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Enabling distributed communication of manual skills

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Abstract

Purpose – The purpose of this paper is to inform the development of mixed initiative systems for distributed digital communication of manual skills. In particular, manual skills that are essential in project production paradigms such as engineer-to-order.

Design/methodology/approach – Findings from survey research, which included literature review and interviews with practitioners, are reported. Literature review investigated media, strategies, and computation relevant to distributed digital communication of manual skills. Interviews investigated attitudes among industry practitioners towards distributed digital communication of manual skills.

Findings – Communication media, instructional strategies, and computational semantics techniques are available which can be integrated to address the limitations of human communication of manual skills.

Research limitations/implications – Only ten organizations were involved in interviews investigating attitudes towards distributed digital communication of manual skills.

Practical implications – Manual skills will continue to be important to project businesses involved in the production, refurbishment, and/or maintenance of large engineer-to-order products such as public buildings and process plants. The limitations of human communication can be addressed by using a variety media, such as augmented reality headsets, to enable new instructional strategies, such as just-in-time training. Further, combinations of media and strategies can be integrated with computational semantics in the development of mixed initiative systems which provide feedback as well as initial instruction.

Originality/value – The originality of the research reported in this paper is that it addresses a full range of enablers for distributed communication of manual skills. Further, an overview of computational semantics is presented which does not rely on prior specialist knowledge. The value of this paper is that it introduces a framework for enabling distributed communication of manual skills. In addition, a preliminary ontology for distributed communication of manual skills is introduced, together with recommendations for implementation.

Keywords Project planning, Skills, Communication, Semantics, Information media

Paper type Technical paper

Introduction

Manual skills involve psychomotor functioning in the manipulation of handheld tools and the positioning of components (Gilchrist and Gruber, 1984). The potential for distributed communication of manual skills is particularly important to project businesses which are involved in the production, refurbishment, and/or maintenance of large engineer-to-order products such as public buildings and process plants. Manual skills are particularly important because alternatives such as near net shape manufacturing and assembly automation are seldom feasible and/or viable within

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project production paradigms. Distributed communication of manual skills is particularly important because work locations are often at numerous and varying geographically locations (Fox *et al.*, 2009).

It has been argued that learning and knowledge sharing are very important capabilities for project businesses (Hawk and Artto, 1999; Prencipe and Tell, 2001; Ruuska, 2005; Maqsood *et al.*, 2006). Currently, manual skills are often communicated through one-to-one interaction between a person with manual skills (e.g.instructor/tradesperson) and a person lacking manual skills (e.g. trainee/apprentice). However, shortages of manual skills are reported throughout the world (Katz, 2008). As there is shortage of people with manual skills, so there is a shortage of people who are available to provide instruction in manual skills. Moreover, one human instructor can only be in one place at one time; and only a few trainees can be at that place to receive instruction at one time.

The research reported in this paper investigated enablers for distributed digital communication of manual skills. In particular, the following topics were investigated: communication media, instruction strategies; mixed initiative dialogue systems, and attitudes to distributed communication of manual skills among industry practitioners. The research included literature review and interviews. The informant style of unstructured interview was used (Powney and Watts, 1987). The interviewer did not seek to control the interviews. Rather, interviewees freely expressed their thoughts and took the interviews in the direction that they chose. This type of unstructured interview can be contrasted to the respondent style of unstructured interview where the interviewer seeks to follow a more defined agenda (Powney and Watts, 1987). Interviews involved industry practitioners at ten different organizations.

The remainder of this paper is organized into six sections. In the next section, alternative communication media are considered. Then, different strategies for digital instruction of manual skills are outlined. Next, an introduction to computational semantics is provided, and its importance to enabling effective distributed communication of manual skills is explained. Subsequently, a preliminary ontology is presented together with recommendations for implementing distributed communication of manual skills. In the penultimate section, findings from interviews with industry practitioners are reported. In the final section, conclusions from the research are stated.

Communication media

In order to enable the distributed communication of manual skills, physical motions have to be described as visual information in digital formats. This can involve taking digital photographs, recording digital video, and/or creating of digital animations of human motions carried out in the execution of manual skills. The devices that can be used include: handheld video cameras; photography cameras, camera phones, and digital paper (e.g. dot patterned paper used in conjunction with a digital pen to create digital documents).

These devices, and others, also provide new opportunities for the communication of manual skills. Digital signage, for example, enables several people to view the same visual information at the same time (Storz *et al.*, 2006) Other new communication devices, such as augmented reality (AR) headsets, are wearable (Dias *et al.*, 2003). While others, such as stereoscopic projected displays, are immersive (Yerrapathruni *et al.*, 2003). As shown in Figure 1, communication of manual skill knowledge can be physical and/or virtual. Physical communication of manual skills can involve physical demonstrations by a human instructor in physical reality.

Other media have more potential for distributed communication. Each has its own particular strengths and weaknesses. For example, video recordings of physical demonstrations can be used for distributed communication of manual skills. Video footage (VF) allows viewers to see live, fluid motion of an expert demonstrating a motion (Dagron, 2001; McNeal and Nelson, 1991). However, video learning has been compared unfavourably with immersive virtual reality (IVR) for learning full body motions because it allows users to only watch a recording of an instructor. Also, video has been criticized for not allowing users to change camera position and orientation.

By contrast, IVR allows users to interact with digital instructors in an environment, allows evaluation from many different positions, and allows performance of novel functions such as sharing body space with the instructor (Patel *et al.*, 2006). On the other hand, devices for viewing VF are much more portable and widespread than IVR environments. However, non-IVR such as VR can be viewed via computer monitors and enable communication of partial body motions such as hand manipulation.

With AR, visual information, such as graphics and/or text, can be communicated in the same field of vision as the physical reality of, for example, a work piece. Also, AR information can be audio (Tikander, 2005) and/or haptic (Scharver *et al.*, 2004). As AR involves active combination of physical reality with VR, it may offer a "best of both worlds" solution for distributed communication of manual skills (Boud *et al.*, 1999; Pathomaree and Charoenseang, 2005). For example, AR may have the potential to make it possible for trainees to be able to view their own partial body motions at the same time as a three-dimensional VR model of a human instructor's motions. This would enable trainees to synchronize their own motions with a human instructor who would not need to be present (Sielhorst *et al.*, 2005).

The world wide web, together with internet broadband access, wireless and satellite communications, provide increasing opportunities for distributed communication via a variety of different media. Distributed communication of manual skills can take place at a variety of locations and within different instructional strategies.

Strategies

The following three strategies for skill instruction were identified for the deployment of alternative media: intelligent tutoring systems (ITS); just-in-time training (JITT); and point-of-use information (PUI).

The goal of ITS is to provide the benefits of one-on-one instruction (Bloom, 1984) automatically and cost effectively. ITS enables trainees to practise their skills by carrying out tasks within highly interactive learning environments. ITS can provide individualized guidance by developing a model of each trainee's skills via observation and assessment of their actions within interactive environments. Based on this model of the individual, the ITS can then tailor instructional strategies in terms of both content and style (Ong and Ramachandran, 2003; Pon-Barry *et al.*, 2006).

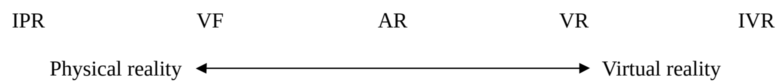

Figure 1.
Communication media

ITS use VR simulations and other highly interactive learning environments (Horwitz *et al.*, 1998). The development of ITS is becoming easier and cheaper with the introduction of authoring tools by academic institutions and commercial organizations. These authoring tools can be used to develop ITS that can be applied to training for tasks, such as equipment maintenance, that involve manual skills (Lesgold *et al.*, 1988; Munro *et al.*, 2006).

The scope of ITS makes them well-suited to the controlled environments such as training centres. By contrast, PUI is intended for application directly at the location where work is being carried out (i.e. the workface). PUI resources support users in performing a task by providing access to required information through the use of text, images and interactive data presentation (Trees, 2006). A PUI resource is used when the learning content is too extensive to retain mentally. Instead of training staff to mentally retain information about large numbers of tasks, some of which they may never carry out; PUI resources, such as an e-manual, can provide all of the information required directly at the time it is required for a particular task. This means that users only make reference to required information as and when it is needed – instead of overloading themselves with information that may never be used.

Wearable devices offer potential solutions for the communication of PUI. Boeing and Airbus, for example, have supported the use of visual AR since the 1990s (Nicolai *et al.*, 2006). This involves the display of information directly into the field of vision of the technicians to eliminate the need for them to refer to paper documentation. In particular, knowledge management has been combined with wearable computing to enable instant access to electronic log book, aircraft manuals and experience knowledge.

JITT is intended to offer people just the right training at just the right time. Moreover, JITT is intended to provide presentation suitable for the importance of the information, the user's current context, and the user's preferences. Technology that spans engineering and training departments can help turn product data into effective JITT content while reducing the expense and time previously associated with generating training content. By reusing design data, for example, a US helicopter manufacturer discovered significant time reduction for creating maintenance training content for all aspects of a 300,000 part aircraft (Trotter, 2007).

JITT research has sought to bring together researchers from areas such as workflow, personalization and tutoring strategies (Davis *et al.*, 2003). In terms of scope and immediacy, JITT can be considered to be a strategy that can provide an important link, at site offices for example, between ITS in training centres and PUI at the workface.

Computational semantics

An illustration of a practical framework for combining different media and strategies is shown in Figure 2. This shows that formulating skill knowledge could involve using video cameras, photograph cameras, camera phones, and digital pens to record best ways of working. Then, the recorded information could be uploaded, via secure, remote, intranet connections, to wikis for selection and combination. Training of skill knowledge could involve individuals using ITS that evaluate and improve their skill levels as they carry out training tasks. JITT could be used to add to their training just in time to undertake specific tasks. Supplementing skill knowledge could involve individuals using PUI in order to support their skill knowledge during complex tasks.

Ideally, training and supplementing would be carried out with mixed initiative systems. Mixed initiative interaction means that the either the user or the system takes

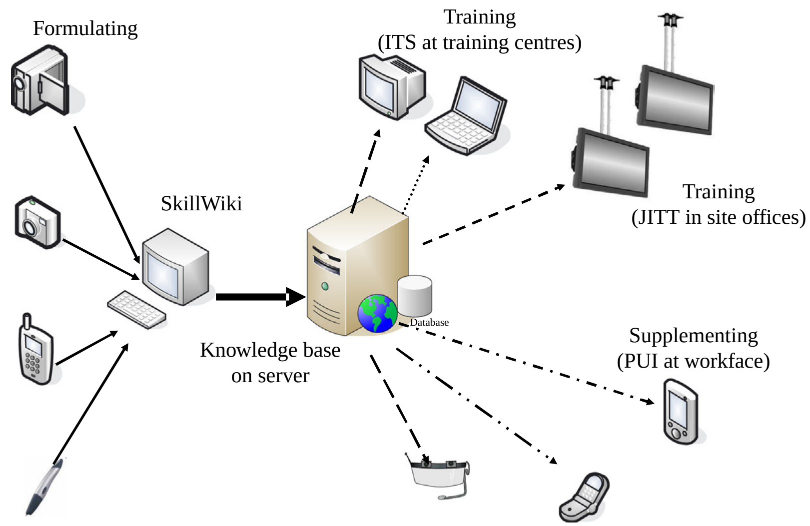

Figure 2.
Practical framework

the lead in the interaction depending upon the need for feedback. Mixed initiative multimodal computer-based dialogue systems have been undergoing development for some years (Freedman, 1999) and often involve automated reasoning through a, so-called, dialogue manager. This maintains the history of the dialogue, retrieves content, decides on best responses to the user, and maintains the dialogue flow (Zue and Glass, 2000). Generally, mixed initiative systems are important in situations where users may be uncertain about what they should do next or where they may be uncertain whether what they have done is correct.

Mixed initiative systems are particular important for the distributed communication of manual skills because feedback is essential to the development of proficiency in manual skills (Magill, 2004; Schmidt and Lee, 2005). Indeed, it has been argued that without feedback, learners will learn only to be consistently wrong – without realizing that they are wrong (Kaufman *et al.*, 1987). Moreover, it has been argued that the timing, frequency and content of feedback can all have a determining effect on the success and speed of learning (Chiviacowsky and Wulf, 2007).

Computational semantics has been used to develop mixed initiative systems such as in-car dialogue systems for activities such as vehicle navigation and music selection. Further, computational semantics has been identified as an important enabler for communication using different media and strategies described above (Belkhatir *et al.*, 2005; Bunt and Romary, 2005; Davis *et al.*, 2003; Janvier *et al.*, 2004; Kenny *et al.*, 2007; Pon-Barry *et al.*, 2006). In simple terms, computational semantics is concerned with the computation of meaning. Experts in computational semantics often have backgrounds in formal semantics and/or computational linguistics. Accordingly, the computational semantics literature is written for such an audience, and contains terminology which that particular audience is already familiar with. This can make computational semantics difficult for people with other backgrounds to understand. In order to develop an explanation of computational semantics applications which can be accessible to industry practitioners, an iterative cycle of literature review, drafting, and validation with experts in computational semantics was carried out during the research. The result is the diagram shown in Figure 3.

This diagram illustrates that common phases in computational semantics applications are human input; multiple analyses; semantic annotation; pragmatic inference; machine control; and computer output. To date human input has often been in the form of natural language. Annotation with semantic tags is common in the association of semantic representations. Pragmatic inferences are drawn from semantic representations. Subsequently, the computational semantics application will control equipment and devices (i.e. machines) that are relevant to the particular application and the specific human input. An in-car spoken dialogue system for music selection will control, for example, DVD player, speakers, etc. Machine control is then the mechanistic result of pragmatic inference. From this control phase will come computer output such as the music which the human input indicated was required. Alternatively, the computer output could be a spoken query through the speech synthesizer controlled by the computational semantics application. A dialogue system for manual skills would tend to communicate more visual information than audio information. Nonetheless, the phases would be much the same. It is important to note that the diagram shown in Figure 3 provides a simplified overview. In practice, the phases shown are often likely to be overlapping and iterative rather than separate and individual.

Many people are becoming familiar with the processes of annotation with semantic tags through their use of digital social networks such as flickr®. In particular, the web sites of digital social networks enable people put word tags to digital photographs and/or VF to enable rapid search and retrieval by themselves and others. Word tags may comprise everyday nouns; such as house, kitchen, table; together with proper nouns; such as the names of people and/or places. These word tags enable users of social networks to find photos and videos which are relevant to a particular topic.

Within flickr®, for example, as many as 75 tags can be assigned to each photo or video. The precision of searches within digital social networks can be increased by combining together an increasing number of everyday words. Within flickr®, for example, one search word "building" yielded 4,727,636 results; two search words "hotel building" yielded 88,744 results; and four search words "Zaha Hadid hotel building" yielded six results. Similar processes are at work within computational semantics applications such as in-car dialogue systems. However, annotation and inference are automated and carried out successfully in response to wide range of unpredictable human inputs.

As shown in Figure 4, a diagrammatic explanation was also developed of the computational processes which enable computational semantics applications. This diagram highlights key processes and illustrates the interplay between them. In particular, the automated process of associating semantic representations can involve interrelated semantic and syntactic analyses. There are two general approaches

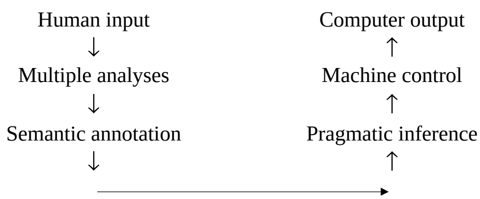

Figure 3.
Common phases in computational semantics applications

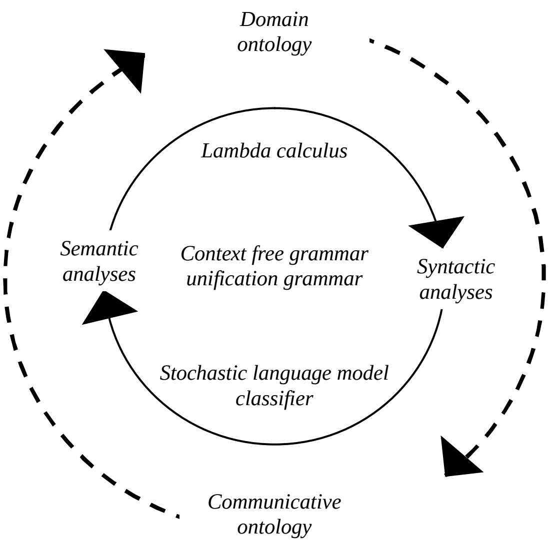

Figure 4.
Potential methods/tools used in associating semantic representations

to these analyses, grammar based and classification. These have various enablers including lambda calculus, context-free grammar, unification grammar, stochastic language models: details of which can be found in the literature (Blackburn and Bos, 2005).

Communicative ontology specifies the concepts, relationships, and other distinctions that are relevant for modelling communication in many domains. Aspects of communication which are common to many domains are, for example: opening, statement, information-request, answer, agreement, closing (Allen and Core, 1997; Bunt, 2006; Gruber, 1993, 2008). Domain ontology specifies the concepts, relationships, and other distinctions that are relevant for modelling particular domains. The literature includes texts and papers containing advice about how to develop domain ontology (Devedzic, 2002; Hovy, 2005; Lopez *et al.*, 1999; Poli, 2002).

Ontology

In this section, recommendations for implementation are provided in accordance with the preliminary domain ontology shown in Figure 5. The ontology was developed during the research through reference to the literature and validated during interviews with industry practitioners.

Task skill requirement

The definition of task skill requirement should take into account task environment as well as task content. Careful analysis of manual skill requirements should be carried out. For example, differences between skill requirements in different types of environments, such as working at ground level versus working at high level, should be defined.

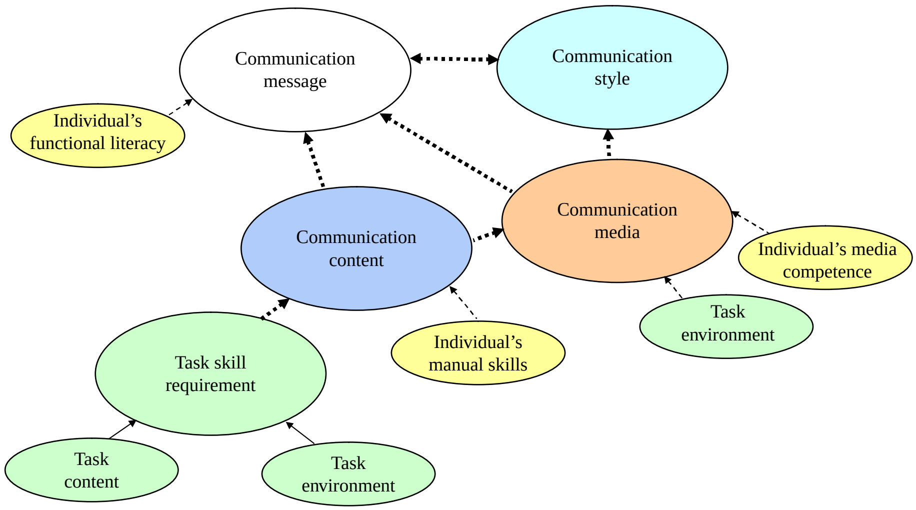

Figure 5.
Preliminary ontology for distributed communication of manual skills

Communication content

Communication content should take into account the existing manual skills of the individual person who shall perform the task. For example, a person who has no relevant existing manual skills will need to see all manual skill information about the task. By contrast, a person who has performed such a task successfully in the recent past may not need to have any part of the task communicated. Existing skills can be categorized in terms of skill levels.

Content should be able to be communicated through a variety of different media. A VR graphic, for example, could be viewed through a computer monitor, laptop screen, mobile phone, or headset. In addition, a VR graphic could be printed onto paper for viewing at exceptional locations with no access to electrical power and/or the internet.

Pilot testing of content should be carried with a variety of different communication media. For example, viewing digital graphics with an AR headset may have the potential to be more easily understood by more people because it presents additional instructional information in the same view as the real world. On the other hand, viewing digital graphics in this way can overlay key information in the real world and, as a result, reduce clarity (Fox, 2010).

Communication media

Communication media have fundamental capabilities and these need to be matched to task environment and user competence, as well as communication content. In a very dusty environment, for example, viewing instruction via an AR headset may be less effective than viewing instruction via print out on paper. Also, while almost anybody may be able to immediately handle paper; many people may not be able to immediately operate an AR headset.

Communication style

Communication style involves different types of interaction. For example, interaction can be user-led and not include feedback. This means that the individual person who will perform the task takes the initiative to access relevant manual skill information. If that individual wants to view the manual skill information again, s/he has to request to do so. By contrast, computer-enabled feedback is provided within mixed initiative interaction. In either case, user interfaces for communication devices should be intuitively understandable.

Communication message

Communication message is determined by individual's functional literacy, as well as communication content, communication media, and communication style. To avoid functional literacy barriers, such as limited ability to understand written words in a particular language, messages which communicate manual skills should avoid use of written text. Rather, visual graphics should be used that direct attention to those details, such as the positioning of hand grip on a tool, the extent of joint movement, etc. which have most influence on the success of skill execution.

Industry attitudes

It has been recognized for several decades that attitudes among industry practitioners can determine whether organizational change and technology implementations are successful or not (Davis *et al.*, 1989; Lawrence, 1969). In order to make an initial assessment of potential attitudes among industry practitioners, interviews were held with ten different organizations.

All of the interviewees were involved in the provision of training. Trainees were not interviewed. This was because the interviews sought to explore the attitudes of those practitioners who would decide whether, or not, new solutions for communicating skill knowledge should be piloted. Subsequently, piloting of selected solutions could involve gathering the opinions of trainees. However, that was outside the scope of the research. The informant style of unstructured interview was used (Powney and Watts, 1987). The interviewer did not seek to control the interviews. Rather, interviewees freely expressed their thoughts and took the interviews in the direction that they chose. This type of unstructured interview can be contrasted to the respondent style of unstructured interview where the interviewer seeks to follow a more defined agenda (Powney and Watts, 1987). Interviewees from six of the organizations also showed examples of their training materials. These ranged from written materials such as manuals and slides, to physical materials such as components which trainees practice assembling.

Interviewees from all organizations expressed opinions about the short-comings of existing approaches to the training of manual skills. Interviewees from five organizations emphasized that the usefulness of the time available at the training centres is limited by the wide variety of experience among different trainees participating in the same training session. This leads to situations where some of a training group are motivated to participate and contribute because they are learning something they consider to be new and valuable. By contrast, others in the same training group are not motivated to participate and contribute because they believe that they have already learnt the particular skills "on-the-job".

This can mean that the limited amount of training time available within the training centres is often not well spent. In particular, it is not possible to provide individual training to match the existing skills of each individual trainee. Rather, training is delivered to groups in accordance with a programme. Interviewees saw this as being an increasing challenge because of the increasing amount of training content. This was summed up by one interviewee when he remarked that, "every year the training manual gets thicker but the time available for training stays the same".

Interviewees from seven organizations emphasized the proportionately high amount of time spent "on-the-job" as being another major challenge in the communication of skill knowledge. In one training programme lasting five years, for example, each operative would spend approximately 900 hours at the training centre compared to approximately 8,000 hours "on-the-job". Further, time at the training centre would be spent during evenings after a day's work had been completed "on-the-job".

The training professionals sought to rotate trainees around a number of companies in an effort to provide them with opportunities to experience a broad range of tasks requiring manual skills. However, examples were given of tradesmen being reluctant to pass on their skill knowledge because they regarded a trainee as being a threat to their own future incomes. Moreover, there could be a shortage of people with manual skills available to communicate what is needed. This can mean that there are no people with manual skills available at all; or that the ratio of skilled to unskilled is too low to enable the communication of manual skills where and when they are needed. Also, the scope and depth of different people's manual skills can vary and may not be an ideal match with the specific manual skill requirements of particular situations. Further, some people with a high degree of manual skills may not be particularly good at communicating what they know to anybody, or at least not particularly good at communicating to slow learners, and/or people with another first language. All together these factors mean that the communication of a specific manual skill, which is most appropriate to a specific task and to a specific person, may often not be available when it is needed.

Interviewees from seven organizations emphasized reliance on the use of natural language as a barrier to the communication of skill knowledge. They gave examples communication difficulties between native English speakers and native Spanish speakers and/or native speakers of Asian languages. Further, it was pointed out that irrespective of their native language, trainees might be functionally illiterate and have difficulties reading written information such as captions accompanying visual images in training books and manuals. Interviewees' opinions about the limitations of communication of manual skills by human instructors are summarized in Table I.

Overall, the interviewees opined the following three major limitations with the communication of manual skills by human instructors: instruction at training centres being delivered to groups in accordance with a programme rather than being delivered to meet the specific needs of individuals in accordance with their existing skill levels; the erratic quality of training available "on-the-job" where trainees spent some 90 per cent of their time; and reliance on the use of natural language. All together these three barriers were seen to perpetuate the current long duration of training programmes.

Accordingly, all the training professionals had a positive view of the possibility of distributed communication of manual skill knowledge that could have the following

Table I.
Limitations of manual skill instruction by human instructors

Existing situation	Short-coming
Training at centres delivered to groups	Trainees have different existing skills
Training "on-the-job" delivered by tradespersons	Erratic availability and quality
Training reliant on the use of natural language	Different languages and variable literacy

characteristics: tailored to existing skill levels of each particular individual trainee; consistently high quality "on-the-job"; and not reliant on the use of natural language. Interviewees stated that they were already making some attempts to formulate digital descriptions of manual skills. These included digital video and digital photographs. None of the interviewees' organizations had defined ontology. However, the definition of some kind of "labelling system" was seen as being important by the interviewees because they were finding the retrieval of digital information to be increasing difficult as its volume increased.

Interviewees from five organizations were familiar with notions of JITT and PUI, but none were familiar with ITS. Nonetheless, they were able to immediately grasp the potential of ITS as means of addressing their concerns about instruction at training centres being delivered to groups in accordance with a programme rather than being delivered to meet the specific needs of individuals in accordance with their existing skill levels. Interviewees regarded the "formulating – training – supplementing" framework, which is illustrated in Figure 2 and summarized in Figure 6, as being a useful way of "pulling together" the transition to digital communication of manual skills. Interviewees saw this transition as becoming increasingly important to due the looming retirements of experience tradesmen who had served lengthy apprenticeships in the 1960s.

None of the interviewees indicated that they foresaw digital distributed communication of manual skills as being a threat to their livelihoods. Rather, it was opined that continued reliance on human instructors was unlikely to lead to the communication of manual skills that was tailored to the existing skill levels of each particular trainee; that was delivered to uniform high-quality delivery "on-the-job"; and that was not reliant on natural language.

Conclusions

Resource management is recognized as being a very important aspect of project business (Engwall and Jerbrant, 2003). The retirement of the, so-called, baby boom generation of trades people is leading to increased shortages of manual skills (Ruiz, 2008). Shortages of manual skill resources can reduce the speed, quality, and/or safety of project production (Risen, 2008).

Reports of skill shortages and interviews with practitioners suggest that there is need for distributed digital communication of manual skills. In particular, the following limitations of human communication may lead to support among industry practitioners:

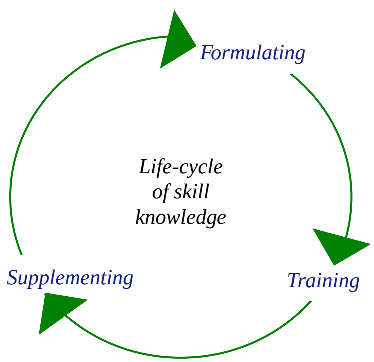

Figure 6.
Phases in distributed communication of manual skills

instruction at training centres by human instructors is not delivered to meet the specific needs of individuals in accordance with their existing skill levels; the erratic quality of training available "on-the-job" where trainees spent some 90 per cent of their time; and reliance on the use of natural language.

An increasing number and variety of media are being introduced which can enable the distributed digital communication of manual skills. These media can be deployed within three strategies: ITS, JITT and PUI. Media and strategies can be integrated within a framework of formulate-train-supplement. In order to provide appropriate guidance and feedback during tasks, media and strategies should be combined in mixed initiative systems. Computational semantics can provide the technological mechanism for mixed initiative systems.

Ontology can provide the starting point for the development of mixed initiative systems for distributed digital communication of manual skills. It is important to note that the development of mixed initiative systems requires expertise in computational semantics which businesses involved in project production may not have internally. However, the necessary expertise from universities' computer scientists can be procured and subsidized via grant-assisted technology schemes operated by national or regional governments.

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