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A framework for design engineering education in a global context

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Abstract

This paper presents a framework for teaching design engineering in a global context using innovative technologies to enable distributed teams to work together effectively across international and cultural boundaries. The Digital Libraries for Global Distributed Innovative Design, Education, and Teamwork (DIDET) Framework represents the findings of a 5-year project conducted by the University of Strathclyde, Stanford University, and Olin College that enhanced student learning opportunities by enabling them to partake in global, team-based design engineering projects, directly experiencing different cultural contexts and accessing a variety of digital information sources via a range of innovative technology. The use of innovative technology enabled the formalization of design knowledge within international student teams as did the methods that were developed for students to store, share, and reuse information. Coaching methods were used by teaching staff to support distributed teams and evaluation work on relevant classes was carried out regularly to allow ongoing improvement of learning and teaching and show improvements in student learning. Major findings of the 5-year project include the requirement to overcome technological, pedagogical, and cultural issues for successful eLearning implementations. The DIDET Framework encapsulates all the conclusions relating to design engineering in a global context. Each of the principles for effective distributed design learning is shown along with relevant findings and suggested metrics. The findings detailed in the paper were reached through a series of interventions in design engineering education at the collaborating institutions. Evaluation was carried out on an ongoing basis and fed back into project development, both on the pedagogical and the technological approaches.

Keywords: Design Education; Design Engineering; Digital Libraries; Distributed Working

1. INTRODUCTION

1.1. Background

In design engineering, there has been a shift from strongly empirical forms of design theory toward more learner-centered approaches that take account of human and social factors in the design activity (Love, 1999). 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 (Palincsar, 1998; Prosser & Trigwell, 1999). Although still assuming there is a process of assimilation from the instructor or coach, this recognizes a "joint enterprise" (Atherton, 2004) with respect to creating new meanings. In product design engineering, this involves the application of knowledge in creative thoughts and ideas in the development of new product configurations. In the educational setting, project work is increasingly used to help students integrate, apply, and expand on knowledge gained from theoretical classes in their curriculum. This approach has been formalized in educational literature as project-based learning (PBL): working in teams, students explore problems, develop solutions, and create presentations to share what they have learned. According to Curtis (2001), compared with traditional teaching methods PBL has many benefits, including deeper knowledge of subject matter, increased self-direction and motivation, and improved research and problem-solving skills.

PBL is similar, but not identical, to problem-based learning. They are both instructional strategies that are intended

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to engage students in "real-world" tasks to enhance learning; they are both student-centered approaches; and both include the instructor in the role of facilitator (Thomas, 2000). There are, however, some key differences. PBL typically begins with an end product in mind and asks students to research, plan, and design to reach this goal; but *problem*-based learning uses an inquiry model where students are presented with a problem, gather information, and summarize their new knowledge, although there may or may not be an end product. Both are authentic, constructivist approaches to learning; but for the purposes of product design engineering, PBL and its focus on the content, knowledge, and skills acquired during the production process is the more appropriate method. Examples of its application in the area of design engineering across a range of institutions (Frank et al., 2003; Mills & Treagust, 2003; Dym et al., 2005) have shown it to be an effective way to prepare students for the challenges of working in industry, particularly with regard to teamwork. This work specifically addresses how the learning mechanisms associated with PBL can be supported through the use of digital technologies, with particular focus on enhancing use of information across teams.

The design knowledge model (Eris & Leifer, 2003) developed at Stanford (Fig. 1) illustrates the interactions between a design team, coaches, and the product development activity. This framework also effectively illustrates the educational issues within collaborative design projects. Whether working alone or in formal design teams, students in the design studio still work in a social context whereby they learn from their peers in an informal manner, and teammates and coaches in a more formal project context. 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. The arrows represent the "acquisition" or "cogeneration: of product development knowledge.

The application of the design knowledge model within design learning contexts has led to the identification of three learning loops associated with any design activity. Eris and Leifer describe these loops as follows:

- Learning Loop 1—Supporting the design process: Teams apply the product development process contextualized for them by coaches in their design practice. They utilize the information embodied in the process, and in doing so they generate new information.
- Learning Loop 2—Coaching: Coaches observe the design practices of teams, and use the understandings they gain in contextualizing the product development process for them. Based on the needs of teams, coaches selectively extract information from the product development process and contextualize it for the teams.
- Learning Loop 3—Formalizing and reusing content: Coaches retain a history of the new knowledge generated during design practice, and extract new elements from it in order to improve the product development process. Instructors manage the capture, indexing, and publishing of the new information that teams generate.

In empowering the student and creating a constructivist learning environment, three distinct opportunity areas were identified for technological intervention to improve the learning mechanisms in design activity. The following section describes the pedagogical aims of the Digital Libraries for Global Distributed Innovative Design, Education, and Teamwork (DIDET) Project and the resulting development of the LauLima (Polynesian for *a group of people working together*) digital library and groupware system to facilitate their implementation.

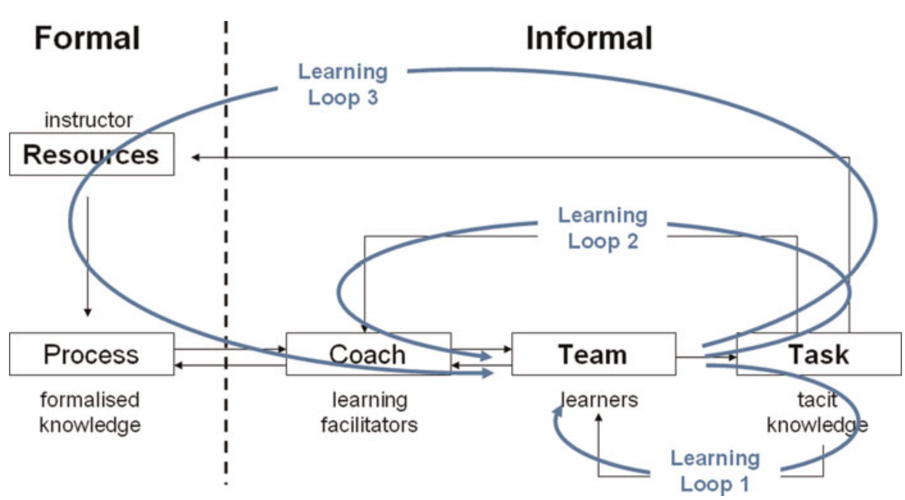

Fig. 1. Three opportunities for technological intervention in enhancing design team learning performance. [A color version of this figure can be viewed online at journals.cambridge.org/aie]

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1.2. Aims and objectives of DIDET

The central goal of the DIDET Project was *to enhance student learning by enabling them to partake in global, team-based design engineering projects, in which they directly experience different cultural contexts and access a variety of digital information sources via a range of appropriate technologies.*

1.3. Methodology

To achieve its aims, the DIDET methodology was twofold. First, the project planned to implement a digital library at the partner institutions to improve learning in design engineering by providing a repository for students to create, store share, use, and reuse information resources for design engineering teamwork. Second, the project planned to develop a new global design project (GDP) that fit the curricula of both the University of Strathclyde and Stanford University, allowing the students at both institutions to work across geographical and cultural boundaries in global design teams. The digital library (and other technologies) would be used to support this global teamwork. After the first 2 years of the project, it became apparent that differences in course structures, time tables, and credit for assessment at each institution made it impossible to develop a single class that was suitable for both. Rather than abandon this part of the methodology, it was decided that it would prove more effective to run a joint element rather than an entire module shared between the institutions. In practice, this meant developing a new global project for UK–USA student teams that would be an assessed element of new classes at Strathclyde and Olin and part of an existing class at Stanford.

1.4. Implementation

The key stages of implementation of the DIDET Project were the development of the digital library, its deployment and evaluation in student classes, and the development of a pedagogical framework. Each of these are discussed in more detail.

2. DEVELOPMENT OF DIGITAL LIBRARY

2.1. Library specification

Early specification of the project digital library involved evaluation of existing groupware and digital library products, a pilot exercise in information seeking at Stanford University, examination of other digital library products, and extensive studies in the classroom of student use of project information and resources. The following key findings relating to the DIDET digital library emerged during specification:

- There is a need for two related repositories: a student-shared workspace where academic staff and students working on projects can upload and develop content to share with others, and a formal digital library, which is a managed repository containing evaluated and validated resources.
- Dublin Core metadata standards (Dublin Core Metadata Initiative, 2009) were identified as the best choice for the repositories with additional fields as required by the project. Recording of educational context and use of content emerged as an additional important need.
- The INSPEC Thesaurus (Inspec, 2009) was identified to provide a controlled vocabulary for keywords; selected terms were made available to students and staff, and the full thesaurus was available to uploading staff and the Librarian/Information Specialist.
- A workflow was required for uploading content to the library system and applying metadata.
- An investigation into UK Intellectual Property Rights and Digital Rights Management led to a redefinition of the student agreement and strict guidelines for content uploading.

2.2. Library development and implementation

Following its specification, the LauLima System was developed at the Department of Design Manufacture and Engineering Management (DMEM) by extensively customizing the open-source groupware TikiWiki (The Tiki Community, 2009) to best suit project requirements. While providing the standard document management facilities including file and image storage, Web-linked galleries, and Wiki pages, our studies identified the need for two interdependent components to the LauLima System (Fig. 2) to accommodate the needs of design engineering practice. These system components are the informal LauLima Learning Environment (LLE) and the more formal LauLima Digital Library (LDL; McGill et al., 2005; Breslin et al., 2007). The LLE is an informal shared workspace, which has a file storage area (file galleries) and allows the creation of dynamic Wiki pages that students can use to document their design process, rationale, and the developing outputs, to share with others. In addition to a suite of integrated communication tools, the system includes a highly controllable permissions system, allowing teams to effectively manage and document their design project work. The more formal LDL is a digital repository of learning resources used to support design engineering students in the classroom and complements other information sources available to students (e.g., books, documents, institutional library resources, and websites).

Modifications to the TikiWiki groupware include the incorporation of a granular permissions system to facilitate the sharing of folders and files with individuals or groups, meaning that rights to pages and objects in the system can be controlled on a world, group, or individual level; the development of a hierarchical file storage mechanism to enable students to organize and manage their information as they upload to the groupware; a digital library component to store, categorize, and aid retrieval of materials; administrative tools to help with the workflow; and integration with the central

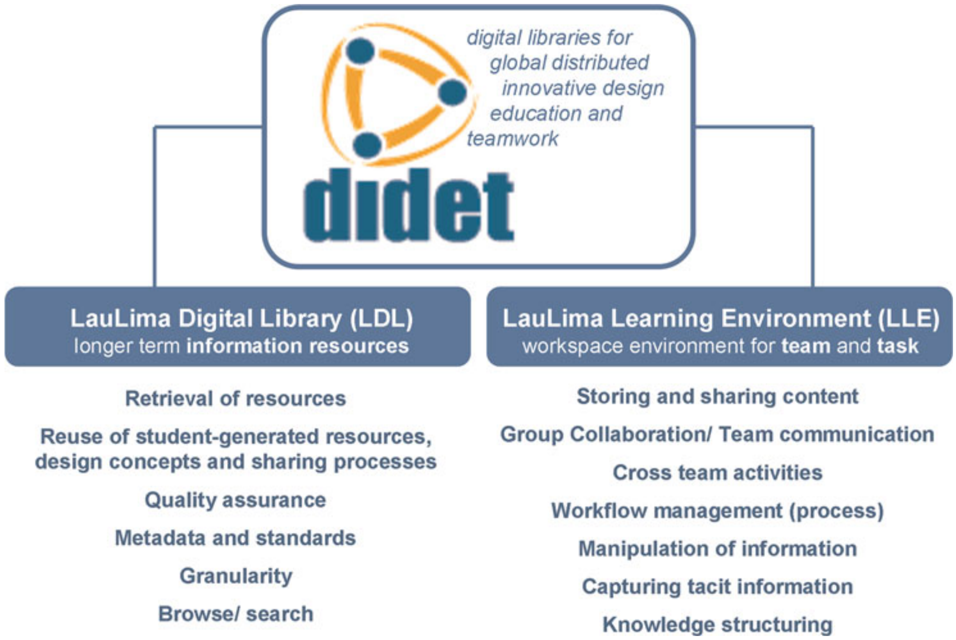

Fig. 2. The LauLima system architecture. [A color version of this figure can be viewed online at journals.cambridge.org/aie]

university login system to negate the need for an additional username and password.

A key implementation was the workflow for uploading content to the system and applying appropriate metadata (Grierson, Wodehouse, et al., 2006). Resources created by students, in the form of sketches, photographs, models, calculations, concept maps, reflective logs, reports, and so forth, are initially stored in the LLE during their design projects. These resources provide a rich record of the design process and of the students' knowledge structures. At this stage metadata is applied automatically by the system (file type, date added, depositor name, and team) and additional metadata can be applied by the depositor (title, format, source, citation, keywords). Teaching staff then harvest the most useful resources from these student LLE workspaces on an ongoing basis and submit them for inclusion in the LDL. Externally created resources, or references to them, can also be stored in the LDL. At this stage further metadata is added in the form of additional keywords and educational context information. The third stage involves an information specialist checking content for appropriateness, quality, and legality, and applying final stage metadata (rights information, additional keywords). At this stage content is officially uploaded into the LDL and is made available for other students and staff to use.

The LDL differs from existing design engineering resource collections, such as SMETE (http://www.smete.org/smete) and EEVL (http://www.eevl.ac.uk), in that it contains more of the unique informal and tacit information and knowledge created by students during the design process (e.g., ideas, decisions, and design rationale), and it gives students access to specific project-related, hard to access formal information and resources (e.g., standards, patents, and company reports), which can often take considerable time to source or need copyright clearance.

In addition, five case studies have been developed to demonstrate the range of uses of the LauLima system, or selected elements of it, and cover the use of LauLima for teaching and learning, to support research and for other information systems (University of Strathclyde, 2009).

3. STUDENT USE OF DIGITAL LIBRARY IN CLASSES

3.1. Overview of classes

One of the primary goals of the DIDET project was to integrate digital resource collections (digital libraries) into the classroom by integrating resource creation and reuse into class activities, thereby providing opportunities for students to improve information literacy skills and develop team-based design process skills. In classes where LauLima supports learning, students receive an induction in the use of the LLE including its technical features. They then engage in a team design project and use the LLE to store and share resources and links to resources that have been created or discovered as part of the design process in one place. Other functionality within the LLE helps students to keep track of different versions of documents created collectively by members of the team and to collectively manage the team workflow. During the development of the design interlinked Wiki pages comprising resources (e.g., sketches, images, descriptive text), stored project documentation and links to resources help to capture students' tacit and developing understanding of the design process. In addition, at different points in the de-

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sign process, students use the LLE and the interlinked Wiki pages to deliver presentations to staff and peers for feedback. Classroom activities are designed to encourage students to engage in analysis and reflection on their own understanding and to help them create new and more elaborate knowledge structures (McGill et al., 2005).

3.2. Evaluation methods

Key to the research philosophy of DIDET is the interpretivist paradigm. As a result, the majority of studies were of an empirical nature within the classroom setting in an attempt to provide insight and deeper understanding of design information processes and experiences. Studies of this kind have gained more importance and are becoming more commonly used in design engineering research since the widening of its view from prescribing to describing design activities (Foltz et al., 2002).

Strathclyde studied the use of LauLima in three key classes over 4 years. Each of the classes had a particular evaluation focus. The Integrating Design Project (IDP) evaluation focused on the use of information storing and sharing and on the use of digital libraries (Grierson et al., 2004; Nicol et al., 2005). The Product Development Project (PDP) focused on gathering students' feedback on the use of LauLima to support project management and reflection in industry-related team projects (Grierson, Ion, & Juster, 2006). The GDP focused on the logistics of running a distributed class—teaching and learning, collaboration, and technologies—all in the context of global product development (Grierson, Ion, & Juster, 2006; Wodehouse et al., 2007, 2008).

A range of quantitative and qualitative methods were used to the evaluate studies in the different projects. Quantitative methods such as surveying class opinion via questionnaires and polls, and weekly analysis of file galleries, Wiki pages, e-mails, and blogs were undertaken. The need for a rich and detailed understanding of how and why various phenomena occurred, and how processes might be improved through change, also necessitated a greater use of qualitative methods, for example, observation, interviews, reflective sessions, focus groups, and the examination of student reflective reports. Evaluation was both formative, to improve the project and inform the development of the infrastructure as it progressed, and summative, to determine the success of the project on an annual basis. It included the collation of both staff and student views, with yearly results fed back to the students to support and improve their learning. The use of student feedback material in project management and reflective work sessions allowed students to make improvements based on previous students' work. Objective data was also collected from the system data logs, showing login details, resources collected, stored, accessed, and the frequency of use.

3.3. IDP

Working in teams of four, third-year product design engineering students taking part in Strathclyde's IDP class have 6 weeks to design and model a crushing device. Each year the type of crushing device is changed (can crusher, ice crusher, fruit squeezer, etc). Teams meet face to face, but tasks and assessment encourage online storing and sharing of information and resources in the LauLima system. These studies focus on information management, teamworking, and use of an online support tool.

Evaluation (McGill et al., 2005) in this class found many students relying heavily on the Internet and library as sources for information rather than using a digital library, as they were quick to use and familiar. They found existing resources in nationally available digital repositories not to be useful to engineering students, with students also requiring considerable guidance on organizing, editing, and structuring information, and searching with key words. Additional support and training in these aspects showed improvement in subsequent classes. The use of interlinked Wiki pages to organize design information and to document the design process positively influenced the way students used information to develop concept work through the emphasis of relationships between information items, the construction of design concepts, and navigation of the overall design process. After 3 years of running the class, there were just over 50 resources selected for inclusion in the LDL by academic staff on crushing devices. By 2006–2007, however, over 400 resources were available, 182 of which were specifically related to crushing projects, which is a sufficient number and range of quality resources to engage students. These included examples of student project work, including market research, sketches, photographs, videos, mind maps, concept ideas, prototypes, and diagrams. Throughout the latter two studies students' interactions with the LDL were logged by the system and a short questionnaire and staff and student focus groups were undertaken. Students used the LDL most at the beginning and end of project work, valuing the contextual material (resources that gave rationale and detailed why things were done) and stimulus for idea generation (building on existing knowledge). Academic selection ensured resource quality, with staff finding the LLE generated valuable resources and exemplars for class teaching and setting standards for students (Grierson et al., 2008).

3.4. PDP

Strathclyde's PDP class enables industry companies to realize projects through collaboration with teams of fourth- and fifth-year students. One of its main objectives is to encourage professional, independent thinking in a project context by encouraging students (in teams of four to five) to take ownership and management of all parts of a project. Teams are required to maintain a presence on the Web using the LauLima system, create a team site, a project log, online minutes, and a project file of project-related documents. These technological interventions are designed to support the processes of PBL by giving students opportunities to reflect on the design process, and to raise awareness and skills in solving complex problems.

Evaluation was through analysis of team Wiki sites, project logs, polls, student reflective blogs, and observation in class (Grierson et al., 2005). Students confirmed previous findings using digital repositories and shared workspaces that having all project information in one central location allows more flexible working patterns for teams, reduces document loss by offering a secure store and reducing the need for hard copies, and saves time in subsequent searching for information.

3.5. GDP

The experience of the IDP and PDP classes supported the development of a collaborative GDP run across the institutions, one of the DIDET Project's key aims (Fig. 3). The intention of the GDP was to give students experience with distributed design teams, allowing them to gain an understanding of the logistical problems that can arise and exposing them to cultural differences, utilizing a variety of different collaborative design tools, including video conferencing, shared workspaces, and digital repositories.

Before implementing the GDP, a series of collaborative experiments took place between small groups of Strathclyde and Stanford students. Consisting of exercises to design paper-based products, the purpose of these was to streamline the pedagogical approach, to establish the logistics of running such classes, and to gain feedback on the use of digital libraries (Grierson, Wodehouse, et al., 2006; Sonalkar et al., 2006). In addition, a series of experiments on the use of video in digital libraries was undertaken at Stanford with a view to optimizing the students' interaction with library materials (Sonalkar et al., 2007). The path of development is summarized in Figure 3.

The GDP was run in 2006–2007 for the first time across Strathclyde, Stanford, and Olin (where one of the DIDET research teams was now based). The class at Strathclyde focused on product development in a global context, with students putting the theory of distributed design management into practice through the GDP experience. This was a 3-week collaborative element where students worked together on a design brief to design a coffee cup holder. Teams were expected to explore the issues related to this task that would apply in their respective countries to develop a design solution to carry multiple cups effectively and safely.

Strathclyde, Stanford, and Olin used the development space on the LauLima system to share plans for their individual classes and the collaborative GDP. Coaches also used LauLima to collate feedback before sending to student teams after each milestone deliverable was submitted. All institutions shared teaching and class plans before and during the first semester.

The global design teams were expected to use a range of technologies to support their collaborative work. All students participating in the class signed up to LauLima and teams were encouraged to create a homepage using the Wiki tech-

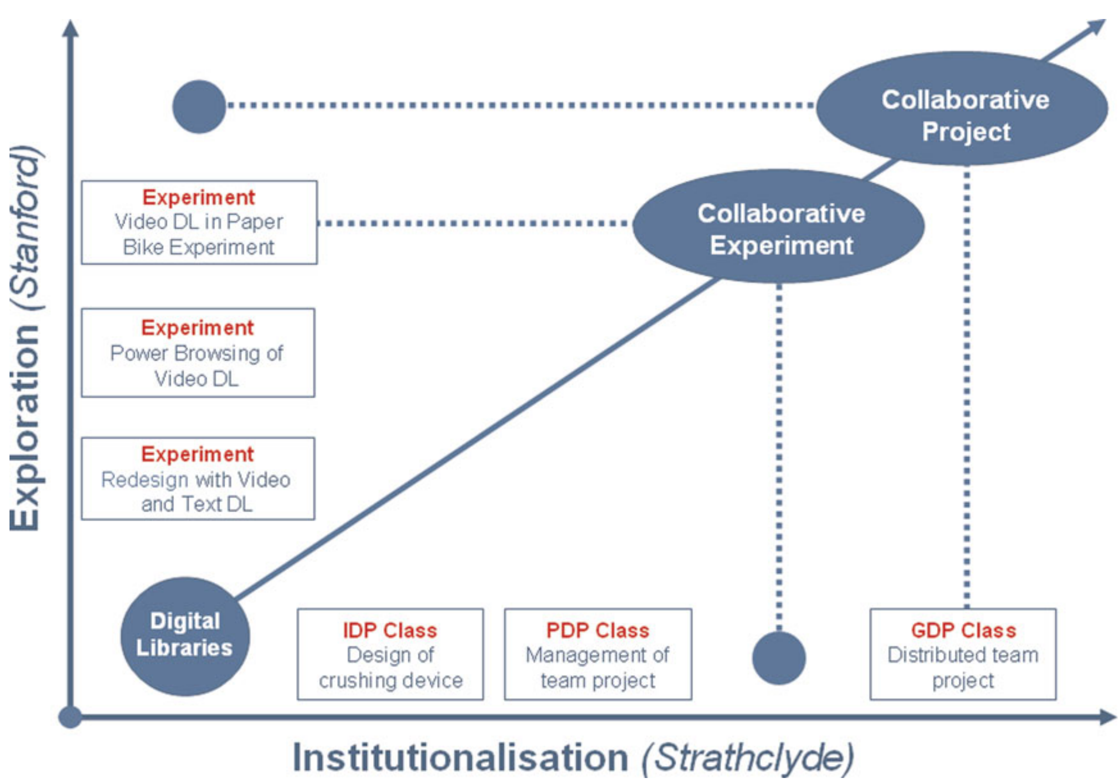

Fig. 3. Working toward the collaborative global design classes and global team design project; DL, digital library; IDP, Integrating Design Project; PDP, Product Development Project; GDP, Global Design Project. [A color version of this figure can be viewed online at journals.cambridge.org/aie]

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Table 1. *Summary of issues when populating the LDL*

Stage: Activity	Role	Issues Identified
Stage 1: upload content to the LLE as part of a series of learning activities within a class	Students Academic staff (secondary)	• Insufficient, misleading, or poor metadata created • Information literacy training is crucial • Interruption of student design process • Time consuming for students • Keyword application increases student interaction with information and encourages reflection
Stage 2: flag content in the LLE for inclusion in the LDL; add more metadata	Academic staff	• Added educational value with context and process related material, specific to classes • Long-term reduction in preparation of class materials • Time consuming to select and move resources • Identification of key time to add content to LDL • Granularity: presently unable to upload linked information that provides added context
Stage 3: index and approve resources for LDL inclusion; resolve IPR and DRM issues	Librarian/Information Specialist	• Rejection of resources due to insufficient referencing or copyright clearance • Time consuming tracking down references • IPR and DRM to be resolved • Maintenance and refreshing of digital library material over long term

Note: LDL, LauLima Digital Library; LLE, LauLima Learning Environment; IPR, Intellectual Property Rights; DRM, Digital Rights Management.

nology, and the LDL was configured to allow students to access the resources in the digital libraries in LauLima across the three sites. Students communicated via PolyCom (http://www.polycom.com) or desktop video conferencing, for example, FlashMeeting (http://flashmeeting.open.ac.uk) and Skype (http://www.skype.com), and they used a range of technologies, for example, LLE and LDL (http://onlinelearning.dmem.strath.ac.uk/laulima/tiki-index.php). They also used information sharing tools such as YouTube (http://www.youtube.com) and Google Documents (http://docs.google.com), messaging tools such as MSN Messenger (http://www.msn.com), real-time collaboration tools such as Campfire (http://www.campfirenow.com) and Thinkature (http://thinkature.com), as well as other Wiki systems. To facilitate access to necessary technology, classes at Strathclyde were held in its Digital Design and Manufacture Studio (Mair et al., 2007).

The project was evaluated using confidence logs, reflective class sessions, analysis of students' archived project work, and focus groups with students. The students who participated not only achieved the learning objectives of developing an understanding of the organization and management of distributed design but also gained valuable experience for future employment. For further information on this first implementation of the GDP, see Wodehouse et al. (2007).

In 2007–2008, following development work on the global design class, a "task-based" approach where students undertook weekly global design tasks with different global partners over three separate weeks was undertaken, rather than one 3-week project. Students were encouraged to reflect on various aspects of the different design tasks, comparing and contrasting different cultures, technologies, and methods of communication. They were able to directly experience and compare synchronous and asynchronous working and relate the theory of the lectures to the case studies given in class (Wodehouse et al., 2008). Continuing use of this targeted approach has allowed the use of different global partners (including the University of Malta and Swinburne University of Technology in Australia) as appropriate for each project topic, and provides ongoing flexibility in the class format.

Note that the first three stages of this implementation (library specification, library development, and implementation and student use of library) were iterative, with several versions of the LDL being specified, developed, implemented, used, and evaluated, and then being respecified and redeveloped based on evaluation results and feedback. Some of the issues (those relating to information input) used to guide this development process are illustrated in Table 1, with full details of evaluation and key findings for each class linked from the project website (University of Strathclyde, 2008).

4. FRAMEWORK DEVELOPMENT AND DISCUSSION

The project team developed the DIDET Project Framework to encapsulate all findings relating to the use of digital libraries in collaborative design education as shown in Figure 4. The framework consists of six principles relating to information resources, teamwork, and the design task, with metrics suggested for each. The principles are outlined in more detail below.

4.1. Information resources

4.1.1. Resource range and utilization

The first aspect of the library in the framework to consider is the range of resources and their utilization. A key approach

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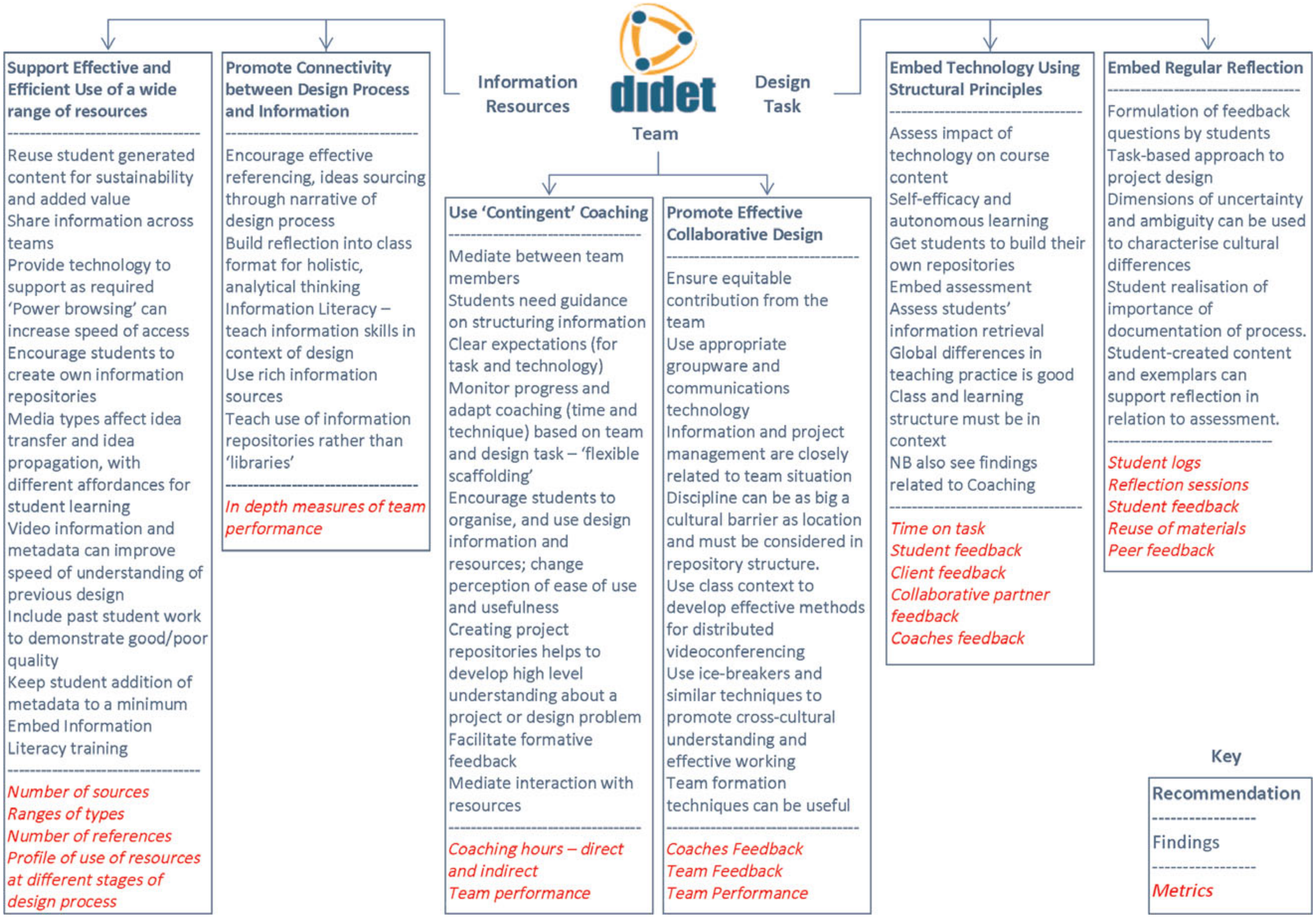

Fig. 4. The DIDET framework for design engineering education in a global context. [A color version of this figure can be viewed online at journals.cambridge.org/aie]

used during the development of the LDL was to use primarily student-generated material. An important benefit of this is to make the library more sustainable. One of the main issues with digital resource collections is that they take a large amount of effort to populate and quickly become obsolete. Asking library users to upload content as part of their work ensures that material is constantly being added. In addition, the contextual information added by users makes the information resources more meaningful to others. Finally, retention of past student work, with the addition of educational context from staff, provides a good indicator of the expected standards. For the library to be a success, sharing of resources across teams must be strongly encouraged, and the technological support required cannot be underestimated. Ideally, all students would have remote access to the digital library through laptops or other wireless devices while still being situated in the typical design studio-based environment. It is also necessary to augment the technological support with Information Literacy training at the outset to familiarize users with the benefits of using the library as well as the mechanics of effective search and retrieval.

Use of video is a rapidly evolving area of development in online resources. The Stanford team explored several aspects regarding the uploading, browsing, and use of video for learning. The addition of appropriate metadata was identified as a critical issue: blocks of video require to be resolved into relevant segments for ease of access. The addition of this kind of granularity is possible but labor intensive and time consuming, making it problematic for large video collections. Regarding the browsing of collections themselves, the concept of "power browsing" was introduced, whereby users would be able to rapidly understand some of the key features of a group of videos without having to open and watch each one. Suggested ways to do this included small moving thumbnails and appropriate display of metadata. It should be noted that different media types have different affordances for student learning, with video being particularly effective in the communication of design concepts and informal knowledge, and this should be a consideration for digital library architectures going forward.

4.1.2. Process and information connectivity

It is critical that there is a strong link between the design process undertaken and the information used in its execution. The use of narrative during the course of projects delivered through the working environment is important in helping the student designer to understand where in the process they lie and what information is applicable. Holistic, analytical thinking is therefore required, with students expected to use rich information sources, which are better described as information resources rather than "libraries."

4.2. Teamwork

4.2.1. Contingent coaching

We recommend that coaching is provided at the point of need as a supportive mechanism rather than being overt, didactic, and constraining for students. This encourages independent thinking and utilizes the social learning engendered by team-oriented, studio-based projects where possible. It is still necessary, however, for targeted coaching where required: monitoring progress and adapting coaching time accordingly can ensure that any major learning issues are addressed.

Placing suitable information resources prominently in the learning environment is an effective way to help students support themselves, and should be perceived as a fundamental coaching responsibility. A key way to engender willingness to engage with such an information resource is to allow the user a measure of control in how items are organized and stored. Project Wiki pages, which document project activity, provide such an opportunity. It is necessary to provide guidance on organizing and structuring such information to ensure ease of use and continuing usefulness throughout the project, and to support this with formative feedback that is deployed when it is needed most. The levels of interaction, rate of construction and consistency of use of such resources can assist coaches with this deployment. It should be noted that we are advocating that the coaches not only add value by providing information resources and technologies to the students, but also by demonstrating and instilling sound information handling *behaviors*.

4.2.2. Collaborative design

Information and project management are closely related to the team situation. To ensure that teams work effectively, it is important to encourage equal contribution during the course of projects. To this end, in global projects discipline is as big a cultural barrier as location, and should be considered in how repositories are structured: visibility, for example, can be useful in ensuring that all team members access and use the shared environment. When teams are required to communicate synchronously, alternative media such as video conferencing may be used and even integrated into the information resource infrastructure. Similarly, icebreakers and team formation techniques can be useful to promote cross-cultural understanding and effective working. In many cases, the student teams who failed to develop and adhere to an information management framework and norms also failed to manage their projects effectively and thus failed to collaborate.

4.3. Design task

4.3.1. Embedded digital libraries

The principle of embedded digital libraries relates closely to the recommendations on coaching: the libraries should be available at the point of need, supporting design activity in its natural studio environment. In addition to suitable physical access in terms of laptops or conveniently located desktop machines, the libraries must be embedded as an integral part of the course to ensure optimal uptake. Delivery of course materials and assessment through the online environ-

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ment can be an effective way to highlight the proximate resources of the digital library.

In addition, increased ownership is afforded by self-constructed collaborative environments, which is a recognized problem with distributed projects. It was found that encouraging teams to personalize their resource collections with front pages often engendered greater enthusiasm and buy-in. The familiarity and confidence with reference material derived from sourcing, linking, and using items in the construction of these collections can also help students cope with the disparities in skills, expectations, and culture, which inevitably form part of global projects. In terms of assessment, system activity provides a clear picture of how heavily individuals use any library that is provided for them. This can then be correlated with student and team performance during project work.

4.3.2. Regular reflection

The team recognized the importance of students undertaking regular reflection during their project work. The provision of contingent coaching allows teams the opportunity to formulate questions, a process that can be useful in helping them recognize where in the design process they lie and what the obstacles are to progression. A task-based approach to the setup of projects breaks the design process into more manageable sections, and these miniprojects give students a sufficient focus while still allowing them freedom to explore and learn autonomously. It is important in projects, particularly the global projects described in this context, that uncertainty and ambiguity are embraced to illustrate differences in approaches and cultures that are integral components of teamwork in large and complex organizations. Finally, an emphasis on recording and uploading material to digital repositories as projects progress can replace traditional report writing as a means of project documentation. This strengthens student understanding of the process of creating a digital library as well as providing valuable resources for possible future use by other cohorts. This behavior is reinforced if the students experience benefits from reusing the information that has been created by other cohorts early on in their projects, and recognize the significance of that mechanism through reflection.

5. CONCLUSIONS AND IMPLICATIONS

This section outlines the project conclusions in terms of technology, pedagogy, and culture and is adapted from a previous DIDET paper on embedding eLearning (Breslin et al., 2007).

5.1. Technology

Any new technology introduced to the educational environment requires adequate technical support and staff training on an appropriate scale: departmental, faculty, institution, and so forth. Integration with existing and new systems may be required, and interoperability may also be an issue. There must be consideration of hardware and peripheral resources and services for the benefits of a system to be maximized. In the case of DIDET, this meant scanners, digital cameras, and so forth to capture design material.

5.2. Pedagogy

Despite potential benefits of introducing new technology, it has been shown that such innovation must be led by the pedagogy (Bates, 2000; Twigg, 2003). In the case of DIDET, the discipline itself was a factor; the unique requirements of Design Engineering led to the development of the digital library system, which allows even tacit design knowledge to be created, captured, stored, shared, and reused. The use of LauLima was embedded into the curriculum of classes in which it was used. The requirement for information literacy education in conjunction with elearning projects such as DIDET is very apparent. This was developed initially by an Information Specialist, and is being handed over to DMEM staff who now have sufficient experience. There is a strong argument that all staff should now have these skills. In terms of delivery, evaluation is required on an ongoing basis to inform project activity and development. This allows regular improvements in teaching and learning and associated systems to be made. Finally, having a sufficient number of high-quantity and quality of resources is critical to the uptake of use of a digital library. Student questionnaires were issued regularly to examine use of LauLima along with system use logs. The LauLima workflow introduced by the then Project Manager has ensured a high standard of quality of resources and their metadata. Time and resource is a major issue for ongoing population of any digital library, and DMEM is currently examining this workflow to investigate if it can be streamlined further.

5.3. Implications

The time to effect change was important in the DIDET project: true embedding of pedagogical change was enabled by its 5-year length. To implement major changes such as those described here, senior buy-in is necessary not only to help ensure commitment to make change but also to ensure that required support is in place. Although many changes can take place from the bottom up, buy-in at other levels may still be required to ensure that sufficient support is in place to embed and sustain transformational change.

A cross-discipline team can provide the range of skills required; however, human factors can become an issue, and strong leadership is required. "While challenges relating to technologies can often become the focus of attention for eLearning projects, it is the attention to human factors and behaviors that moved the DIDET Project forward" (McGill et al., 2005). DIDET adopted a "course team approach" whereby all of the core project team was involved in team coaching. This gave those not traditionally involved in the classroom a greater understanding of how the pedagogy and technology were applied.

The experience of DIDET demonstrated that there are many cultural issues not only with location but also with academic discipline; for example, those with backgrounds in mechanical engineering often approached work differently from those with backgrounds in design engineering. In addition, uptake and acceptance of new methods and technologies can be difficult to encourage with both staff and students. In global projects, each site tends to favor their own chosen or developed technologies, for cultural and practical reasons, for example, familiarity and availability of support. Different methods can be used to overcome cultural issues for teamwork, including preparatory work to clarify aims and objectives, ice-breaker exercises to establish good working relationships, and effective project management to ensure on-going team effectiveness. Dynamic digital information environments with "inward" facing elements such as LauLima provide an opportunity for facilitating the communication, synthesis, and thus, negotiation of the different perspectives associated with diverse cultural and disciplinary backgrounds; negotiation does not take place in the absence of characterization and synthesis of perspectives. These experiences therefore provide students with the necessary communication and organizational attributes to work successfully in the global arena.

6. CONCLUSIONS

Through wide dissemination, the findings from the DIDET Project have been propagated to professionals in the fields of pedagogy, design engineering, engineering education, and educational technology. After presenting and publishing their findings related to global design, the team developed guidelines for those institutions who may wish to implement similar projects or classes. During the experiments and when running the new global design class at Strathclyde, it became apparent that the logistics of coordinating global activities were much more complicated and time consuming than first assumed. As expected, these logistical issues became easier to deal with each year as staff became more experienced and processes became more streamlined. The GDP also changed in format based on experience, and was run in its second year using a task-based approach (Wodehouse et al., 2008). The team feels that there would be value in further exploring potential enhancement in coaching models and perhaps exploring global coaching models where the staff–student relationship is distributed.

More research and evaluation could be carried out related to system use, for example, investigating its use relating to assessment and assessment of global teamwork. One major finding of the DIDET Project's work on the reuse of student created resources was that students are keen to view previous work in the context of assessment. The project has already evolved to allow for this, and the "educational context" field of each resource in the LDL gives information on why a particular resource is useful. Regarding assessment, the resource could be an exemplar, or the metadata could explain weaknesses that could be improved. Although students would always be encouraged to maximize their learning, not only focusing on assessment, there is potential for students and student teams to be able to self-assess by using available resources in the digital library with a range of marks and to judge how their own project outputs compare.

During the 5 years of the DIDET Project, the technology and its availability have moved on. The Wiki technology that was adopted was emerging at that time and is now well established, even in teaching and learning contexts. There may be further potential in now exploring new emerging technologies and their potential for use in the classroom.

Please refer to the DIDET Project video for a short overview of the project, which features student interviews: http://www.jisc.ac.uk/media/avfiles/programmes/dlitc/didet.wmv

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