Automotive technicians' training as a community-of-practice: Implications for the design of an augmented reality teaching aid

Margarita Anastassova a, *, Jean-Marie Burkhardt b,1

a Laboratory of Applied Research on Software Intensive Technologies, French Atomic Energy Commission (CEA-LIST), 18, route du Panorama, BP6, 92265 Fontenay-au-Roses Cedex, France
b Ergonomics, Behaviour and Interactions—EA 4070, Paris Descartes University, 45 rue des Saints-Pères, 75270 Paris Cedex 06, France

ABSTRACT

The paper presents an ergonomic analysis carried out in the early phases of an R&D project. The purpose was to investigate the functioning of today's Automotive Service Technicians (ASTs) training in order to inform the design of an Augmented Reality (AR) teaching aid. The first part of the paper presents a literature review of some major problems encountered by ASTs today. The benefits of AR as technological aid are also introduced. Then, the methodology and the results of two case studies are presented. The first study is based on interviews with trainers and trainees; the second one on observations in real training settings. The results support the assumption that today's ASTs' training could be regarded as a community-of-practice (CoP). Therefore, AR could be useful as a collaboration tool, offering a shared virtual representation of real vehicle's parts, which are normally invisible unless dismantled (e.g. the parts of a hydraulic automatic transmission). We conclude on the methods and the technologies to support the automotive CoP.

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1. Introduction

The automobile industry goes continuously through rapid changes provoked by increased competition and constant pressure to reduce cost and time-to-market. These processes result in a shortening of the design life cycle, a reduction of the number of physical prototypes, a fast renewal of models, an increase in outsourcing and in the number of suppliers, and a massive introduction of electronics (Pierreval et al., 2007). Despite the efforts of automobile manufacturers, these processes influence negatively both the duration and the content of Automotive Service Technicians' (ASTs') training programmes. The major difficulties of ASTs today are presented below.

1.1. Major difficulties of current ASTs

To our knowledge, there are few empirical studies on ASTs' activity and training. A literature review, based on scientific and professional sources, shows that:

- Training programmes, whose duration has been reduced, are estimated as too short by the majority of ASTs.
- Diagnostic knowledge to be acquired and transmitted has become more sophisticated because of the introduction of electronics and in-vehicle networks. Today the electronic infrastructure of a luxury car consists of up to more than 70 electronic control units, each typically dedicated to only one application service (Peti et al., 2005).
- The diagnostic activity and the influence of all these changes on it have not been studied thoroughly and have not been formalised in order to feed the development of training programs and equipment (Anastassova et al., 2005).
- Training curricula have to be updated frequently to reflect changing technology. The resulting ASTs' knowledge is thus barely stabilised and in constant evolution, especially in the first year after the release of a new model (Barkai, 2001; Mulholland et al., 2001).
- Even if properly updated, training may have been provided too early or too late to fully satisfy operational day-to-day needs in repair shops (Saint-Venant et al., 2002). For example, ASTs working in large repair shops, which are part of a manufacturer's network, may have worked on some of the latest models before actually receiving formal training on them. Conversely, the ASTs working in small, independent repair shops may work on such models only six months or one year after the training programme.
- Knowledge is often transmitted “on-the-job” (i.e. ASTs learn the trade by working with experienced colleagues). Hence,
some authors suggest that knowledge acquisition and improvement result primarily from “horizontal division of substantive expertise” (Barley, 1996) and from informal learning processes such as accumulation and dissemination of maintenance practices by ASTs. However, the organisational resources to support the formalisation, capitalisation and transmission of this knowledge are hardly ever mobilised (Amiel et al., 2004; Barkai, 2001).

- Training programmes are a part of a complex sociotechnical system involving a large number of actors (suppliers, training designers, managers, trainers, trainees, etc.). Furthermore, trainers and trainees are at the end of this chain. Therefore, these operators’ activity is largely dependent on the information, sometimes incorrect, received from all the actors upstream (Grusenmeyer, 2002).

For all these reasons, ASTs’ training may no longer be considered as a well-structured, closed and smoothly functioning learning system. Consequently, it could no longer be investigated only by traditional methods such as strictly controlled experiments on trainees’ representations and knowledge acquisition and transfer (e.g. Bonnet, 1975). It is necessary to describe the functioning of this open learning system, and to study both formal and informal learning processes in context (in repair shops and in automobile manufacturers’ training centres). The two field studies of ASTs’ training, presented in this paper, are a contribution towards the achievement of this goal.

These studies were done in order to inform the design of a future Augmented Reality (AR) teaching aid. AR is defined as a combination of views of the real world with views of a virtual environment (Caudell and Mizell, 1992). This is an emerging technology whose potential utility for supporting numerous industrial applications, including ASTs’ training, is largely promoted nowadays by researchers and industrial organisations (Doswell et al., 2006; Regenbrecht et al., 2004; Wiedenmaier et al., 2003). The benefits of AR in this context are summarised below.

1.2. AR benefits for ASTs’ training: assumptions and empirical results

Broadly speaking, AR would be useful for training, because the information is presented “just-in-time” and “just-in-place”. Actually, AR systems would support training by:

- Giving to trainees the possibility of “learning-by-doing” (i.e. of constructing knowledge actively and autonomously directly in the workplace, Doswell et al., 2006; Fjeld and Voegtl, 2002);
- Facilitating trainees’ information search: as information would be provided when and where needed, trainees would not have to look for it (Cooperstock, 2001);
- Reducing the error likelihood: as necessary data and real-world spatial cues would be found with little user effort, memorisation and recall would be facilitated (Neumann and Majoros, 1998; Regenbrecht et al., 2004).

Moreover, during ASTs’ training, the simultaneous presentation of physical artefacts (e.g. a fuel injection engine) and the associated abstract technical concepts (e.g. remove-and-replace instructions and spare parts structural models) in a virtual form could facilitate the comprehension and retention of information (Stedmon and Stone, 2001). Moreover, animated virtual objects would enhance the understanding of dynamic phenomena evolving in time and space (Shelton and Hedley, 2002). AR systems would also help multiple users (e.g. trainees and trainers) share the same view of a virtual environment (Chastine et al., 2007; Schmalstieg et al., 2002).

Despite such claims, actual empirical results did not consistently report a benefit of AR applications for training (for a review see Anastassova et al., 2007). We consider that this effect could be partly explained by the fact that AR, as an emerging technology, is upcoming and in search of potential applications. Thus, research in the field of AR is essentially technology-driven, meaning that users’ requirements and the effectiveness of the applications remain designers’ minor concerns. As a result, the few existing prototypes are mainly proof of technological concepts and offer very few functions to support trainees’ and trainers’ activities (Anastassova et al., 2007; Wilson and D’Cruz, 2006). In addition, HCI specialists, if ever requested, are mainly involved in late design stages. The possible positive impact on design decisions is hence limited insofar as the possible interface and hardware modifications are also limited (Kjeldskov, 2003).

In order to overcome this last shortcoming, the two field studies presented in this paper were done very early in the design of the future AR training aid. Furthermore, as these studies adopted a user-centred design approach, the main issues addressed concern the training goals to be implemented within the future AR prototype and the pedagogical configurations to be supported rather than some technical challenges.

1.3. Goals and organisation of the paper

The objective of the field studies presented in this paper is thus twofold. They try to provide (1) a description of ASTs’ training as it is currently organised in an automobile manufacturer’s training centre, and (2) a number of usable results for establishing the specifications of the future AR training aid. The studies concerned training in new models of vehicles, since a preliminary research showed that this was one of the most problematic aspects of ASTs’ activity (Anastassova et al., 2005).

The paper is organised as follows. First, we present Study 1 based on interviews with trainers and trainees. Then we present Study 2, based on observations in real training settings. The presentation and the discussion of the results of each study follow the methodology. The results of both studies show that today’s ASTs’ training could be considered as a community-of-practice (CoP). As the two studies have a common industrial objective (to elicit the user requirements for the future AR training aid), we summarise these requirements at the end of the paper and we conclude on the methods and technologies to support CoPs in automotive maintenance.

2. Study 1: an initial description of ASTs’ training

The purpose of Study 1 was to obtain an initial insight into ASTs’ training as a network of actors, and to clarify trainees’, trainees’ and training designers’ activities and roles in it. A special emphasis was put on the actors’ difficulties when designing, implementing and attending training. Twenty-three interviews with different operators were conducted and the collected verbal protocols were analysed.

2.1. Operators and sites

Twenty-three operators, all male, divided into three groups, participated in the study. There were:

- Six trainers aged from 30 to 53 years (\(M = 40, SD = 11.2\)), with an average experience of 5 years in this job (\(Min = 1, Max = 11\)). Their average prior experience as ASTs was of 14 years (\(Min = 3, Max = 27\)).
2.2. Procedure and apparatus

After a brief presentation of the project, all the operators were interviewed in their workplace during the normal working hours. Confidentiality and anonymity were guaranteed. The 23 semi-structured interviews, all tape-recorded, had a duration ranging from 10 min to 45 min ($M = 19$, $SD = 10.9$). The interviews with the trainees concerned their impressions of training programmes (i.e. perceived utility, eventual problems). The interviews with the trainers and the training designers concerned the difficulties they encountered in their daily activity, and the resources they used to cope with these difficulties.

The concept of training resources was not limited to material resources, but included all types of information and interactions with trainees, peers and hierarchy (for a similar conception of training resources see Roth, 1996; Sibson and Machen, 2003). The trainers and the training designers were also questioned about the eventual applications of AR in their jobs.

2.3. Data analysis

The verbal protocols obtained (8 h 25 min), transcribed verbatim, were then analysed, using classical techniques for theme-based protocol analysis (Ericsson and Simon, 1999). The unit of analysis corresponded to a federating idea, expressed in one or several lines of the verbal protocol (for more details see Anastassova, 2006). The resulting coding of the verbal protocols had been validated during a meeting with trainers and training designers. The appearances of each unit in the verbal protocols were then counted and descriptive statistics were done on the data.

2.4. Results

2.4.1. A complex network connecting a large number of actors with both bottom-up and top-down learning processes

A first general result, emerging in the operators’ interviews, was an outline of the place of training in new models within the larger and complex system of vehicle design and maintenance (Fig. 1).

The training design and delivery imply actors from numerous departments. Thus, vehicle designers provide information on vehicles’ technical characteristics to designers of diagnostic methods and repair instructions. The diagnostic methods designers draft a first version of these instructions and transmit it to training designers. The latter set training goals, and develop training manuals and programmes. Then, they provide all these documents as well as training vehicles to trainers. Finally, the information reaches the trainees by two channels: (1) the repair instructions contained in the manuals used in repair shops and (2) the formal training sessions. It should be noted that, in the studied organisation, only rather experienced technicians attend training. They are further supposed to transmit the acquired knowledge to their colleagues in repair shops during on-the-job training.

The information also goes bottom-up from ASTs to vehicle designers via two institutional departments. These are (1) the trainers, who provide feedback to training designers and (2) the hotline support, whose role is to help ASTs with the resolution of unusual faults, to collect these faults and to further transmit them to vehicle designers.

This description shows that today ASTs’ training follows a model of instructional design, which is quite different from the traditional linear one, stating that training goals and content are well-formalised before the actual training implementation and should merely be transmitted to trainees by their trainers.

The widely distributed organisation of ASTs’ training has two major consequences on the actors involved in it. On the one hand, it provokes some difficulties and, on the other, it provides a number of shared resources and strategies to cope with the difficulties. These two facets of the organisation, as reported by the actors, are described below.

2.4.2. Trainers’ difficulties: shortage of resources, short training, reliability and timeliness of information

In the trainers’ interviews, there were 188 units of analysis in total. Almost half of the statements (85/188) concerned various difficulties encountered in their daily work. The federating idea in these statements was some problems in collaborating with other actors involved in the design and the implementation of training: a graphical representation.

![Fig. 1. Actors involved in the design and the implementation of training: a graphical representation.](image-url)
departments, particularly with training designers. The most important problems are the following:

- The shortage of usable material resources provided by training designers (i.e., ready-to-use spare parts and vehicles for demonstrations and simulations, 33% of the difficulties, \( n = 28 \)). This shortage had been reported to limit the possibilities of simulating realistic didactical faults.
- The shortness and perfunctoriness of the training that the trainers themselves receive (17%, \( n = 14 \)).
- The discrepancies between different vehicle prototypes used by different actors in the organisation (15%, \( n = 13 \)). Quite often, training designers work on a first vehicle prototype to prepare training documents; then, trainers work on a second, usually more advanced prototype to prepare and deliver training; and finally, clients buy and use a third “version” of a vehicle.
- Some erroneous information in training documents (13%, \( n = 11 \)).
- Some delays in delivering the latter (13%, \( n = 11 \)).

2.4.3. Training designers’ difficulties: access to information and time constraints

In the designers’ interviews, there were 175 units of analysis in total. Again, more than half of the statements (59%, \( n = 103 \)) concerned different types of difficulties encountered in their daily work. The most important problems are the following:

- The difficulty to obtain up-to-date, relevant and correct information on vehicles’ technical characteristics from the other actors in the organisation (49% of the verbal units, \( n = 50 \)).
- Time constraints (17%, \( n = 18 \)).
- The insufficient number of vehicle prototypes (12%, \( n = 12 \)).
- Some difficulties to “translate” the highly technical information they receive from vehicle designers into a form understandable by trainers (11%, \( n = 11 \)).

2.4.4. Trainees’ difficulties: shortness of training

As for the trainees’ reports, 6 of the 11 statements (55%) concerned the shortness of the training both in training centres and in repair shops; two statements concerned the strong theoretical orientation of the training programmes in training centres. Three of the statements (27%) did not report any particular problems.

2.4.5. Trainees’ and designers’ resources to cope with the difficulties

In the trainers’ and training designers’ verbal protocols, about one third of all the statements concerned the resources these operators use to cope with the difficulties described above. These resources could be organised into two groups, namely interactional and material resources. Interactional resources are all the pieces of information obtained from different sources, as well as the supplementary efforts made by operators to methodically prepare their courses. Material resources are physical artefacts used in their activity in order to accomplish their tasks.

Both the trainers and the designers evoked the use of interactional resources more often than the use of material ones (i.e., in 58% of trainers’ verbal units, \( n = 35 \), and in 68% of designers’ verbal units, \( n = 41 \)). Among the available interactional resources, the trainers report most often the use of:

- Information provided by training designers (35%, \( n = 12 \));
- Some information they found themselves (29%, \( n = 10 \));
- Trainees (20%, \( n = 7 \)); and
- Colleagues (17%, \( n = 6 \)) as sources of information.

As for training designers, among the available interactional resources, they report most often the use of:

- Some information they found themselves and their personal knowledge (41%, \( n = 17 \));
- The information provided by vehicle designers (39%, \( n = 16 \)); and
- The information provided by trainers, which is rarely evoked (7%, \( n = 3 \)).

In addition, both the designers and the trainers reported using material resources. The trainers evoked the use of the existing repair instructions (36%, \( n = 9 \)) and the available training vehicles and spare parts in order to verify the information provided by training designers (64%, \( n = 16 \)). The designers evoked the use of existing programme templates (47%, \( n = 9 \)), vehicle prototypes (37%, \( n = 7 \)) and photos of spare parts (16%, \( n = 3 \)).

2.5. Discussion: current ASTs’ training as a community-of-practice

The results from Study 1 show that the actors involved in today’s ASTs’ training evolve in a very compound socio-organisational system, which possesses many of the characteristics of a community. Thus, information is exchanged within a complex circle, whose members are clearly inter-related and mutually dependent. A part of the knowledge about vehicle maintenance is built within this circle thanks to the collaboration of all the actors. Moreover, training in repair shops is mainly done by peers. Based on social negotiation, this type of learning encourages collaboration and the construction of a common “system of reference” (De Tersscak and Chabaud, 1990; Leplat, 1991). These empirical results support and extend previous findings and assumptions (e.g., Amiel et al., 2004; Barkai, 2001).

Study 1 also shows that this community functions as a just-in-time process in constant evolution. For example, the perceived time constraints, the delays in delivering training materials, the shortage of usable spare parts for training, and the different versions of vehicles used by the different actors may be attributed to this time-to-market pressure, pointed out recently by Pierreval et al. (2007). The same is valid for the erroneous information in training materials and the fact the trainers perceive the training they obtain and deliver as perfunctory. While this orientation may be economically advantageous, it causes various problems to all the actors within the system and creates a risk for its long-term reliability and effectiveness. Thus, if one of the components is missing or “defective”, this social system incurs a risk of generating a knowledge gap. Though considered and expected by Barkai (2001), these changes have not received empirical evidence up to now.

One original result of our study shows that the same social system provides to its actors the resources to deal with the difficulties. For example, their hierarchy, peers and trainees are a valuable informational resource for trainers. These actors taken together are evoked more often as a resource to cope with the difficulties than the available physical artefacts. As for training designers, they say they rely mainly on their own knowledge and experience. Thus, both groups of actors acknowledge the use of informal interactional resources to properly design and deliver training.

We consider that a new explicative metaphor such as Community-of-practice (CoP, Lave and Wenger, 1991) could better account for the complexity of this social system and the informal character of the majority of the resources used within it, compared to the traditional linear model of training. A CoP is defined as a sustained social network of mutually interdependent individuals who share and build up knowledge, beliefs, values and experiences through
common practice and/or enterprises (Barab et al., 2003). To our knowledge, there have been no empirical studies on automotive maintenance training as a CoP, but we consider that Study 1 shows that today’s ASTs’ training could be regarded as a non-institutionalised, self-formed CoP.

In order to gain a deeper and more objective insight into the characteristics of this CoP, we performed a second study based on observations in real training settings. The methodology and the results of this study are presented below.

3. Study 2: insights into the CoP in real training settings

3.1. Participants and observed training sessions

Seven training sessions delivered by six of the previously interviewed trainers were recorded. The trainers were aged from 30 to 53 (M = 40, SD = 11.2). They had an average experience of 5 years as trainers (Min = 1, Max = 11), and an average experience of 14 years as ASTs (Min = 3, Max = 27). Fifty-two trainees were participating in these training sessions.

Three training sessions concerned a novel type of fuel injection engine. The other four sessions concerned a new model of vehicle.

3.2. Data collection

The seven training sessions were tape-recorded after obtaining an oral informed consent from all the actors involved. We used one digital video camera directed at the trainer and his actions.

3.3. Data analysis

The videotapes (52 h) were then analysed. The analysis was partly based on a research methodology for capturing the use of resources in educational settings (for more details see Barab and Kirshner, 2001). In the original methodology, video data are segmented into action-relevant episodes, which are further coded and registered in a database. The episodes are defined by a change of the major theme discussed, the activity of the group, the actor or the resources used. As we are interested in the “augmentation” of existing learning resources by technological means, the unit of analysis in our study, further referred to as an “episode” of resource use, was defined by the change of resources. The following characteristics were associated with each episode:

- **Duration**;
- **Major topic discussed**: e.g. briefing/debriefing, presentation of fault diagnosis methods, simulation of fault resolution;
- **Material resources used by trainers and trainees**: these are physical artefacts such as training vehicle/spare parts and annotations (i.e. additional information in the form of drawings or text on the blackboard);
- **Interactional resources used by trainers and trainees**: these are part of the collective’s sociotechnical capital, which could be mobilised in order to attain a training goal (e.g. information, question, information given by trainees, trainer’s actions);
- **Goals of using the material resources**: e.g. to support discussion, to demonstrate;
- **Goals of using the interactional resources**: e.g. to present diagnostic methods, to acquire knowledge on field practice, to describe field practices.

This coding scheme had been validated during two meetings with trainers. The frequency of each unit in the video data was then quantified and bi- and multivariate exploratory statistical analyses were carried out on the data.

3.4. Results

In total, there were 5279 episodes with a minimum duration of 1 s and a maximum duration of 8 min 45 s (M = 30 s, SD = 46 s). Our subsequent analysis showed that the patterns of trainers’ and trainees’ activity were similar in both types of training sessions. The major results describing these patterns of activity are summarised below. More details can be found in Anastassova (2005) and Anastassova et al. (2005).

3.4.1. Common activity patterns observed in both types of training sessions

In both training sessions, only few difficulties could be directly observed. Therefore, a number of difficulties were inferred from the total time spent in discussing a given training topic. Thus, the longer a topic is discussed the more important and/or difficult it is considered to be for the training process. In all training sessions:

- The presentation of fault diagnosis methods and the simulation of fault resolution seemed central; the general technical presentation and the briefing were of minor importance (cf. Table 1). This result confirms the conclusions of a former study in repair shops (Anastassova et al., 2005).
- Explanations and information were the preferred interactional resources.
- Trainees’ narratives on their field experience are a valuable interactional resource.
- Training vehicles and annotations were the preferred material resources.

The learning resources may be regarded as basic components supporting the knowledge construction in the CoP, as they are the means for attending a given goal. In this sense, it is interesting to investigate which specific goals would favour the use of specific resources. In order to analyse the relationships between the trainers’ and the trainees’ goals and the learning resources used, we calculated Relative Deviations (RDs)\(^3\) and performed a Correspondence Analysis (CA).

3.4.2. Which goals of use for which interactional resources

The RDs for both types of training showed that information (RD\(_{IET} = 1.44\); \(RD_{NMT} = 0.11\)) and explanations (RD\(_{IET} = 0.70\); RD\(_{NMT} = 0.22\)) were mostly used by the trainers to present

| Table 1
| Common activity patterns in both types of training sessions. |
|---------------------------------|-----------------|-----------------|
| Behaviour indicators            | Injection engine training (IET) | New model training (NMT) |
| Time for the presentation of diagnosis methods and fault resolution | 9 h (75% of the training time) | 27 h 15 min (68%) |
| Time for general technical presentation and briefing | 2 h 50 min (25%) | 12 h 50 min (32%) |
| Preferred interactional resources: explanations and information | 7 h 03 min (57%) | 25 h 20 min (64%) |
| Preferred interactional resources: trainees’ narratives | 1 h 16 min (12%) | 6 h (15%) |
| Preferred material resources: training vehicles and annotations | 6 h 40 min (69%) | 33 h (83%) |

\(^3\) RDs measure the association between two nominal variables. They are calculated on the basis of a comparison between observed and expected frequencies (i.e., those that would have been obtained if there was no association between the two variables). There is attraction when the RD is positive, and repulsion when it is negative.
diagnostic methods of electronics and electricity. Explanations were also used to describe vehicle’s technical characteristics \( \text{RDIET} = 1.39; \text{RDNMT} = 0.33 \). The trainers used questions to acquire knowledge on field practice \( \text{RDIET} = 2.68; \text{RDNMT} = 1.34 \). In the NMT, hypotheses were used in the same context \( \text{RDNMT} = 0.28 \). Moreover, questions were used to assess the trainees’ knowledge \( \text{RDIET} = 3.46; \text{RDNMT} = 0.29 \). The trainees’ knowledge was also evaluated by judgements \( \text{RDIET} = 5.76; \text{RDNMT} = 0.88 \). The trainers expressed agreement when they wanted to encourage the trainees \( \text{RDIET} = 22.38; \text{RDNMT} = 0.22 \). Logically, the trainers acted on training vehicles in order to resolve a simulated fault \( \text{RDIET} = 20.10; \text{RDNMT} = 0.45 \).

Interestingly, the trainees asked questions to acquire knowledge on the field practice of their colleagues when diagnosing electronics \( \text{RDIET} = 14.24; \text{RDNMT} = 0.02 \). Accordingly, the information that the trainees gave was in order to describe these field practices \( \text{RDIET} = 1.75; \text{RDNMT} = 0.23 \) and to suggest a possible fault resolution \( \text{RDIET} = 2.42; \text{RDNMT} = 0.26 \). Note that even judgements were used by the trainees to describe their field practices \( \text{RDIET} = 3.91; \text{RDNMT} = 0.60 \). The trainees used actions mainly to resolve a simulated fault \( \text{RDIET} = 19.22; \text{RDNMT} = 1.31 \). All these associations relative to the IET are quite strong \( \chi^2 = 0.46 \), while those relative to the NMT are weak \( \chi^2 = 0.02 \).

A graphical representation of these relationships is presented in Fig. 2.

### 3.4.3. Which goals of use for which material resources

During the NMT, the trainers used annotations \( \text{RDNMT} = 0.83 \) and training documents \( \text{RDNMT} = 0.54 \) in order to support their presentation of electronics and electricity. The training documents were also used during the briefings and debriefings \( \text{RDNMT} = 2.34 \). These associations are intermediate \( \chi^2 = 0.11 \).

As for the ITE, in order to study the relations between the material resources used and the goals of their use, a CA was performed. CA \( \text{(Benzecri, 1984)} \) is a descriptive technique based on RDs. It is designed to analyse simple two-way tables containing measures of correspondence between the rows and the columns. In our study we used two cross-tabulated nominal variables: the variable “Material resources” having three attributes (training vehicle/spare parts, annotations and training documents) and the variable “Goal of use” having seven attributes (to support discussion, to demonstrate, to note additional information, to describe functioning, to resolve simulated faults). According to the correspondence analysis techniques (for further details see Rouanet and Le Roux, 1993), we retained two dimensions (100\% of the inertia explained).

Fig. 3 is a graphical representation of the examined variables and attributes in a geometric space based on the retained dimensions. For the interpretation of the dimensions, we used the factorial coordinates of each variable on axis 1 or 2 (F column), the quality of representation (QLT column), the cosine squared \( \text{COR} \) and their contributions of the variables \( \text{CTR} \) to the axis inertia (Appendix A). The results of this interpretation are as follows.

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4 \( \chi^2 \) or Cramer’s \( V \) measures the magnitude of the association between two nominal variables. It is calculated using the phi squared \( \phi^2 \) divided by \( \chi^2 \max \), \( \phi^2 \max \) being the smallest dimension of the table minus 1. Cramer’s \( V \) lies between 0 and 1. It is conventionally considered to be small when \( V^2 < 0.04 \), to be intermediate when \( 0.04 < V^2 < 0.16 \), and to be strong when \( V^2 > 0.16 \).
4. User requirements for the future AR teaching aid

For the automotive maintenance CoP described before, one would spontaneously suggest the implementation of recognised computer-supported collaborative work (CSCW) systems such as online knowledge depositories, discussion spaces, shared whiteboards, etc. (e.g. May and Carter, 2001). Nevertheless, we believe that AR, though not a "labelled" CSCW technology, could be useful for the actors in the automotive maintenance CoP. Thus, it could offer the possibility for trainers to use the most recent Computer-Aided Design (CAD) data on new models of vehicles. These data, provided usually by vehicle designers, should constitute the virtual elements of the AR system. They could be overlaid on the real vehicles, used during the training, in order to complete and/or correct the information already available, but probably obsolete. This is particularly valid for electrical and electronic systems, whose functioning seems constantly evolving and difficult to grasp by both the trainers and the trainees. In practical terms, a real training vehicle could be equipped with physical markers indicating the position of invisible vehicle parts such as processors and sensors. These markers could be read by a camera-equipped handheld device and overlaid on the real vehicle to provide additional information.

5. Discussion

The results of Study 2 offer supplementary and more objective arguments supporting the assumption that ASTs' training nowadays could be considered as a constantly evolving CoP with fuzzy boundaries and roles. Thus, although the trainers use primarily traditional expositive teaching methods (i.e. explanations and information), they no longer have the role of absolute "gatekeepers of knowledge". They are rather facilitators of the shared knowledge construction process, since the trainees and their narratives on field diagnosis practices are extensively used as an informational resource both by the trainers and the peers. On the basis of existing literature (e.g. Barkai, 2001) this new role of ASTs' trainers could be mainly explained by (1) the sophistication of electronics and in-vehicle networks; (2) the frequently updated technology, and (3) the reduction of training duration.

To our knowledge, the importance of narratives as learning resources for the automotive maintenance CoP has not been empirically demonstrated up to now. Yet this seems a significant issue both from a descriptive and from a developmental point of view. Actually, narratives could be potentially constructive for CoPs, since they are memorable, grounded in experience, comparable with one's own practice and source of informal social support (Marchand-Sibra and Falzon, 2006; Swift and Dieppe, 2005).

However, though the results of Study 2 show that though trainees’ narratives on field experience are an important interactional resource, the trainers still keep certain authority. Thus, they feel free to pronounce judgements to assess trainees’ knowledge while, interestingly, the trainees use even their judgements to report on field practices.

As for the practices of using material resources, they demonstrate that the training vehicles and the available spare parts, although insufficient because complemented by annotations during the presentation of dynamic electronic and electrical systems, are very important for the didactical interaction. Since they serve multiple goals, the resources could be considered as flexible ones, in contrast with the more rigid material resources such as training documents. Although both types of resources are essential, one might believe that flexible resources are more beneficial for knowledge construction within the fuzzy context of the automotive maintenance CoP, where roles and boundaries evolve and information is exchanged multidirectionally.

Another argument supporting the hypothesis that today's automotive maintenance training is evolving as a CoP is the existence of numerous online discussion forums in the field (e.g. www.planeterenault.com, www.auto-evasion.com/forums, www.problemauto.com). These forums suggest that the community is even larger, because they include maintenance professionals, clients and even vehicle designers interested in vehicles' technical characteristics and unusual faults.

On the basis of these results, some user requirements for the future AR teaching aid were specified. They are briefly reported in the next section.

Fig. 3. Material resources and goals of use: a graphical representation of the CA.
interaction device such as a PDA or a mobile phone controlled by the trainer. A large display could be used for a shared visualization of the combination of real-world and computer-generated data. The “virtual” part of the AR system could also assist the trainer in provoking realistic faults (e.g. sensor damage) without dismantling the available training vehicle. In fact, our study showed that the number and the usability of this material resource were judged problematic.

Such a system could thus facilitate the construction of shared representations and understanding of vehicle’s invisible systems. Moreover, because a part of the knowledge resides with ASTs and trainers, the future AR training aid should also give the possibility to collect and save field experiences in the form of narratives, which could then be shared with training and vehicle designers. The implementation of such an AR teaching aid seems more cost-effective in the automotive training CoP than the implementation of a learning system for trainees, this being so for two reasons. First, in such a configuration, less investment will be necessary, because the trainees will not be equipped with individual prototypes. Second, a prototype controlled by the trainer should reinforce his authority and influence.

In terms of usability, the future AR system should be easy to use, based on ASTs’ vocabulary, compatible with the technologies used already during training and with minimal cost.

However, it is clear that no technological aid would solve all the problems in the automotive maintenance CoP. In order to be efficient, the introduction of a technology should be accompanied by organisational transformations. The organisation should adopt a larger vision for the enterprise knowledge management and should strive for the integration of diagnostic and repair knowledge in the very early phases of vehicle design. Furthermore, this vision should promote “best” field practices sharing knowledge in the very early phases of vehicle design. Furthermore, different graphical representations of resource use and dynamics will be tested in order to better characterise this aspect of the trainer-trainee interactions. As for the industrial perspectives, an AR prototype is currently under development. It will be evaluated in due course with ASTs and trainees.

5. Limitations and research perspectives

The studies have three major limitations. First, the sample of trainers, trainees’ and training sessions is relatively small. Second, it was impossible to have auto-confrontations with trainers because of their time constraints. Third, the coding scheme adopted does not describe the dynamics and the shift from one resource to another, as well as the content and the patterns of use of narratives on field practices.

In the future, we intend to further analyse trainees’ and trainers’ verbal interactions to investigate the nature and the patterns of knowledge transmission within the CoP. Furthermore, different graphical representations of resource use and dynamics will be tested in order to better characterise this aspect of the trainer-trainee interactions. As for the industrial perspectives, an AR prototype is currently under development. It will be evaluated in due course with ASTs and trainees.

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These studies were funded by the French Atomic Energy Commission and Renault S.A.S. We would like to thank Mr Pierre Ehanno for the organisational support, all the trainers and trainees for their participation in the studies, and Mme Christine Mégard for here valuable remarks on this work.

Appendix A. Factorial coordinates, contributions and quality of representation of variables

<table>
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<th>Variables</th>
<th>QLT</th>
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<th>Axis 2</th>
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<td>COR</td>
<td>CTR</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>COR</td>
<td>CTR</td>
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<td>functioning</td>
<td>Resolve simulated</td>
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<td>–1.069</td>
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References


Ehanno for the organisational support, all the trainers and trainees for their participation in the studies, and Mme Christine Mégard for here valuable remarks on this work.

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Margarita Anastassova has a Ph.D. in Psychology and Cognitive Ergonomics from Paris Descartes University (former University of Sorbonne – Paris 5). She is currently a post-doctoral researcher in CREATE-NET International Research Centre in Trento, Italy. Her research interests concern human factors of emerging technologies, the involvement of human factor specialists in design, as well as the development of Communities-of-Practice.

Jean-Marie Burkhardt is Associate Professor in the Ergonomics-Behaviour-Interaction Group at the University of Sorbonne – Paris 5 since 1998, and researcher in the EIFFEL2 Group at INRIA. After a Master’s Degree in Ergonomics (1992) and a Master’s Degree in Cognitive Psychology (1993), he obtained a Ph.D. from the University of Sorbonne–Paris 5 in 1997. He carried out his Ph.D. work in INRIA, investigating the cognitive and ergonomics aspects related to object-oriented software and reuse. His current research interests concern cognitive ergonomics of design in the context of emerging technologies such as Virtual, Mixed and Augmented Reality.