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Organising industrial knowledge dissemination on frontier technology

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This paper describes the challenges faced by frontier technology education, typical among large integrated EU projects. These include an evolving nature, the scarcity of experts and established material, and the need for relevant material. Classical approaches to learning seem to not adequately address the needs of frontier technology alone. Following this observation we develop a training model, where the instructional model, architectural design, and delivery mechanisms are developed according to the needs, goals, homogeneity, and distance among learners. We then use principles of constructivist methodology to address the needs of frontier technology. Throughout the paper radio frequency identification (RFID) training at the Cambridge Auto ID labs is taken as an example. The methodology leads to a successful training delivery where students have achieved the targeted success criteria.

Keywords: frontier technology; RFID; constructivism theory; collaborative learning

1. Problem statement

Cambridge auto-ID lab is a part of the distributed information and automation laboratory (DIAL), which is based within the institute for manufacturing at the Cambridge University engineering department. The lab has been involved in the area of automated object identification since 2000 when it joined the auto ID centre project (1999–2003) that has driven numerous industry mandates in the adoption of radio frequency identification (RFID) technology. RFID is seen by many as a revolutionary enabler in automated data capture. RFID tags coupled with readers and information systems can increase visibility of operations by synchronising the physical flow of components/products and the related information flow without human intervention. In addition, RFID technology has found uses in a variety of other manufacturing-related applications in production automation and inventory management. Specific RFID research themes at the lab include: methodologies for tracking and tracing objects, Quantification of the impact of RFID introduction, and RFID integration with sensing and automation systems.

Within the above research frame, the centre is involved in the development of decision support systems for sophisticated product-embedded information devices, including RFID, within the

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PROMISE-integrated project, funded by the EU (www.promie.no). A particular focus towards the end of the PROMISE project is to disseminate know-how created to industrial partners as well as industrial audiences across the EU.

RFID-based technologies are a typical example of frontier technology. Consequently when dealing with knowledge dissemination the following challenges surface frequently:

- Frontier technology constantly evolves and so should the teaching material.
- There is typically a lack of established reference material students can be referred to.
- Knowledge typically comes from distributed sources and may be conflicting as there is not yet a consensus.
- Finding credible experts who are willing to share information is difficult as knowledge equates power especially during initial phases of technology exploitation.
- A multi-disciplinary approach might be needed if technology is created and disseminated using knowledge from different disciplines.
- Learners are likely to be demanding information relevant to their operational environment.
- State of the art tools may not be available to purchase and demonstrate.
- As a result of the above, classical teaching methods may not apply which places a heavier burden on the teacher.

There is limited literature on industrial knowledge dissemination as they simply do not take into account the challenges of frontier technology. On the other hand, most frameworks offered to teach frontier technology that are offered are based on school set ups and do not take industrial needs into account.

Following experiences in RFID technology education at the Auto ID centre, this paper seeks to develop a methodology to address the challenges of teaching frontier technology by comparing with existing approaches to learning (Section 2), forming an educational framework that frontier technology course designers can use (Section 3), and testing the framework with a real case study (Section 4).

2. Approaches to learning

This section gives an overview of different approaches to learning and discusses how and to what extent they can address the challenges of frontier technology training.

2.1. *Problem-based learning (PBL)*

This type of learning gives the learner a problem and a ‘map’ showing necessary information to solve the problem (Barron 1998). The problem is specifically designed to lead the learner through a specific learning path. The approach encourages active learning where the teacher is the facilitator. In frontier technology, the source of expertise lies typically within an academic and frequently an industrial resource. Although this kind of learning might be suitable for the latter stages where a firm base of knowledge is established, it is not suitable as an initial approach as it is difficult to find or devise example problems with readily available solutions. As the technology evolves and better solutions emerge, devised solutions might quickly go out of date.

2.2. *Project-based learning (PjBL)*

PjBL uses constructivist pedagogy to promote learning by allowing learners to use an inquiry-based approach to engage with issues and questions relevant to their lives (Barron 1998). This type of approach leads to a bottom-up teaching model that is less structured than traditional, teacher-led classroom activities. There is high emphasis on collaborative learning as the students determine their own projects and take full responsibility for their learning.

The collaborative approach resulting from project-driven activities might be suitable to address the typically multi-disciplinary needs of frontier technology training. In this case a leader might facilitate the set up of a project a team and solving a problem in an organised manner through pre-determined tasks.

2.3. *Case-based learning*

This type of learning promotes knowledge through the use of case studies and discussion. Students are engaged in critical thinking and decision making about realistic problems in a discipline. From a frontier technology point of view, it is useful in determining how certain activities lead to a certain outcome through examples, if the laws of behaviour for a given system are not yet determined. Case studies may also help in putting systems in an industrial context where learners from a business background can learn about relevant applications and learners from a technical background can learn what set ups lead to what performance or core competencies of a technology. On the other hand, much like PBL or PjBL, case studies alone may not be expected to fully allow comprehension of the technology.

As a result of this analysis it can be deducted that no learning approach alone can address the challenges of frontier technology training and a combination approach should instead be followed. The next section builds on the PROMISE project training model to incorporate a framework to include combinations of these approaches.

3. Developing a methodology to address the challenges of teaching frontier technology

Figure 1 shows an overview of the PROMISE project training model, built to disseminate technology and business know-how acquired during the project. The development of training is structured in three main phases starting with the *Macro-phase*. This phase derives the specifications of the instructional design, where the learners are analysed in terms of their needs and the training goals of the project. Following this, the main concepts to deliver are identified, and the resources to be used for training are defined. Specifications are derived relating to the following:

- Characteristics of learners who will use the training architecture including their role and goals from the training activity, physical distance, access to technology, domain and level of expertise, and homogeneity among learners.
- Selection of the learning concepts to be delivered to learners is defined to fulfil the training goals.

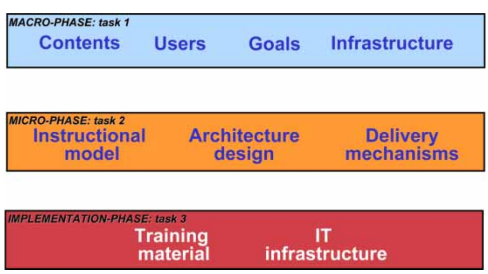

Figure 1. PROMISE project training model (Matta *et al.* 2007).

- After an assessment of the users, the overall learning goals of the course that match their users' learning goals as widely as possible are defined. The goals influence the way in which the instructional design is formed in the micro-phase.
- Resource constraints are identified, both human and technical, that have a limiting effect on the training delivery.

During the *micro-phase* specifications on users, goals, contents, and infrastructure are further detailed. The approach leads to the instructional strategy, composed of the following elements:

- Instructional model: the integration between presence and distance courses, learner autonomy, learning assessment strategy are defined.
- Architecture design: the training content structure, decomposed in modules, and the IT infrastructure to facilitate training are defined.
- Delivery mechanisms: the tools used to deliver training contents such as multimedia, forums, and hardware are defined.

In the implementation phase the instructional design, training material, and IT infrastructure is developed and delivered, as well as assessed.

We use the PROMISE training design and delivery model to assess and address the needs of frontier technology training in a structured form. The following sections highlight the needs that must be considered while following the model.

3.1. *Changing goals*

The unstable nature of frontier technology brings on the need to equip learners with skills to find new information and self-study, which becomes one of the overall goals of training. The learner not only must gain the most up to date know-how, but also become aware of the possible future changes in technology. Hence, the deliverer of knowledge should be equipped with a sense of direction that the new developments in technology may take.

3.2. *Infrastructure challenge*

When assessing the potential infrastructure a number of issues need to be taken into account:

- Experts in frontier technology are scarce, and they may be geographically distributed. A further geographical challenge is the distribution among participants in typical European projects. A distance-based learning tool might help ease this challenge. Even when presence-based learning is possible, distance-based learning tools might help bring learners together outside the standard learning environment, and promote a collaborative platform to exchange experiences with technology.
- Although distance-based learning might play a significant role, the intuitive development, experienced best with hands-on learning through experimentation, should not be discounted and encouraged if a group of participants have the chance to be together and have access to necessary equipment.
- It should be noted that a common goal amongst European projects is cultural exchange and development of long-term academic and industrial relationships. In both distance-based and presence-based learning activity this need should be accommodated either through dedicated forums in the former case, or through dedicated informal time in the latter case.
- Due to the changing nature of technology, forums and news feeds gain importance to update learners on new developments. Dedication to forum and news feeds participation is then required

by learners as well as the teachers themselves as more participation increases the chances of awareness in latest developments.

3.3. *Developing intuition*

The importance of hands-on experience in intuitive development in engineering and technology education have been emphasised on various occasions. The vitality of the expert's facilitation of experimentation can then be shown by the equation: intuition = expert–novice (IEN). Many educational specialists agree that intuitive development is part of the answer to what experts 'know' more than educated novices.

Frontier technology education, with its scarce access to experts and need for information from various multi-disciplinary fields to solve problems, makes the development of intuition a key goal. This goal then affects the design of instructional model in the micro-phase. Observational and PjBL approaches can be used in this context to support the transfer of intuition from the expert to the novice. The course designer needs to think about what tools can be used to develop intuition. Project solving set-ups such as games can be used to encourage learners in testing and furthering their knowledge by experimentation.

3.4. *The role of learner*

The typical lack of established reference material and consensus on knowledge results in the need for a filtering mechanism for the learners or course designers to create their course content. Once main themes are learned, this lack of established material could be used to advantage. A common filtering activity, facilitated by the expert, can lead to a valuable discussion-based exercise where students can decide what material is worthy of being an established resource. The students critique the resource through the help of the teacher.

An additional responsibility of the student is dedication to collaborative learning. The multi-disciplinary nature of the technology, the need for European cultural exchange, the likeliness of new developments, and the lack of central established sources of knowledge gives the student a key role in steering his/her own learning as well as collaborating to that of his/her peers. Students shall not only participate in live debates, moderated by teacher, but where possible, shall make use of both asynchronous (forums) and synchronous (chats) information system tools, which give way for the information exchange to be recorded for the benefit of others. Collaboration is also a case for better understanding: students only remember the 20% of what they listen but the 90% of what they talk about and make (Felder *et al.* 1995).

3.5. *Dynamic content*

As the students have developed basic skills they attempt to filter data through discussion to create a common knowledge base. The information system that is in use shall be capable of accommodating dynamic content as well as linkage to the reasoning behind the changes in content. An example of this can be found in learning management systems (LMS) where current course content is linked to discussion activities such as forums or chats, and learners can access the version history of the course to understand the evolution behind of the course material.

3.6. *The role of constructivism*

Constructivism proposes to give more significance to the learning contexts as an alternative to memorisation. This permits to build knowledge, doing activities closer to the real world and generally involves discussion groups (Crook 1998). The significant contexts for the constructivist authors are situations of the real world that help to put into practice the experience (Knuth and Cunningham 1991). A main characteristic of a constructivist learning environment is that it proposes a 'communitarian learning', where the students work together helping each other, reinforcing the social dimension of the education (Terhart 2003) and need each other in order to complete the group's task successfully. The student in this respect is an active manager of his own learning process, and a person who has to generate knowledge for himself as well as others.

Regarding the role of the computer in the constructivist environments, the constructivist authors consider that it should not be used only merely to put out knowledge, but it must be a supporter tool for the experimentation and building of knowledge.

When the needs of frontier technology education are considered, the above frame matches the proposed solutions: the need for real-case examples as learners are likely to be demanding information relevant to their operational environment, the need for collaborative and co-dependant learning due to multi-disciplinary nature of the technology, the need for European cultural exchange, the likeliness of new developments, and the lack of central established sources of knowledge, and finally the need for active steering from the learner's part due to the lack of or limited access to expertise.

3.7. *Learning management systems (LMS)*

As mentioned earlier, the use of a LMS can significantly enhance the development and delivery of course content for frontier technology training. The features demanded from LMS in support of the constructivist approach are: the LMS should enable dynamic content, have collaboration tools such as forums, should enable the linkage of forums to learning content, the students should be able to schedule their learning time, and encourage students themselves to include and coordinate content by implementing new activities, managed and administrated by them, about existing topics or repeat the same activities developed in the class.

4. Concept testing: RFID as a frontier technology

This section describes the steps taken to deliver RFID training at the auto ID labs, with respect to the PROMISE training model, to achieve the methodological needs considered to deliver frontier technology education.

4.1. *Macro-phase*

The Macro-phase resulted in the following observations:

Physical distance. Members of the project consortium are distributed across nine different countries. Joining a consortium learning activity will require an average travel effort in time of 5 h (one way) for a partner to bridge the physical distance. Consequently, a notable physical distance should be taken into account not only between the individual learners but also between learners and tutors/trainers. In addition it should be mentioned here that the physical distance results also in a difference in time of up to 2 h within the group of the consortium. Previous research has indicated that working in different time zones has a negative influence on trust building and, as a consequence, the ability to exchange knowledge.

Access to IT technology. All partners have access to internet during their daily working hours.

Domain and level of expertise. The learners' backgrounds consist of the following diverse functional domains: Management, Finance, Marketing, IT, Engineering and have at least two years of experience in their functional domain, and are in non-leading positions. The industrially based learners come from include construction, railway, automotive, white goods, and telecom equipment.

Homogeneity among learners. There is little homogeneity among learners and their needs have to be accommodated by providing a large selection of material from basic to advanced levels.

Users' learning goals. The learners are motivated by intrinsic motivation as they are interested in how the technology can enable them to bring competitive value to their organisation, and extrinsic motivation, as their companies are involved in the PROMISE project and have commitment towards a set of deliverables using the technology. Depending on their roles in using the technology, learners are categorised into software developers, end users, and researcher groups.

Selection of the learning concepts. Following the wide range of domain expertise and lack of homogeneity among users, a wide range of course offerings have been developed. Table 1 shows the module architecture of the courses along with their content description. The high variety of domain expertise reflects positively on the course development, as different backgrounds will have different viewpoints and bring in different contributions. For instance, the business implications of RFID technology are best evaluated by learners from business backgrounds, with a critical eye on business cases and new developments on value drivers. New case studies come into light can be shared by the researchers. On the other hand, technological limitations and developments of RFID can be deducted by learners from relevant backgrounds and funnelled to business application learners.

Resource constraints. The constraints include the scarce availability of legal experts in RFID, and the limits on the number of people the laboratory can accommodate at a time. Although the need for an understanding of RFID legislation exists, there are no legal experts within the learner group or in the teacher group. It was thus concluded that policies and standards are given as an online course, with material primarily developed by teachers, to be updated and discussed by the learners, as they gain more understanding by following newly developed case studies and applying RFID in their organisations.

Overall learning goals. Table 2 displays the overall goals of training categorised in terms of identified user groups. As mentioned earlier, equipping learners with skills to find new information on the topic should be a common goal in frontier technology education. Developing technological

Table 1. Modules and content.

Module	Content
Motivation and background	Describe why the RFID technology is needed, what are the objectives of the technology.
Components	Present overview of the technology involved including unique ID.
Physics of RFID	Present different types of RFID technologies. Describe environmental effects on RFID readability.
Legislation and policy issues	Introduce legislation regarding power levels and UHF Bands. Present Health & Safety and privacy regards, general standards on RFID, and sources of legislation.
RFID DIY	Allow users to test RFID solutions on their products.
RFID Hardware integration	Illustrate the integration of RFID to existing hardware.
RFID software integration	Illustrate the development and integration of software that can communicate with the PEIDs.
RFID-based product data management	Discuss advantages of holding distributed and centralised data. Describe sensor integration of data coming from different RFID.

Table 2. Overall learning goals.

User group	Goal
All	Equip learners with skills to find new information and self study to become aware of the possible future changes in technology.
Researcher	Develop technology intuition on RFID limitations, and hardware use cases.
Developer	Develop software intuition on RFID-based product data management and software integration.
End user	Develop business intuition on RFID applications, and business opportunities.

intuition in terms of identifying limitations and opportunities in different technology environments of RFID is an important and ambitious goal targeted to researchers from a technology background. Similarly, developers are looking to develop intuition in how to manage product data with RFID, and how to integrate RFID-based data within legacy systems. End users are looking to develop an understanding of how RFID can help their business.

4.2. *Micro-phase*

The micro-phase defined the following instructional and architectural model, and the associated delivery mechanisms:

Instructional model. Table 3 outlines the integration between presence and distance of the modules, and the learner autonomy. After consultation with the project consortium the following types of learner evaluation were planned:

- Evaluation of learner satisfaction: this assessment evaluates if participants enjoyed the course, if the material is relevant to their work and if they are able to use the training in their jobs.
- Evaluation of training delivery mechanism: this assessment evaluates the participants' perceptions on the stability and user-friendliness of the delivery mechanism, and the ease of understanding of the content.
- Evaluation of learning achievement: evaluation at this level measured to what level the participants achieved learning.

The success criterion for the evaluation was 70% of the participants to respond with a positive satisfaction feedback. The target for the learning achievement evaluation is 70% of the participants to obtain the 50% pass grade in each course.

Architecture design. The module structure is given in Table 1 including training content. All modules except the practical RFID DIY module are supported by e-learning self-study platform

Table 3. Module learner autonomy and distance *vs.* presence.

Module	Learner autonomy	Distance/Presence
Motivation and background	Low	Both distance and presence
Components	Medium	Both distance and presence
Physics of RFID	Low	Both distance and presence
Legislation and policy issues	High	Distance
RFID DIY	High	Presence
RFID Hardware integration	High	Both distance and presence
RFID software integration	Low	Both distance and presence
RFID-based product data management	Low	Both distance and presence

Figure 2. Moodle interface.

Table 4. Module delivery mechanisms.

Module	Lecture	Video	Blog	Forum	Chat	Laboratory	Case study
Motivation and background	✓	✓	✓	✓	–	–	✓
Components	✓	–	–	✓	✓	✓	–
Physics of RFID	✓	–	–	–	–	✓	–
Legislation and policy issues	–	–	–	✓	✓	–	✓
RFID DIY	–	–	–	–	–	✓	–
RFID Hardware integration	✓	–	✓	✓	✓	–	✓
RFID software integration	✓	–	✓	✓	✓	–	✓
RFID-based product data management	✓	–	✓	✓	✓	–	✓

which is followed at distance. All modules except legislation and policy issues have a presence component where lectures are followed by hands on practical experience.

Figure 2 shows the interface of the LMS, Moodle, for accessing online training content. Many features of the platform including blogs, forums, chat, and news are used. Moodle is an open source e-learning platform supporting constructivist learning theory, which formed the basis of our choice for the learners (Moreno *et al.* 2007).

Delivery mechanisms. Table 4 shows the description of tools used to deliver training contents of different modules. An initial motivation and background lecture prepares learners on what to expect, what training goals and their responsibilities are, and evangelises and criticises the technology using case studies and videos. Hardware and software integration is supported by case studies. Legislative issues are taken on a case-by-case basis and discussion forums support dissemination of new developments among learners. Physics and components of RFID are largely taught by lectures and lab-based sessions.

4.3. *Addressing challenges of frontier technology education*

The Moodle shown in Figure 2 supports the changing nature of frontier technology using collaborative tools. When a learner is aware of a new development, a news feed may be sent to other learners, and a discussion can take place using the forums. Despite the geographical distance between consortium members, physical contact is required where cultural exchange between

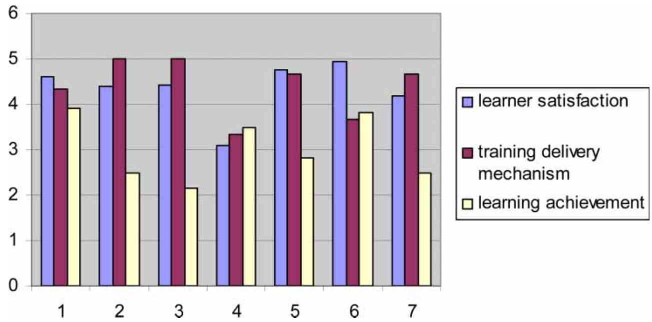

Figure 3. Learning evaluation.

project partners can take place, and intuition can be developed through hands on experience. We organised a common training day where most partners could attend, to hold the initial lectures, and introduce learners to the technology. We used this opportunity to organise an RFID DIY (do-it-yourself) workshop in which learners are divided into groups to play a game where the more items are scanned simultaneously by the reader the higher the score, rewards the most efficient tagging and reader set up. The game was a project, set up to simulate a factory dock door environment where goods are shipped in and out. The learners then have a go at tagging and reading items they have brought with themselves, making the practice more relevant to their business application. The game set-up helps learners to interact and develop the important group feeling, which helps support the interaction as a virtual group when the training continues with the LMS. The common training day also helped learners understand their crucial role in the development of training material. It was decided that students take responsibility in critiquing literature material with help from course teachers and in developing their online glossary and bibliography with material they think is established after a consensus is reached among them.

4.4. *Course evaluation*

Figure 3 shows the resulting normalised assessment from the first round of training delivery, from seven learners. Learner satisfaction and training delivery mechanism were the highest among the different evaluation types. Learning achievement target was reached as all but one participant reached the pass grade required.

The evolution of the Moodle shows that online materials are updated, and students actively participate in their learning. A common glossary is developed, and forums are formed. Learners comment that the approach helped them understand the technology and generated sufficient interest to engage in continuous collaborative learning.

5. Conclusion

Discussions in literature on the methodological requirements of frontier technology education are limited. The demanders of frontier technology education are typically a mature audience ranging from developers, and parties looking for potential business applications, to researchers who look to engage in latest developments and learn relevant case studies. A common demand for this type of education arises from integrated European projects, where frontier technology is developed and used by several geographically distributed partners. This paper outlined the design, development, and assessment of a methodology for frontier technology education using the RFID training given by Cambridge auto ID labs along the course of the PROMISE project as an example. First the physical distance, IT access, domain and level of expertise, homogeneity, and goals of learners are examined, which resulted in selection of a number of learning concepts. Then, resource constraints are gathered to design appropriate delivery mechanisms. Once overall training goals are outlined, the instructional model, module design, and delivery mechanisms can be defined.

The intuitive development and cultural exchange needs are addressed via a common training day where initial lectures and goals of training were given. Learners were pointed to the LMS and collaborative training needs were emphasised. A lab-based game was set up to develop an intuition of the technology and bring learners together. The training continued with a distance-based LMS where learners filtered available material and formed their own reference material. Initially targeted assessment thresholds in terms of learning achievement, satisfaction with the course, and training delivery mechanism were achieved. The methodology needs to be further applied to other cases.

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