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Enhancing Design Learning Using Groupware*

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Project work is increasingly used to help engineering students integrate, apply and expand on knowledge gained from theoretical classes in their curriculum and expose students to 'real world' tasks [1]. To help facilitate this process, the department of Design, Manufacture and Engineering Management at the University of Strathclyde has developed a web–based groupware product called LauLima to help students store, share, structure and apply information when they are working in design teams. This paper describes a distributed design project class in which LauLima has been deployed in accordance with a Design Knowledge Framework that describes how design knowledge is generated and acquired in industry, suggesting modes of design teaching and learning. Alterations to the presentation, delivery and format of the class are discussed, and primarily relate to embedding a more rigorous form of project-based learning. The key educational changes introduced to the project were: the linking of information concepts to support the design process; a multi-disciplinary team approach to coaching; and a distinction between formal and informal resource collections. The result was a marked improvement in student learning and ideation.

Keywords: Design education; digital repository; Design Knowledge Framework

INTRODUCTION

Background

WORK DESCRIBED in this paper is part of the DIDET ('Digital Libraries for Global Distributed Innovative Design, Education and Teamwork') project, one of four in the Digital Libraries in the Classroom programme. The DIDET project brings together a range of expertise from the department of Design Manufacture and Engineering Management (DMEM) at the University of Strathclyde (UK), the Center for Design Research at Stanford University (CA, USA), and Olin College of Engineering (MA, USA). It was undertaken to transform the education process for design engineering by enabling them to participate better in team-based design engineering projects through the use of digital resources. In this context, DMEM has developed a web–based groupware product called LauLima [2] to facilitate the storing, sharing, structuring of information when students are working in design teams. This paper discusses the changes made from Year 1 to Year 2 of a DMEM class called Integrating Design Project (IDP), in which LauLima has been deployed with the aim of improving student learning.

Class context

The class consisted of 3rd year design engineering students working in teams of four to rapidly design a crushing device for domestic use: in Year 1 it was a can crusher, in Year 2 an ice crusher. The project was organized and run over a six week period—the main stages of the project are shown in Fig. 1—using both mini-topics (short introductory lectures) and studio sessions (students and coaches working in an informal open-plan space). Each class would last for two hours. Teams were asked to use LauLima as a digital repository and collaborative tool. Each team created a private domain where they could upload images and files, and create wiki pages—web pages that can be linked together and edited by multiple users—where they could build hierarchies and links for this information. This was then used as their means of presenting their work at the end of the project.

The work took place primarily in the design studio, an informal physical space for both individual or group work. There is interaction with peers and coaches in the studio, when the information from the mini-topics is augmented with discussion

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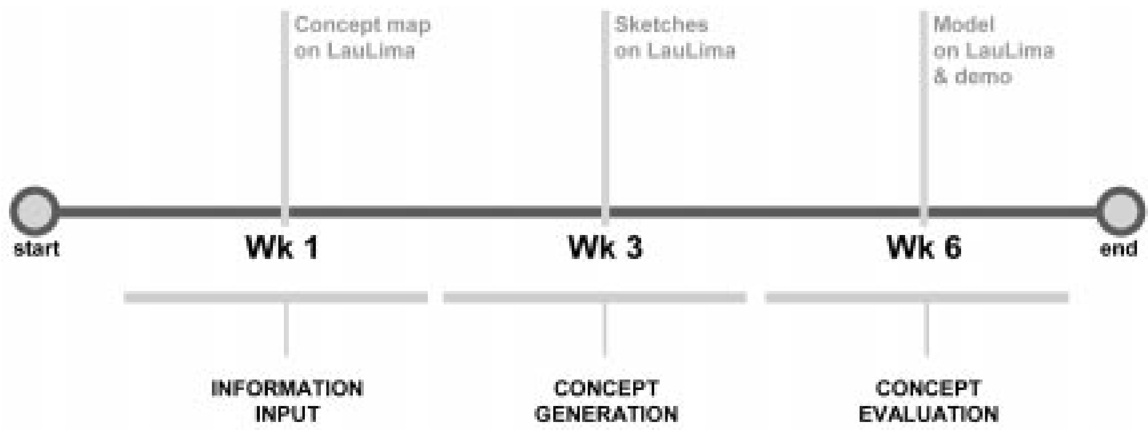

Fig. 1. Project structure.

and examples, helping the students understand and improve on their designs.

Evaluation focused on students' and teaching staff's perceptions and experiences of the learning experience. Year 1 and Year 2 made use of: observation of student teams working in the design studio; student focus groups; reaction cards; team presentations; end of project feedback; analysis of team activities in the wiki pages and file galleries in the groupware.

EDUCATIONAL AIMS AND OBJECTIVES

Strathclyde University's DMEM has built up expertise in the implementation of digital technologies in the classroom to help aid student learning over a number of years [3], with a particular emphasis on trying to contextualize student learning. To this end the aim of the IDP class is to integrate, apply and expand on knowledge gained from theoretical classes in their curriculum through project work in design teams. In engineering design, there has been a shift from strongly empirical forms of design theory towards more learner-centred approaches which take account of human and social factors in the design activity [4]. This is concomitant with the general educational trend where social interaction (in this case in the design studio) is thought to be fundamental in developing internal knowledge [5–7]. While still assuming there is a process of assimilation from the instructor or coach, this recognizes a 'joint enterprise' [8] with respect to creating new meanings. In product design engineering, the application of knowledge to creative thoughts and ideas allows the designer to develop new product configurations, and DMEM has therefore tried to foster a creative studio environment, supported by a coaching team, where students are free to develop and form new ideas in project-based activities. This has led to the adoption of a project-based learning methodology in the IDP class.

Project-based learning

Project work is increasingly used to help students integrate, apply and expand on knowledge gained from theoretical classes in their curriculum [11]. This approach has been formalized in educational literature as project-based learning: working in teams, students explore problems, develop solutions and create presentations to share what they have learned. According to Curtis [9], compared with traditional teaching methods PBL has many benefits, including:

- Deeper knowledge of subject matter;
- Increased self-direction and motivation;
- Improved research and problem-solving skills.

Project-based learning is similar, but not identical, to problem-based learning [10]. They share more than the same abbreviation: they are both instructional strategies that are intended to engage students in 'real world' tasks to enhance learning; they are both student-centred approaches; and both include the teacher in the role of facilitator or coach [11]. There are, however, some key differences. Where project-based learning typically begins with an end product in mind and asks students to research, plan and design to reach this goal, problem-based learning uses an inquiry model where students are presented with a problem, gather information and summarize their new knowledge— there may or may not be an end product [10]. Both are authentic, constructivist approaches to learning, but for the purposes of product design engineering, and the IDP class in particular, project-based learning (referred to as PBL from here on) and its focus on the content, knowledge and skills acquired during the production process is the more appropriate method.

The Design Knowledge Framework

The Centre for Design Research at Stanford developed a Design Knowledge Framework (DKF) [12], shown in Fig. 2, to illustrate how design knowledge is created and shared during the interactions between a design team, coaches, instructors; the product development activity (the

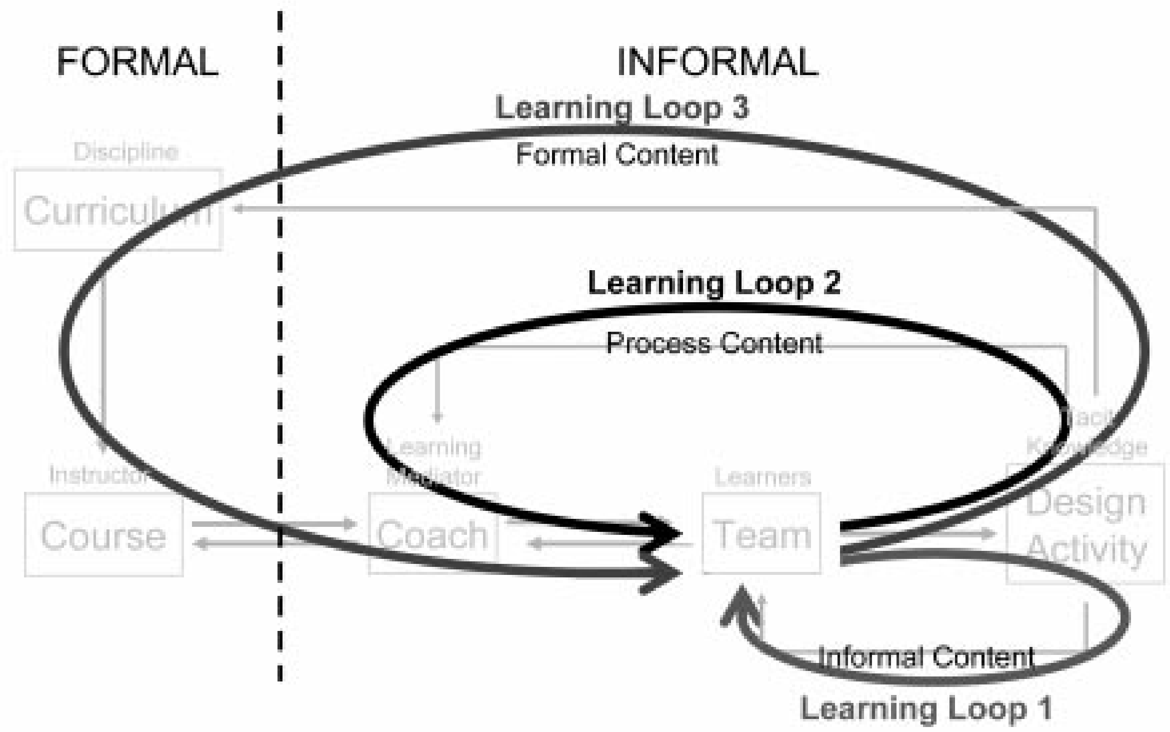

Fig. 2. Three opportunities for technological intervention in enhancing design team learning performance.

presented version of the framework has been adopted from its original industry context to an educational context). 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, product development history and product development process (the essential structure and core teaching material of the class) are considered to be predominantly formal elements. Coaches, teams and product development practice are considered to be informal elements, although the coaches reside in close proximity of the formal-informal boundary. The arrows represent the 'acquisition' or 'co-generation' of product development knowledge.

The application of this framework has led to the identification of three learning loops associated within design activity. Eris and Leifer describe these loops as follows:

1. Supporting the design process: teams apply the product development process in their design practice, create new knowledge.
2. Coaching: coaches observe the design practices of teams and use the understandings they gain in contextualizing the product development process. Based on the needs of teams, coaches selectively extract information from the product development process and present it to the teams in a meaningful way.
3. Formalising and reusing content: the course retains a history of the new knowledge created during design practice. Instructors manage the capture, indexing and publishing of the new information that teams generate.

These three learning loops constitute opportunities for technological intervention for supporting a constructivist learning environment. The following section describes LauLima, a tool developed at Strathclyde in order to take advantage of these opportunities.

THE LauLima TOOL

Groupware has been shown to provide a supportive environment for collaborative learning [13, 14] and is particularly advantageous in enabling PBL in terms of facilitating communication between team members and external contacts. It also provides access to remote physical and digital resources for research. Students can then create knowledge sources collaboratively, participating in a virtual environment to accomplish a real task. Several projects have already tried to improve the mechanisms of PBL through technological intervention, such as the NetPBL and ITCOLE systems [15, 16]. In addition, there have been several previous attempts to coordinate information flows using software [17-19]. However, none of these attempts specifically and collectively targets the types of knowledge creation and sharing mechanisms outlined in the DKF that are typically undertaken by a design team and how they affect design learning. The intention was therefore to improve the learning mechanisms in

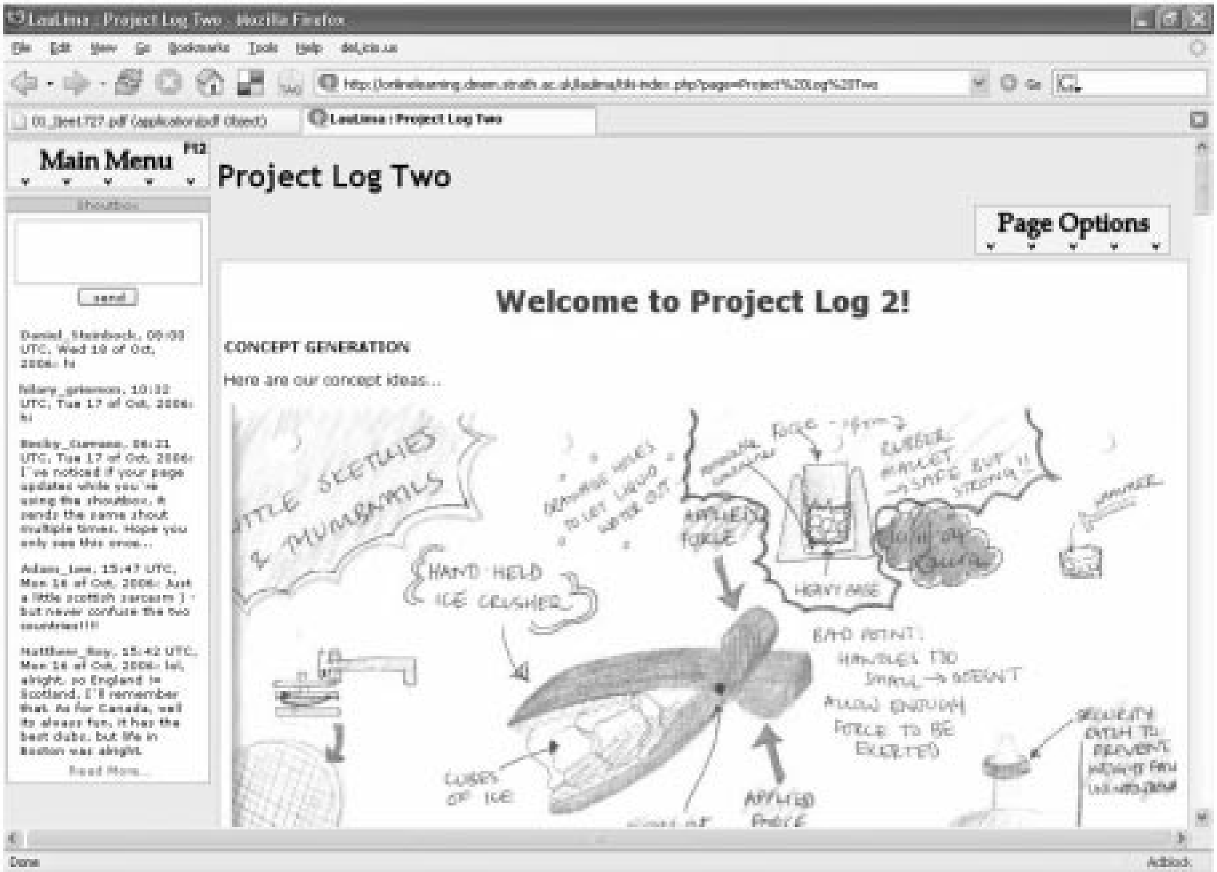

Fig. 3. An example of student concept generation work stored in the LauLima environment.

the DKF using the LauLima groupware developed by DMEM.

LauLima (Polynesian for 'group of people working together') is a customized version of open-source groupware called TikiWiki, and is similar to WebCT and other groupware packages in that it provides standard document management facilities including file storage, image and web link galleries, but also has wiki pages and an associated digital repository orientated towards design students which is added to with each project undertaken. Students are asked to represent the development of the product using linked wiki pages. These inter-linked wiki pages are intended to help students work to develop a shared understanding of their design problem and solution (Fig. 3).

The next section will illustrate how the separate DKF learning loops have been identified, implemented and improved in Year 2 of the IDP class, with LauLima being the medium used to deliver these educational concepts.

CHANGES TO THE CLASS FRAMEWORK

The emphasis in the IDP project was on studio-based design activity. It was a short, intensive project where students were asked to design and build a prototype (a can crusher in Year 1, an ice crusher in Year 2) but to use the digital environment to store, share, organize and record all design ideas and activities. According to the principles of PBL the students were learning primarily through the act of designing, and improvement of their learning experience was orientated around ensuring the level of structure and coaching they were given allowed them maximum independence without inhibiting their creativity. The instructor would deliver the mini-topic and then the coaching team (typically between two and four people) would coach the students informally while they were carrying out their design work. Although the general aims and format of the IDP class remained consistent from Year 1 to Year 2, there were several changes made and these are summarized in Table 1.

The following sections describe three types of restructuring which had to be done for LauLima to be effectively integrated to the class.

Supporting the design process

Pugh's [20] design methodology breaks the design process down into recognised discrete stages, which the designer works through in a typical product development process. In all the project work set for the students, effort was made to return to this framework to illustrate the

Table 1. How class features relate to the Design Knowledge Framework

Learning loop	Class feature
1	Groupware intervention
1	Linking information concepts
2	Structured framework
2	Multi-disciplinary coaching team
3	Mini-topics
3	Informal & formal resource collections

types of activities they should be undertaking and how it relates to the broader process. This contextualization is something mentioned often in the work of Biggs [21] as 'constructive alignment', a key feature of PBL and student-centred learning. Therefore, a key aim of the LauLima implementation was to provide adequate support for students to undertake the required activities at each stage.

Groupware intervention

For a designer to develop sound concepts, it is important to explore and grasp the pertinent subject matter. Research has shown that creating and sharing relevant documents can assist in this [14]. The LauLima groupware helped to ensure that their project files were located in one central area which could be accessed or added to by any team member at any time. The teams could also communicate through this environment to aid synchronous and asynchronous working. Wiki pages could be updated dynamically, rather than having to exchange Word documents and avoiding multiple versions of the same document. Although students may already have access or even own such resources, the key aspect of their use in this context is that teams were encouraged to have the groupware running as background support for informal design meetings in the studio. With this in mind, a pool of laptops was secured by the department for student use, and these were made available to the teams during each two-hour class. It was found that in Year 2 there was a marked increase in the use of the laptops, with teams using it as a medium to show and discuss work both amongst themselves and with coaches. This begins to integrate the groupware into working practice, rather than being an environment where students are forced to store and share work.

Linking information concepts

The students were required to do preliminary research on all aspects relating to ice crushing (ergonomics, mechanisms, safety, environment etc.) in order to be able to begin their idea generation work. This was done with the assistance of a librarian, ensuring that more specific information literacy aspects were embedded in the class. She came into the class in the early stages of the project and ran through specific search and retrieval activities with the students, as well as discussing search strategies. Thereafter, she continued to provide support as required during the rest of the project. Jonassen et al. [22] have emphasized the importance of knowledge structuring for design learning, as it gives the students the opportunity to 'actively inter-relate concepts, ideas, facts and rules with each other and with prior knowledge, the deeper the understanding and learning'. [22]

In addition, for effective learning, it is student-generated knowledge structures that are important, not structures provided by coaches [23]. It was therefore decided to ask the students to build concept maps to help them to create knowledge structures that illustrate their conceptual thinking and to communicate it easily to others outside their team using LauLima. Students created the concept maps in any medium they saw fit- some teams created their map by hand and scanned or photographed it, others created it digitally. In the future, it is hoped to integrate features which allow maps created within the LauLima environment to provide a foundation for team searching and storing exercises, further increasing the social learning of Loop 1 in the DKF.

Coaching

When students undertake design in the studio environment, a number of design coaches provide teams with support. This support is predominantly process-related, i.e. helping teams to interpret the information delivered by the instructor and assisting with navigation through the product design process, but also includes technical advice on design work where appropriate. Therefore, coaches typically have a design-related background. The shared workspace support the coaching process by enabling 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 teams and individual students. The most familiar educational term for the accommodation of this cultural perspective is Vygotsky's Zone of Proximal Development (ZPD) [24]. This is a metaphorical distance between what a learner can achieve independently and what can be achieved in the company of a more skilled collaborator. The LauLima system was implemented with the aim of controlled interactions between peers and coaches that would increase knowledge. Clear methods of achieving this were particularly necessary given the short project timescales. Students were therefore encouraged to externalize their design work by uploading material onto LauLima, providing a forum for interaction with coaches.

Structured framework

One of the major challenges in teaching design is to allow students freedom to explore new ideas and to express themselves, but also to ensure that they are meeting the academic criteria set for each course. The IDP project was intended to emphasize rapid proof-of-concept designing, and therefore had a structure which was intended to help provide guideposts to move students through the process quickly, while allowing them freedom to choose their own process to some extent. Therefore, during the course of the project, the students were asked to keep project logs. This also provided a point in the design process where coaches could reflect and discuss with the team the approach they had taken and progress made. The logs took the form of online Wiki page templates which were distributed at the relevant point in the process and required certain key tasks to be completed. For example, in Project Log 1 teams were required to complete a concept map to assist with defining their information structures. Three logs were completed as the project progressed, with teams spending roughly two weeks on each log. These were an accurate reflection of what happened during the design process, as reworking of the logs later in the project was discouraged. These were used for assessment purposes instead of a formal report and were focused around the deliverables for the three main project stages: a summary of research for Log 1, a summary of concepts for Log 2 and a final design for Log 3.

Because the students had already been storing all their gathered information and generated sketchwork in LauLima, it was convenient for them to then present the information within this structured log. They were then asked to evaluate where they were in relation to the suggested project progress with their coach. The logs were not made compulsory, but students were encouraged to adhere to them with the knowledge that they could use the logs as a means of presenting their work at the end of the project, with the result that the majority of students did complete them. This equates to Learning Loop 2 on the DKF, as students had to contextualize the design work they had done with the broader requirements of the class and review this critically with their coach.

Multi-disciplinary coaching team

The coaching team had varied backgrounds, including an architecture, engineering and product design. This provided students with a number of perspectives on how to approach the design problem. Additionally, Year 1 highlighted that with shared workspaces coaching requires a broader range of skills: coaches not only need to assist students in process and technical aspects of the design process, but also coach them in the retrieval, organization and application of content to support this. This presented a challenge to the coaches who did not have an understanding of the complexities of information retrieval and the organization of content or an understanding of how these issues might affect the design process.

One of the most significant changes during Year 2 was the involvement of a librarian within the coaching team. This ensured ongoing information literacy support was integrated throughout the design project. Students responded positively to this support. This was evidenced in several project logs where students described their experiences. Many reported that the support they received helped them organize their own resources in hierarchical file structures and that it was easier to find resources uploaded by other team members. One team noted that their first impressions of LauLima was that it *'seemed pretty worthless putting information onto a web page'* . . . however, as they progressed it was *'very useful for distributing information . . it reduced the workload . . was able to be accessed by other groups . . . made information readily available and easier to find'.* They also reported that well structured wiki pages made finding the information easier and were *'good for presenting . . . preferable to writing a report'*. These were typical comments for a lot of the teams. There were several comments from students that they had *'learnt about digital resources and design'* from the LauLima system: for the majority, this was the first time they had used groupware.

Information literacy was assessed through the students' contribution to the project logs in terms of the quality and organization of resources uploaded. To fulfil the coaching role it was important that the librarian developed a thorough 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 librarian from more experienced designers on the coaching team. This ensured that the process content of Loop 2 was delivered to the students as efficiently as possible.

Formalizing and reusing content

Vicente [25] states that engineers deal 'mostly with practical problems, and engineering knowledge both serves and grows out of this occupation'. In PBL, the digital repository has potential to be developed as a means to encourage students to engage more with design information throughout the design process, thereby helping develop their design knowledge. However, there is currently little use of existing electronic resources such as subject gateways and portals amongst undergraduates [26]. Students find these resources unresponsive when trying to inform their design work, as the information is often stored in a hierarchical structure and presented in a traditional, multi-layered interface which is not necessarily orientated to the needs of engineering designers [27]. The LauLima environment has, therefore, attempted to integrate the needs of the students, coaches and instructors in providing an environment which will allow quick and easy capture, archiving and indexing of engineering knowledge, and grow through its use.

Mini-topics

During the first 30 minute mini-topic section of the class, the instructor would outline the types of activities the students should be working on, discuss technical issues relevant to that particular stage of the design process and show examples of the type of work they were expected to produce. This was the project backbone, informing both students and the coaching team what was expected to happen each week. The LauLima system proved to be of great benefit in helping to illustrate to students the type and quality of work expected, since the Year 1 class had been through the same process of working, storing and presenting their work in the TikiWiki environment. It was therefore extremely easy to select exemplars to show Year 2 students. This reuse of material is crucial to the sustainability of LauLima as previous student generated resources are used by instructors in preparation of future classes.

The advice given to students was also altered as a result of information gathered on how the students were working from Year 1. For example, in Year 1, students used a controlled convergence matrix [20] to choose between their concepts. This was inappropriate, as the concepts were insufficiently developed for such a selection tool. In Year 2, it was possible to illustrate this vividly to the students by showing an example of a matrix and why it was not valid, and to suggest alternative methods for concept selection. This means that year on year there is iterative improvement in the formalized knowledge delivered through the mini-topics, all students are made aware of pertinent issues and coaches are briefed to reinforce the message. The quality of students' work in Year 2 was perceived by the coaching team as being appreciably better than in Year 1.

Informal and formal resource collections

The project team had intended that coaches and future cohorts of 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 (i.e. through the interlinked Wiki pages, concept maps and reflective logs). This 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.

While an informal shared workspace can 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 informal and formal resource collections. The issue with current formal information repositories is that they are not dynamic enough to meet the rapidly evolving nature of conceptual design. By placing a formal part of the repository with examples of student-generated work, which has adequate metadata for retrieval, in close proximity to the learning environment and as part of the overall groupware, it may be possible to make this more of an integrated, dynamic resource.

DISCUSSION

The changes made to the IDP class have been considered with respect to the LauLima architecture, a revised DKF, and the implications for teaching practice.

Architecture of the LauLima system

This study has identified the need for the development of two parallel systems: a shared workspace (where the teams store, share and present information during the project) is now referred to as the LauLima Learning Environment (LLE), while a digital repository (the long-term library where information is stored and reused) is called the LauLima Digital Library (LDL) (Fig. 4). It is felt that this separation of formal and informal design information, while retaining the proximity of communication tools and information in the virtual environment, gives teams the most flexibility in terms of searching, storing and accessing resources, and could provide a model for other digital repositories. The process of moving resources from the LLE to the LDL involves staff selecting materials stored in the LLE by student teams, which already have some basic metadata applied, to an approval gallery. At this point, coaches flag content for inclusion in the LDL and potentially add more metadata, particularly with regard to educational context. It was recognized by the project team that a final approval stage was required where material is formally deposited in the LDL. This arose due to 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 library/information specialists results in improved retrieval [28]. It is expected that metadata added by students in the LDL will also add to the richness and retrieval capabilities, an innovation which may suggest a new direction for other digital libraries used in education.

Revision of the Design Knowledge Framework

This development of both formal (LDL) and informal systems (LLE) has helped to clarify what is required to effectively support the three learning loops of the Design Knowledge Framework, as shown in Fig. 5.

Learning Loop 1: the LLE is the arena in which teams collaborate and actively design. Information is gathered both from external sources and by searching the LDL. The information gathered by searching the LDL will be primarily student-generated content and should contain an element of context from its metadata. A team accessing this information reclaims it for the informal domain in order to apply it to their particular design situation. The groupware facilities allow students to gather, store and share both types of information (the library objects with applied metadata and raw

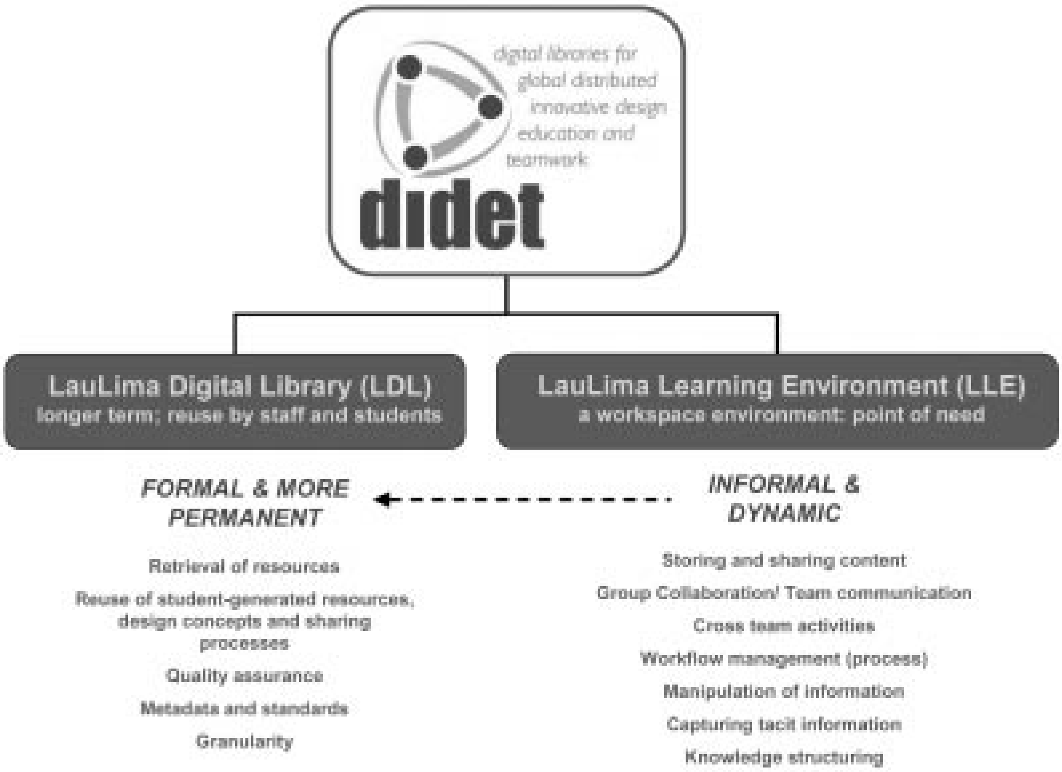

Fig. 4. Architecture of the LauLima system.

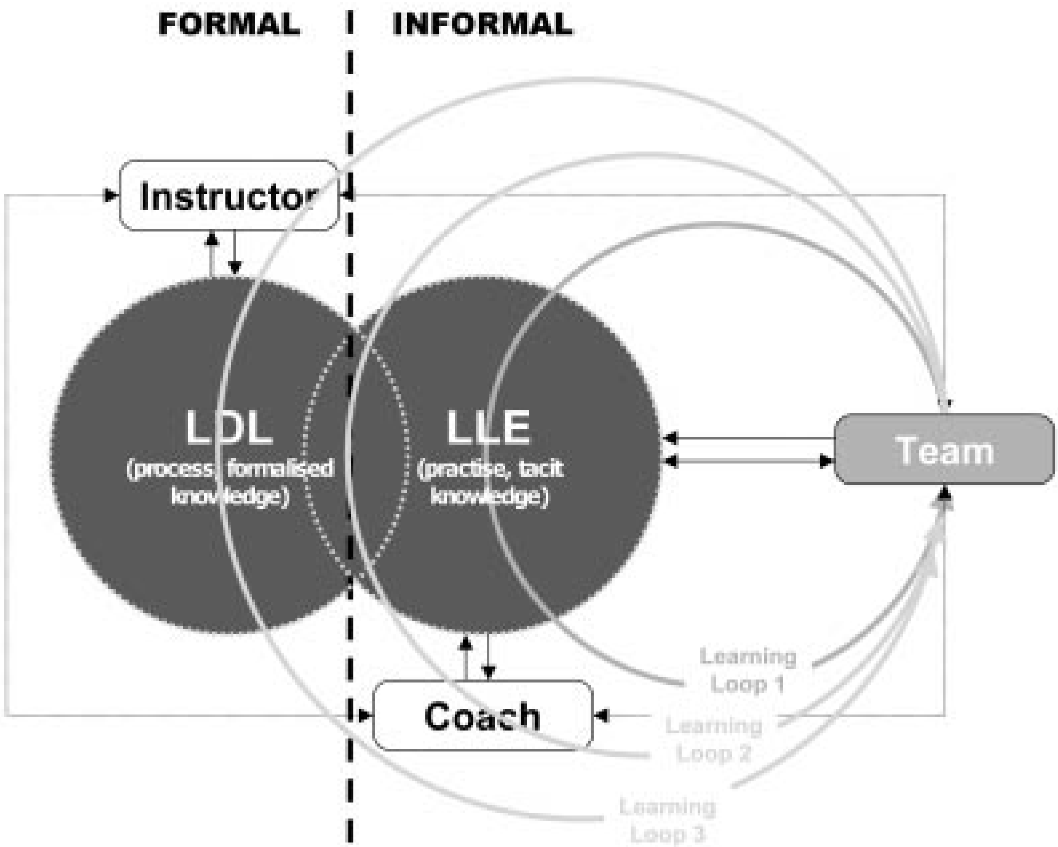

Fig. 5. The revised Design Knowledge Framework.

information harvested) to interact with teammates and colleagues in their linking and organising, increasing understanding of the design problem and encouraging autonomous learning. Although students can create private areas they share only with designated ‘buddies’, it is possible for both the instructor and the coach to monitor the work being carried out by the team through LauLima activity logs, uploaded material to public areas of the LLE and design studio practice.

Learning Loop 2: the coaches interact with the design team both face-to-face and through the LLE. During studio sessions, coaches will talk through design problems and issues faced by the team. As teams begin to sift, link and organise information in their Wiki pages and logs, they create knowledge structures which illustrate their interpretation of the design problem. In the studio a laptop will normally be present, and the coach can quickly and easily assess progress by examining this developmental work, allowing appropriate and tailored support to be provided. This process can be undertaken remotely using LauLima’s collaborative tools, making it possible to provide support outside normal class times—often when the student actually needs it. The coach can also access the LDL to cite examples of previous work they may be familiar with. Feedback to the instructor can take place both through meetings with the coaching team as well as by monitoring logs, coaching comments and other student output in the LLE.

Learning Loop 3: formal class information is delivered primarily through the mini-topics. These are subsequently posted on the class homepage on LauLima. Additional resources such as web links, milestones and class announcements will also appear as the project progresses. The formal digital library is where resources generated by students, which have been selected by the instructor and approved by the library/information specialist, will reside. As well as providing an important source for students, material in the LDL will be used by the instructor in preparing mini-topics and class examples. Additionally, the outputs in the LLE from both the coaches and students can be fed into the mini-topics generated and delivered as the class progresses. These more formalized resources, contextualized by process and/or metadata, are the wisdom garnered from the experience of previous classes and hopefully passed to the next. This means that resources move in a cycle from Loop 1 through Loop 2 to Loop 3.

Emerging themes

The changes in the IDP class from Year 1 to Year 2 were planned, discussed and implemented during the summer break as part of an ongoing process of optimizing the technology to support team design projects. The effects of these changes have been monitored through several evaluation methods. The feedback was generally positive, both in terms of student reaction and staff appraisal of the effect on design learning. The results are summarized in Table 2.

The principles of PBL will continue to be embedded in the class. The construction of the concept maps has strengthened the social context of the learning, emphasizing the Vygotskian perspective of PBL [5] in the early design stages. This has proved useful in externalizing and discussing conceptualizations of the design problem and fits with the visual bent of the designer. In future, the map could be developed further as the project

Table 2. Evaluation results from Year 1 and Year 2.

	Year 1	Year 2
Evaluation methods	Student focus groups; reaction cards; team presentations; analysis of team activities, Wiki pages and file galleries in groupware.	End of class student feedback; team presentations; analysis of team activities, Wiki pages and file galleries in groupware.
Findings	Moderate use of pool laptops and shared courseware for uploading and storing files on LauLima.	Sustained use of pool laptops with LauLima running as a support tool for team management and communication purposes, as well as an information store.
	Students needed guidance on organizing, editing and structuring of information.	Student reflections revealed that concept mapping exercise aided in structuring and organising information, and understanding of the problem.
	Most students relied heavily on the Internet and the library for sources of information, reporting they preferred to use sources they were familiar with.	Student reflections highlighted a broader awareness of different information sources and revealed flexible and more effective search strategies.
	Students began to realize the importance of documentation as part of the design process.	Project logs gave an indication of expected progress as well as documenting design process.
	Organising and structuring information in the Wiki pages allowed sharing of resources.	Student feedback that there was a ‘logical process’ to information gathering activities.
	Class structured to allow coaches to interact informally with teams in studio.	Positive student feedback highlighted importance of regular informal input from coaches.
	The most successful teams were those that reflected on their design process and considered how to resolve issues.	As previous. The re-use of previous student examples in mini topics allowed major issues to be anticipated and highlighted.

progresses, with the nodes representing direct links to the relevant resources by digitising the map and becoming a project hub for resource storage and retrieval. This may be one way of formally linking knowledge structures to the resource stored in the LauLima digital library based on student usage. Further work is being carried out to determine which resources prove most popular with students, particularly with respect to different stages of the design process, and to establish the preferred form in which students wish to access this material.

Another important concern of the IDP class is to encourage autonomous learning, with teams and individuals working self-sufficiently through the design process. In constructivist learning theory, a key aspect of this is self-reflection. This student ownership of their work and learning is conductive to the kind of student-regulated reflective cycle advocated by Cowan [29]. The storage and sharing facilities provided by the LLE system allows them to access and use information generated and obtained during their work to undertake the necessary reflective and planning activities more effectively, while the LDL provides an alternative to lectures and notes, allowing students to search and acquire new knowledge for themselves [30]. There can be a tendency for students to ask for 'the answer', but in accordance with the principles of PBL (and similar to the ideas of scaffolding in ZPD) the coaching team encourage students to seek out the appropriate information and to make informed decisions themselves.

Despite encouraging this level of self-sufficiency, the role of the coach remains key in providing appropriate support for individuals and teams by provide advice on the design process and methods—as opposed to specific design decisions. While instigating this independence of thinking is perceived at DMEM as key to students' future success as designers, tailoring the level of support for different teams and individuals remains crucial to the success of a PBL class. In this regard LauLima proved invaluable. The project logs provided a facility for the coaching staff to quickly establish where the respective teams were in the project, and to evaluate the quality of their work by reviewing the team wiki pages as the project progressed, and in particular at key project milestones. This allowed extra attention to be given to teams who were struggling, and to stimulate further teams who were making good progress. Given the freedom to work autonomously or consult with coaches depending on how comfortable they were with their existing knowledge, accessing digital and textual resources and navigating the product development process, it was noted that high performing design teams often explored their ideas further independently (but still within the structure of the project logs) and would speak to the coaches more to update on what they were doing or intended to do. In future, an automated method to measure and display the performance of teams at a high level may be useful, but having all project design information in an accessible format in LauLima helped the coaching team.

The mixed discipline coaching team was found to be advantageous in providing students with a broad educational experience. In particular, the expertise provided by the librarian, coupled with the concept map exercise, had a positive influence on the way students searched, stored and organized their information in Year 2 in comparison with Year 1, who had no such training or formal exercise. This was evidenced by better structuring of teams' file galleries and improved addition of metadata to uploaded resources when team Wiki sites were reviewed.

It was found that the different backgrounds of coaching staff occasionally led to them giving different advice to students on the same problems and this led to some confusion. One can argue that 'mixed-messages' are very much a part of real world problem solving, and this mode of interaction introduces students to the idea of handling that difficulty early on. However, in future it would be advantageous for the coaching team to be briefed beforehand to ensure a consistency of message in relation to what is expected of students. This should be derived from the mini-topics delivered by the instructor. Again, LauLima can be used to help distribute this knowledge by setting up a coaching group on the system where key information from each mini-topic can be summarized and sent to the coaching team. A short meeting before each studio session should then be sufficient to ensure that there is no confusion. This also provides another mechanism for feedback to allow the mini-topics to be altered according to how the class is progressing: the coaching team works closely with the students and can provide the instructor with their viewpoint on what, if anything, needs to be changed. Another benefit of the mixed skills of the coaching team is that expertise in particular areas (such as information literacy) can be fed into the mini-topics at this point. Indeed, the 'dissonance' arising from these variations in expertise can lead to the stimulation of new ideas and help keep the class material fresh and relevant [31].

With access to laptops in an informal setting in the studio, use of the LauLima system became an integral part of the design working routine. In accessing material, however, navigating hierarchical file lists is still problematic and the system interface could be enhanced further through the use of thumbnails for image previews. Uploading large amounts of visual information is also an issue, and more digital cameras, image-capturing equipment and digital sketching devices will be purchased as DMEM continues with its long-term vision of a media-rich studio environment. Additionally, although the process of adding metadata to uploaded materials has been shown to help with contextualizing information, the process must be optimized and automated as far as possible to ensure that it is not tedious for the student who is undertaking the project and for the instructor and librarian in moving materials from the LLE to the LDL [32]. Work continues on the system.

CONCLUSIONS

This paper describes how the LauLima digital groupware has been embedded into an activity-based design project and had a positive effect on the students' design learning activity: the student feedback in the form of questionnaires and verbal feedback was affirmative. A Design Knowledge Framework was used to identify learning mechanisms of design engineering students, and LauLima was used to help facilitate changes in the class structure from Year 1 to Year 2 to enhance these learning mechanisms.

Teams were encouraged to use the LauLima groupware as a support tool in the studio environment. The process of generating, uploading and linking resources helped to encourage autonomous learning within the design teams. Students were forced to reflect on what resources were useful and how they related to their design work. Concept maps were successfully introduced as an exercise used to help formalize this.

In terms of coaching, project, logs were used to allow staff to quickly assess team progress and to tailor support accordingly. It was noted that the better performing teams tended to work independently, interacting with the resources they uploaded to the repository as their designs developed and using the coaches as a sounding board. Poorer performing teams had less material in the repository to manipulate and required more focused guidance. The mixed discipline nature of the coaching staff also introduced a variety to the opinions students received. This helped, particularly with regards to information literacy, to broaden the learning experience although at times mixed messages could confuse less confident learners. It was particularly important that all the coaching staff were willing and able to use the LauLima system. As with the introduction of any new software system, it requires considerable support for new users to accept it. The coaching staff were crucial in providing this.

With regards to formalizing and reusing content for future cohorts, the LauLima system proved helpful in illustrating to students the type and quality of work expected. Through the selection of exemplars from previous cohorts, the material delivered by the instructor was tailored to address specific issues. Year on year, this process will ensure that the formalized knowledge encapsulated by the class framework will consistently improve to meet the students' needs. The time taken to capture and upload content, and how this can impinge upon the natural 'flow' of design work, is an issue common to all digital repositories, and one the research team continues to explore through changes to the uploading procedure and hardware available for data capture.

These changes proved successful—what appears to have happened is that LauLima supported the exchange of project logs between students and coaches, the sharing of concept maps, the realtime documentation of design ideas. Although there was some initial resistance from students to the new software introduced, a high level of support from the coaching staff and lectures to outline the tangible benefits of good information management practice mean that by the end of the project there was generally a good level of engagement. The standard of work was perceived by staff as higher, and student enjoyment also seemed to increase, with a higher attendance during class hours recorded and more positive informal feedback.

The LauLima software will therefore continue to be developed in order to improve the learning mechanisms identified by a revised Design Knowledge Framework. By revising the LauLima architecture to take account of the difference between formal and informal design knowledge, it has been possible to integrate it with a revised format of the Design Knowledge Framework, providing a clear structure for teaching interactions and the master-apprentice framework for the class. Development of the LauLima system and strengthening the PBL principles as illustrated in the DKF in the class structure will continue in parallel, and it is projected that over the next two years this work will be conducted across global design teams.

This project is being evaluated as part of the Digital Libraries for Distributed Innovative Design Education and Teamwork (DIDET) collaboration between the University of Strathclyde and Stanford University funded by JISC/NSF (NSF Grant No. 0230450). This entails students using digital library resources to aid team-based design activity as a first step towards running globally distributed team-based design projects, supported by digital libraries and associated technologies.

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