided them with more incentive to follow the policies and procedures which they had jointly developed.

If design-build exercise are to form an on-going part in the implementation of CDIO 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 more readily available to any institutions involved in the provision of DBEs.

CONCLUSIONS

- Design-build experiences are an integral part of the CDIO programme, but carry a higher level of risk to student health and safety than traditional teaching methods.
- The implement and operate phases of a design-build experiences carry the highest level of risk to student safety.
- Risk in design-build experiences can be mitigated by conducting formal or informal risk assessments.
- Typical risks in the implement and operate phases can be identified across all levels of design-build experience.
- Additional risks exist when operating a design-build experience off-campus.
- High risk activities are very appealing to students, but require additional work by staff to minimise the exposure to risk of everyone involved in the project.

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APPENDIX 1: ADVANCED RISK EVALUATION

Activity	Hazard	Persons Exposed	Severity[1] (a)	Likelihood[1] (b)	Number of People Exposed[1] (c)	Risk (a x b x c)
Using Circular saw	Wood dust	All in woodworking shop	2	3	3	18
	Moving Blade	Operator	3	1	1	3
	Noise	All in woodworking shop	2	3	2	12

1) Scale of 1 - 3 corresponding to low, medium and high

APPENDIX 2: FORMULA STUDENT RISK ASSESSMENT (PARTIAL)

ACTIVITY	**HAZARDS** LIST ONLY THOSE WHICH YOU COULD EXPECT TO RESULT IN HARM	**PEOPLE** LIST GROUPS OF PEOPLE WHO MIGHT BE HARMED	**RISKS** WHAT IS THE RISK UNDER NORMAL CONDITIONS IN WORKPLACE	**CONTROLS** WHAT, IF ANY, EXISTING CONTROL MEASURES EXIST	**ACTION** LIST ADDITIONAL CONTROL MEASURES REQUIRED	**RESPONSIBLE** ACTION BY WHOM AND BY WHEN
Working with hand tools	Cuts Bruises Abrasions Crush injuries Eye injuries	Staff Students	Low	Students' competence with hand tools will be assessed initially by observation. If required, students will be instructed in the correct and safe use of hand tools. Appropriate personal protection equipment is available and must be used while working with hand tools.	Appropriate procedures for the assessment and training of students in the use of hand tools to be drawn up. Details of first aid personnel to be clearly displayed.	JK [01/10/06] GC [01/05/06]
Working with power tools	Cuts Bruises Abrasions Crush injuries Eye injuries Electric shock	Staff Students	Medium	Before using any power tools, student must be instructed in their correct and safe use. Power tools must not be used unless authorisation has been given. Personal protection equipment is available and must be used while using power tools. All power tools to carry a current electrical test sticker.	Appropriate training to be provided for the use of all common power tools. PPE to be provided for complete protection during use of common power tools. All power tools to be checked for electrical compliance sticker. Details of first aid personnel to be clearly displayed.	JK [01/10/06] GC [01/05/06]