Creating an information-rich learning environment to enhance design student learning: challenges and approaches

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Abstract
The use of technology with engineering design students is well established, with shared workspaces being particularly supportive of the collaborative design process. This paper reports on a study where a design knowledge framework involving three learning loops was used to analyse the effectiveness of shared workspaces and digital repositories in supporting design education. The issues discussed include the relationship between knowledge and information structures, the importance of integrating information literacy support, and the need for different systems within the learning environment to support formal and informal storage of resources. These issues are explored within the context of experiences of working in a multidisciplinary team with different approaches, research methodologies, and discourses.

Introduction
Groupware has been shown to provide a supportive environment for collaborative learning (Sclater, Grierson, Ion & MacGregor, 2001; Shaikh & Macauley, 2001; Sikkel, Gommer & van der Veen, 2002). When groupware is configured as a shared workspace, it acts as a central repository for students to store and share resources. This offers great flexibility for students working in groups. They can access and update resources from any location at any time and can collectively manage their work flow. Distributed working is a common feature of engineering design teams where the sharing of information and resources is important (Ion, MacCallum & Neilson, 1997; Siemieniuch & Sinclair, 1999). In addition, constructing resource collections in shared workspaces can benefit learning especially when students are required to reflect on, and interact with,
the information and resources they upload into the workspace (Denard, 2003; Jonassen & Carr, 2000; Nicol, Littlejohn & Grierson, 2005).

The digital libraries for global distributed innovative design education and teamwork (DIDET) project is examining how the creation, use, and organisation of digital resource collections can enhance student learning in a global, team-based design engineering context. This work builds on existing research into shared workspaces and the construction and use of digital resource collections. In addition, it explores ways in which the reuse of these collections might benefit teaching and the learning of future cohorts of students. This project is jointly funded by the Joint Information Systems Committee (JISC) and the National Science Foundation as part of the Digital Libraries in the Classroom Programme and is led by the Department of Design Manufacture and Engineering at the University of Strathclyde, UK, and the Centre for Design Research (CDR) at Stanford University, USA.

This paper explores ways in which digital repositories, including shared workspaces, support design learning. The study is based on a design knowledge framework developed at Stanford (Eris & Leifer, 2003). The paper highlights a range of issues and lessons learned during research on design education. These include how to support the design process, the needs of design coaches, and resource reuse issues (e.g., metadata, intellectual property rights (IPR), and management of digital collections). The paper also discusses difficulties of implementing transformational educational projects where multidisciplinary teams are involved.

Educational approach: problem-based learning and the design knowledge framework

One of the educational approaches found to be most appropriate for design engineering education is that of problem-based learning (Savin-Baden, 2000). Problem-based learning usually begins with an open-ended problem around which students in groups organise their studies. Normally, this would involve discussing a problem issue, searching for resources, and working together towards a solution or a set of recommendations. The solution to a problem usually calls for resources from a variety of sources. A tutor’s role in problem-based learning is to facilitate critical and reflective learning and to coach students rather than to transmit information (Eris & Leifer, 2003). The use, creation, and sharing of information by design teams are critical elements of the design process (Ion, Wodehouse, Juster, Grierson & Stone, 2004).

The CDR at Stanford developed a ‘Design Knowledge Framework’ (Eris & Leifer, 2003) to illustrate the interactions between a design team, coaches, and the product development (PD) activity. This framework also effectively illustrates the educational issues within collaborative design projects. A key element of the framework is the distinction between the formal and informal aspects of practice and knowledge. The instructor, PD history, and PD process are considered to be predominantly formal elements. Coaches, teams, and PD practice are considered to be informal elements. The arrows represent the ‘acquisition’ or ‘co-generation’ of PD knowledge (Figure 1).
The application of the framework within the design learning contexts has led to the identification of three learning loops associated with any design activity. Eris and Leifer (2003) describe these loops as follows:

1. Learning loop 1—Supporting the design process: teams apply the PD process contextualised for them by coaches in their design practice. They utilise the information embodied in the process, and in doing so, generate new information.

2. Learning loop 2—Coaching: coaches observe the design practices of teams and use the understandings they gain in contextualising the PD process for them. Based on the needs of teams, coaches selectively extract information from the PD process and present it to the teams in a meaningful way.

3. Learning loop 3—Formalising and reusing content: tutors retain a history of the new knowledge generated during the design practice and extract new elements from it in order to improve the PD process. Instructors manage the capture, indexing, and publishing of the new information that teams generate in loop 2 in the form of a PD process.

The instructor would normally be responsible for the formulation and implementation of the learning activity. Responsibility for monitoring the design process would lie with the coaching teams. A coaching team would normally include lecturers and tutors, but might also include students who have already completed the course (Figure 2).

The following section reports on two studies within which design learning was organised around the three learning loops.
Educational context
The first study involved 40 3rd-year undergraduate engineering design students (Grierson, Nicol, Littlejohn & Wodehouse, 2004; Juster et al, 2004) who worked in small teams over 6 weeks to design a proof-of-concept model of a domestic can-crushing device. This project had three phases: information gathering, storing, and organising; concept generation; and proof-of-concept through models and videos of team presentations. Team collaboration required the students to store resources (either generated by themselves or externally located), manipulate these during the design process, and manage their work flow. Classes included formal instruction and allocated time for face-to-face teamwork where tutors acted as informal ‘coaches’. There was also time outside the classes for students to work face-to-face or in a distributed way through the shared workspace.

The system designed to support this activity was a customised version of open-source groupware called TikiWiki (http://TikiWiki.org/TikiWiki). This provides standard document management facilities including file storage, image and web-link galleries, and Wiki pages (Web pages that can be linked together and edited by multiple users). Students were asked to upload content into the file storage areas called file galleries. They were also asked to represent the development of the product using linked Wiki pages. These interlinked Wiki pages were intended to help students work to develop a shared understanding of their design problem and solution.

The second study occurred 1 year later with the same 3rd-year project, where students had a similar brief—to produce a proof-of-concept model of a domestic ice crusher. The class design was amended both as a result of lessons learned during the first study.
Information-rich learning environment

(Table 1) and because changes in the project team introduced new expertise. In particular, a learning technologist was appointed with experience in librarianship/information science. This person had experience in managing digital resource collections, teaching information literacy, and working with academic colleagues to support student learning through the use of information and communication technology (ICT). In addition, a new digital library (DL) specialist joined the project team to work on the repository, bringing knowledge of IPR and Digital Rights Management (DRM). By the time of the second study, the system name had been changed from TikiWiki to ‘LauLima’ (Polynesian for ‘group of people working together’) to distinguish it from the original open-source system.

In the second study, the students used the Wiki pages to create logs to record reflections on their progress with the design and to link to the resources they created and used. In addition, significant changes were made in relation to information literacy instruction and support. The first two class sessions included input from the learning technologist who acted as a coach throughout the design project. The learning technologist provided sessions on the use of team concept maps to support the planning stages of information searching, including identifying search terms, using appropriate sources, modifying searches, evaluating resources, copyright issues, organising information, and assimilating found information into their own design concepts and referencing.

The effectiveness of groupware in supporting learning and the design process was evaluated using a variety of methods including student focus groups, 1-minute reaction cards, team presentations and analysis of activities, Wiki pages, and files created by students in the groupware. The detailed results of the first study are reported elsewhere (Grierson et al., 2004; Juster et al., 2004; Wodehouse et al., 2004). Below, the findings of both studies are interpreted in terms of the three-loop model.

Loop 1: supporting the design process
As shown elsewhere (Nicol & Macleod, 2004; Sikkel et al., 2002), the studies reported here show that a shared workspace (TikiWiki, LauLima) helped support collaborative learning. The students reported the value of being able to access and contribute to the development of resources at any time and from any location.

What was unique in these studies was the use of tools that might facilitate the interlinking of facts, concepts, ideas, theories, and diagrams in a structured way. In the design project, the students were asked to illustrate their conceptual thinking and to communicate this to others outside their team. This was achieved in two ways. In the first study, the students constructed a set of interlinked Wiki pages in TikiWiki. These interlinked pages illustrated the team’s shared understanding about how they interpreted the resources they had studied during the design project. In the second study, the students collaboratively constructed a ‘concept map’. This provided a visual representation of the design problem. The nodes of the concept map could be directly linked to the relevant resources. The provision of these tools enabled the students to collaboratively construct their own ‘knowledge structures’ in the design problem domain and

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<td>Worked in teams of four meeting face to face several times per week supported by groupware support</td>
<td>As previous</td>
<td>As previous</td>
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<td>Duration: 6 weeks</td>
<td>As previous</td>
<td>As previous</td>
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<tr>
<td>Design brief</td>
<td>Prototype a domestic can-crushing device</td>
<td>Prototype a domestic ice-crushing device</td>
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<tr>
<td>Technology/tools</td>
<td>TikiWiki: open-sourced product</td>
<td>LauLima: customised version of TikiWiki</td>
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<td>Technology/tools</td>
<td>Main features—document management facilities (file, image, and Web-link galleries and Wiki pages) and communications tools ('shout' facility, email, forums for technical problems)</td>
<td>As previous</td>
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<tr>
<td>Class content</td>
<td>Pre-project introduction to software</td>
<td>As previous</td>
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<tr>
<td>Class content</td>
<td>Three phases to project</td>
<td>As previous</td>
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<tr>
<td>Class content</td>
<td>Weeks 1 and 2: information gathering, storing, and structuring</td>
<td>Weeks 1 and 2 amended to include concept mapping, information retrieval, management, and sharing</td>
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<td>Class content</td>
<td>Week 3: concept generation</td>
<td>As previous</td>
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<tr>
<td>Class content</td>
<td>Weeks 4 and 5: development and prototyping</td>
<td>As previous</td>
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<td>Class content</td>
<td>Week 6: presentation</td>
<td>As previous</td>
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<tr>
<td>Teaching support</td>
<td>Formal</td>
<td>Formal</td>
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<tr>
<td>Teaching support</td>
<td>1-hour weekly lecture</td>
<td>As previous, with additional content by learning technologist</td>
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<tr>
<td>Teaching support</td>
<td>Informal</td>
<td>Informal</td>
</tr>
<tr>
<td>Teaching support</td>
<td>2 × 1-hour face-to-face group work session with coaching support</td>
<td>As previous, but coaching team included learning technologist</td>
</tr>
<tr>
<td>Student team outputs</td>
<td>Wiki pages to structure the design problem, organise resources, and document the design process</td>
<td>Concept maps to structure the design problem and organise resources</td>
</tr>
<tr>
<td>Student team outputs</td>
<td>Concept maps to identify research areas and search terms and phrases</td>
<td>Reflective logs of design process as Wiki pages</td>
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share these representations within and across their project teams (Nicol et al., 2005). Knowledge structuring is important for design learning because the more opportunities the students have to actively interrelate concepts, ideas, facts, and rules with each other and with prior knowledge, the deeper the understanding and learning (Jonassen & Carr, 2000). There is also a consensus amongst researchers that one characteristic of experts in any professional domain is that they possess well-organised and flexibly accessible

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<td>Evaluation methods</td>
<td>Student focus groups; reaction cards; team presentations; analysis of team activities, Wiki pages, and file galleries in groupware</td>
<td>End of class student feedback; team presentations; analysis of team activities, Wiki pages, and file galleries in groupware</td>
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<tr>
<td>Findings</td>
<td>Most students heavily relied on the Internet and the library for sources of information, reporting that they preferred to use sources they were familiar with. Students need guidance on organising, editing, and structuring of information. Organising and structuring of information in the Wiki pages allowed sharing of resources. Students are beginning to realise the importance of documentation as part of the design process. The most successful teams were those that reflected and thought how to resolve issues.</td>
<td>Student reflections highlighted a broader awareness of different information sources and revealed flexible and more effective search strategies. Student reflections revealed that concept mapping exercise aided in structuring and organising information. Student feedback that there was a ‘logical process’ to information-gathering activities. As previous.</td>
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<td>Findings</td>
<td></td>
<td>As previous. Building reflection, with associated tasks and assessment into the project was of value to the students. Positive student feedback to additional formal information literacy and concept mapping exercise at the beginning of the process. Positive student feedback highlighted the importance of regular informal input from coaches.</td>
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internal knowledge structures (DeCorte, 1996). In addition, for effective learning, it is student-generated knowledge structures that are important, not the structures provided by tutors (Jonassen, Beissner & Yacci, 1993).

Loop 2: coaching
The shared workspace supported the coaching process. It enabled coaches to monitor student progress in a way not possible in traditional design classes and to adjust their coaching methods according to the needs of the team. The first study highlighted that with shared workspaces, coaching requires a range of skills not normally possessed by design tutors. In this environment, these tutors not only need to coach students in the design process but also coach them in the retrieval, organisation, and application of content to support this. This presented a challenge to the tutors who did not have an understanding of the complexities of information retrieval and the organisation of content or an understanding of how these issues might affect the design process. Moreover, the short timescale of the class provided little opportunity to deal with the issues that arose from this lack of student and staff understanding (Eris & Leifer, 2003).

One of the most significant changes during the second study was the involvement of the learning technologist within the coaching team. This ensured that ongoing information literacy support was integrated throughout the design project. The students positively responded to this support. This was evidenced in several project logs where the students described their experiences. Many reported that the support they received helped them organise their own resources in hierarchical file structures and that it was easier to find resources uploaded by other team members. They also reported adapting their searches when using different external sources and showed an understanding of the need to apply broader or narrower search terms as appropriate. They also reported that they had applied a range of different methods to limit the number of items retrieved. Information literacy was assessed through the students’ contribution to the project logs. To fulfil the coaching role, it was important that the learning technologist developed a good understanding of the design process, the learning activity and outcomes, and the role of a coach in this context. An important element of this change in approach was the provision of support to the learning technologist from more-experienced designers on the coaching team.

Loop 3: formalising and reusing content
The project team had intended that the tutors and future cohorts of the students would be able to retrieve and reuse the resources created in the shared workspace. The resources created during the two studies provide a rich record of the design process and of students’ knowledge structures (ie, through the interlinked Wiki pages, concept maps, and reflective logs). However, effective reuse of these resources would require that they are organised and managed in a formal repository with quality-controlled metadata based on standards. In contrast, the shared workspace is an appropriate environment for storing and sharing resources that are continually being developed as
ideas and representations of the design problem change and new resources are accessed and generated. This suggests that whilst a dynamic and informal shared workspace could help support the design process, it might be much less helpful as an environment for collecting together resources that can be reused with cohorts of students who were not party to the initial design. One solution to this problem is to develop separate but interlinked systems that support dynamic and formal resource collections.

Another issue raised by the first study was on the IPR and DRM. The IPR was less problematic for content generated by students during the design process (e.g., scanned concept sketches, photographs and videos of concept models, computer-aided design drawings, word documents, and assessed reflective statements). In this case, the students had signed an agreement transferring property rights to the university. However, externally sourced content (e.g., information about recycling, market, user environment, mechanisms, aesthetics, ergonomics, and safety) is equally important in the design process but poses a significant problem in relation to IPR (HMSO, 2000a,b). This content cannot be legally stored in an electronic format without obtaining rights clearance, which is not a realistic option for students on time-limited projects.

In order to address this issue, the members of a team carried out an investigation into the legal issues affecting the project and reported these to the team, summarising key points and illustrating these with examples from the first study. The teaching staff felt that the legal restrictions could have a negative impact on the fluidity of the design process. From these discussions, a series of measures was identified to minimise this, including the education of students, use of copyright-cleared content available in other repositories, and the creation of our own content. Despite the tutors’ reservations, the students followed the advice provided in relation to incorporating externally created Web-based content allowing them to legally share information at the point of need in the design process. They did this by describing the content and providing access to team members through links either in a Word document or on the Wiki pages. Although this method is unlikely to be effective as a long-term solution, because of longevity issues of websites, it added to the extent and breadth of resources used, as evidenced during the assessment process.

The third issue in relation to the reuse of resources was granularity. **Granularity** refers to the number of small resources that comprise a larger resource. There is a trade-off between the size of a resource and its educational value (Duncan, 2003; Thorpe, Kubiak & Thorpe, 2003). It is relatively easy to reuse small resources (e.g., image files, text documents, etc) and these can be very useful to stimulate ideas during the early stages of the design process. Small resources, however, have limited context that could compromise their educational value to future cohorts. Larger resources such as project reports and a whole team space on LauLima are likely to have more value to learners. This has implications for recording the context either as metadata or in some descriptive ways (Nicol, 2003) and will be a future area of research for the DIDET Project team.

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Discussion

Electronic environments to support the design process

This study has identified the need for the development of two parallel systems. Currently, these are being developed within the same software. However, the functions and management of the two have been separated. The shared workspace is now referred to as the LauLima Learning Environment (LLE), while the digital repository is called the LauLima Digital Library (LDL) (Figure 3).

This development of both formal (LDL) and informal (LLE) systems has helped to clarify what is required to effectively support the three learning loops of the design knowledge framework. However, in creating two systems, issues have been raised about how resources are moved from one (LLE) to the other (LDL). Figure 4 provides a work-flow model illustrating the process of adding content within the LLE and its transfer to the LDL, including the application of metadata.

The first column in Figure 4 illustrates three stages of activity in relation to content flow between these two systems. The first stage involves the students and staff uploading and using content as part of a learning activity. At this point, some metadata are automatically applied and some by the depositor. The second stage requires the teaching team to flag content for inclusion in the LDL and potentially add more metadata, ideally with some educational context information. The need for the third stage presented a significant development in the understanding of the project team as it began to acknowledge the need for a librarian/information specialist (LIS) at the final stage where information is formally deposited in the LDL. This arose because of metadata issues, the decision to
use a controlled vocabulary in the LDL, and the need to ensure that IPR and DRM were properly taken into account. There is also evidence to suggest that metadata produced by both academic and LIS result in improved retrieval (Currier, Barton, O’Beirne & Ryan, 2004). It is expected that metadata added by students in the LDL will also add to the richness and retrieval capabilities.

**Multidisciplinary team working**

The DIDET project requires input from a range of professional disciplines. As a result, team members often had to engage with knowledge, research literatures, methods, and disciplinary discourses that they had not previously encountered (eg, technologies for teaching and learning, design engineering education, DLs, information behaviour, and information literacy). Within the DIDET team, the learning technologist took on the role of project coordination to ensure that the diverse facets of the project and skills of the project team were effectively synchronised and to facilitate information and knowl-
edge sharing. It has been acknowledged that the awareness of connections between disparate elements of e-learning projects constitutes a significant role for this emerging professional group (Beetham & Jones, 2000; Struthers, 2002). The addition of a learning technologist to the DIDET team had a positive impact on both project management and progress. Developments in technology require much greater reliance on such multidisciplinary working in the higher education sector, and this highlights an institutional need to effectively manage task-based groups and build expertise across a range of professional disciplines. The Higher Education Academy is currently researching and supporting organisational change of this kind in the UK.

One area that has proved challenging for the DIDET project is in evaluating the impact of shared workspaces and digital repositories on student learning. Recent work in the area of educational informatics (Levy et al., 2003) acknowledges the need for a new field of research relating to the impact of ICT on educational practice and provides theoretical frameworks and methodological approaches that may be particularly relevant to multidisciplinary e-learning projects. It is hoped that future research within the project will add to the understanding of this emerging field.

Summary
Whilst challenges relating to technologies can often become the focus of attention for e-learning projects, it is the attention to human factors that has moved the DIDET project forward. Early, unrealistic assumptions about the ability of students to effectively retrieve, evaluate, organise, and utilise information in an electronic environment resulted in a need to re-examine and amend the formal and informal learning and teaching support. Efforts made to inform the project team and challenge perceptions around information literacy, metadata and IPR/DRM issues have led to an integrated approach to both the development of the DL and the design of classroom activities.

References


