Context Becomes Content: Sensor Data for Computer-Supported Reflective Learning

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Abstract—Wearable devices and ambient sensors can monitor a growing number of aspects of daily life and work. We propose to use this context data as content for learning applications in workplace settings to enable employees to reflect on experiences from their work. Learning by reflection is essential for today's dynamic work environments, as employees have to adapt their behavior according to their experiences. Building on research on computer-supported reflective learning as well as persuasive technology, and inspired by the Quantified Self community, we present an approach to the design of tools supporting reflective learning at work by turning context information collected through sensors into learning content. The proposed approach has been implemented and evaluated with care staff in a care home and voluntary crisis workers. In both domains, tailored wearable sensors were designed and evaluated. The evaluations show that participants learned by reflecting on their work experiences based on their recorded context. The results highlight the potential of sensors to support learning from context data itself and outline lessons learned for the design of sensor-based capturing methods for reflective learning.

Index Terms—Reflective learning, sensor data, context, learning content, pervasive computing

1 Introduction

Context information is commonly used to adapt learning content to the particular situation of the learner and to provide insights that match the learners' experience and situation [1]. Not only have advances in context acquisition and analysis been mainly adopted in formal learning environments, they also offer potential in work settings that rely on informal learning [2]. In fact, on-the-job training is still the dominant form of learning in many workplaces that require highly specific procedural knowledge and focus on adaptive application of knowledge to the situation. For instance, a carer in a dementia care home facing an aggressive patient might find a person-centric approach to be more appropriate to calm the resident. In this setting, the correct action can only result from experience, i.e. knowledge about the particular resident and similar situations. The required content for learning would be the past experience of the carer. In such workplace settings, can the context, which until now has been largely used to select content, serve as content itself?

In a growing number of personal coaching applications, context data is already the main content. Fitbit[1] and Lumoback[2] are examples of commercially available tools. The Quantified Self (QS) community [3] aims at capturing and visualizing data. While available applications mainly target private life and especially health, additional tools to capture behavioral data at the workplace have been developed by the ubiquitous computing community [4], [5], [6]. However, all these tools and technologies lack an approach for in-depth learning based on context. Learning from context data requires a review and a close examination of the context itself. This approach to learning does not necessarily follow a predefined goal but draws insights from the available context data.

This article describes an approach to utilizing context as content by using reflective learning theory to facilitate in-depth acquisition of procedural knowledge and support behavioral changes at work. From a theoretical perspective, Boud et al. [7] define reflective learning as *those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations*. In our methodological approach, we outline three main design decisions to build applications that can support reflective learning by capturing context at the workplace. This approach was used to implement applications for two different workplace environments: dementia care and crisis preparedness. The conducted evaluations in the respective environments revealed that employees can learn from captured context data.

In the following, we provide a brief overview of reflective learning theory and how context can facilitate reflective learning by drawing from persuasive technology, the Quantified Self community, and research on computer-supported reflective learning (CSRL). Drawing on this background, we present the three main design decisions and related challenges. After briefly outlining our research approach, we discuss two use cases which serve as starting

1. www.fitbit.com
2. www.lumoback.com

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points for the application of our approach to the design of two context-capturing applications: CaReflect and WATCHiT. We describe the design, evaluation, and results of both applications before we summarize our lessons learned and review the impact on learning. The conclusion summarizes our investigation.

2 Theoretical Underpinning

Reflective learning has been a research topic since the work of Dewey [8], which describes how we learn by comparing our expectations to new experiences. This section provides a brief overview of the available reflective learning theories and introduces a model for computer-supported reflective learning.

2.1 Reflection Theory

According to Boud et al. [7] the reflection process has to be understood in relation to the experiences reflected upon and the resulting outcomes. The reflective process consists of three stages in which the learner re-evaluates experiences, eventually gaining outcomes. Outcomes are mainly intangible, like the experiences and the reflection process itself. For instance, a new perspective only becomes apparent by articulating it or by a change in behavior. Outcomes may lack the commitment to action and remain hidden in the first place. However, these changes in the cognitive framework of the learner will influence the behavior in the long term.

Kolb [9] also describes experiential learning in the form of a cyclic process: the so-called Kolb Cycle. The Kolb cycle defines reflection as a process that involves not only reinterpreting existing experiences, but also the initial perception and interpretation of the raw experience. This cultivation of the capacity to reflect in action (while doing something) and on action (after you have done it) has become an important feature of professional training programs in many disciplines [10]. A more detailed description and discussion of existing theories can be found in [11].

2.2 Computer-Supported Reflective Learning

The MIRROR project [12] has developed a model for computer-supported reflective learning [13] which describes the reflection process as a cycle and presents the possible support categories in the workplace. Fig. 1 depicts the four stages of the reflection cycle described in this model. In this cycle, the data captured in the *plan and do work* stage is used to initiate reflection and is transformed to provide a frame for the reflection session. The outcomes of the reflection session are applied to change work practices. A reflection session refers to the time-limited activity of reflecting—whether short or long, informal or formal, planned or spontaneous, individual or collaborative.

Reflection triggers are a critical element of the model because they initiate the reflection session (see central arrows depicted in Fig. 1). Reflection can be triggered in several phases: during work, while an outcome is about to be applied, or during the reflection session itself. For instance, collaborative reflection in a team meeting may trigger individual reflection of a participant or reflections about organizational topics. The transitions between these

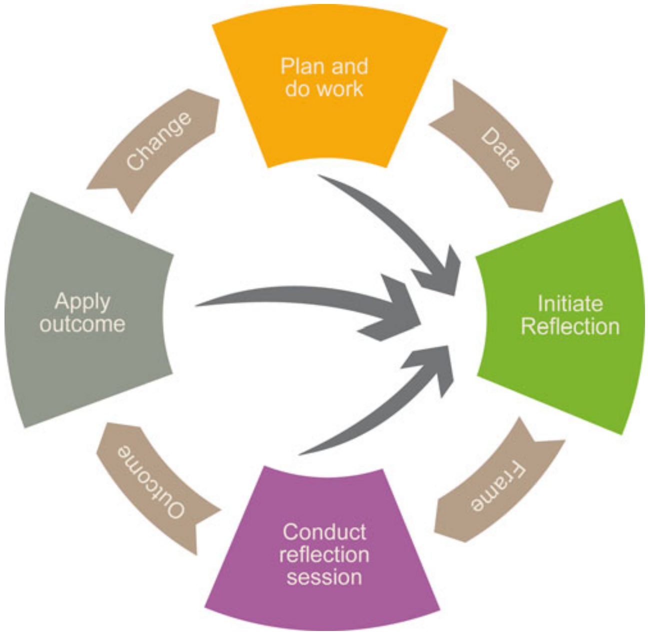

Fig. 1. CSRL cycle by Krogstie et al. [13].

three levels (individual, collaborative and organizational) are discussed in [14].

While there are different options to support reflection, e.g. by guiding reflection [15], this article focuses on the capturing and presentation of relevant data. Therefore, the addressed question focuses on the first stages of the model. How can computer-based technology generate content for reflective learning? According to the CSRL model presented above, the data collected on the learner's context in the *plan and do work* stage is captured and processed to provide alternative perspectives on past experiences. This context encompasses a wide range of information, or as Abowd et al. define it: *Context is any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves* [16].

Developers of CSRL applications face the challenge to select, record, and visualize context in a form that optimally complements the experience of the user during the *initiate reflection* and *conduct reflection session* phases. Boud et al. [7] do not explicitly define the beginning of the reflection process because *most events which precipitate reflection arise out of normal occurrences of one's life.* However, the provided examples can be linked to the cognitive dissonance theory [17]. The cognitive dissonance theory describes how a mismatch between attitudes and behavior can lead to rethinking attitudes and experiences. This mismatch is perceived as psychological discomfort (dissonance) and motivates a reconsideration of existing attitudes. CSRL apps can offer rich data to support a triggering of reflective processes by raising awareness and inducing cognitive dissonance.

3 Related Work

The initial idea to learn from sensor data is not new. Indeed, we see many sensors and mobile applications that collect data to provide new insights, ranging from fitness to health applications.

There are first prototypes that directly support reflection [18], [19] and approaches to guide design [20]. Capturing tools like the SenseCam [18] have explicitly supported reflection by capturing images. Echo [19] is a smartphone application for recording experiences in the form of pictures, text descriptions, and ratings of emotional state. Furthermore, Fleck and Fitzpatrick [20] developed a framework on reflection and guiding questions to design for reflection. However, the presented approaches either target the private life or are focused on passive image capturing as the support for reflection. They consider neither the whole plethora of capturing opportunities nor the particular challenges of the workplace.

Persuasive technology and Quantified Self applications provide pragmatic approaches to collecting meaningful data that influence user behavior and are often related to reflection and learning. However, these applications lack the theory to cover the wide variety of applications in learning as well as a methodological approach that guides their design for diverse workplace settings. The integration of these approaches from persuasive technology and the Quantified Self with reflective learning theory can facilitate learning from a wider range of sensor data to address the specifics of a selected workplace.

3.1 Persuasive Technology

Persuasive technology refers to *computing systems, devices, or applications intentionally designed to change a person's attitudes or behavior in a predetermined way* [21]. Self-tracking is the most prominent approach to technology-supported behavior change. In terms of the CSRL model, self-tracking in persuasive technology directly connects captured data to predefined outcomes. Visualizations are designed to directly trigger the target behavior instead of reflection. Due to the fixed outcomes, persuasive technology is limited to application domains where strict adherence to rules results in clearly measurable progress, e.g. in healthcare [22], [23]. Ubifit [22] aims to facilitate physical activity by displaying the activity measured by an acceleration sensor and biosensors on a smartphone. MAHI [23] helps individuals with diabetes to track glucose levels.

A predefined target behavior is the starting point for design strategies to create persuasive technology. The theory-driven design strategies by Consolvo et al. [24] provide guidelines for the development of persuasive applications. The iterative step-by-step approach by Fogg [25] begins by choosing a simple target behavior and continues by refining the definition of this target behavior in subsequent steps before selecting an actual technology. According to Fogg, the selection of a simple behavior is crucial, because *many projects are too ambitious, and thus are set up for failure* [25]. Hence, designing for reflective learning may take a similar step-by-step approach but requires additional guidance.

3.2 The Quantified Self

Sellen and Whittaker argue that life-logging should target specific goals, among which they mention reflection and reminiscence [26]. Recently, the growing number of life-logging tools, i.e. tools to track personal data generated by our everyday activities, simplify the process of tracking. A wide range of personal data like exercise, food, mood, location, sleep, alertness, productivity, and even spiritual well-being can be logged and measured. These approaches may not be deliberately designed to change behavior or trigger reflection, but they target similar challenges.

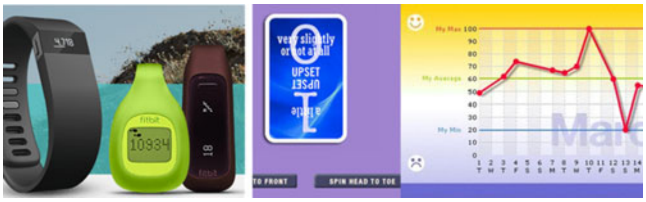

Fig. 2. Popular QS tools: Fitbit family of activity and sleep trackers (left). Moodscope, a mood tracking and sharing web application with mood measuring based on a card game (right).

The community of users and developers around these tools is called the Quantified Self [3]. Their philosophy can be summed up as *self-knowledge through numbers*. They use these tools to conduct experiments with the intention to learn about their own behaviors, habits, and thoughts by collecting relevant information related to them. The QS initiative is not driven by scientific theories, but it is based on empirical self-experimentation. Their inherent curiosity about themselves drives the QS community to explore and reflect on their data. In some cases, a goal-driven motivation is pursued (e.g. losing weight, controlling a particular disease). In many other cases, it is just the enthusiasm for technology and data that drives this quantifying behavior without having identified in advance any concrete benefit from it (e.g. track any kind of social contact with other people or which streets of a particular city have you already passed by). A selection of prominent tools used in the QS community is shown in Fig. 2. Choe et al. [27] provide a more comprehensive overview of QS tools and practices.

The QS approach and corresponding tools come under a variety of names, including personal informatics, living by numbers, self-surveillance, self-tracking and personal analytics [28]. In a study by Li et al. [29], *participants collected different types of data so they could figure out the correlations between them*. This deliberate broad capturing of data with an explorative mindset is linked directly to the challenges faced in CSRL.

Nonetheless, the workplace setting imposes additional constraints that inhibit the iterative and open-ended development pursued by the QS community. The QS tools are not intentionally built to support reflective learning in a particular work environment and therefore many challenges and barriers are not considered.

4 From Context to Content: A Methodological Approach

Designers of reflective learning applications for a workplace have to map the requirements from reflective learning theory to the opportunities provided by context capturing within the constraints of the specific workplace environment. While they can learn from design guidelines for persuasive technology [24] and the analysis of successful QS tools [27], a methodical guidance is required to analyze requirements and evaluate opportunities. Workplace settings provide a plethora of opportunities to capture data for

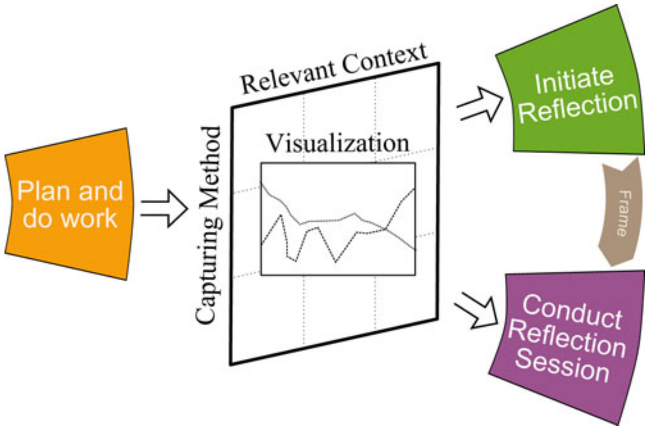

Fig. 3. Design decisions to turn context into content, in relation to the CSRL model.

reflection. Many activities are already recorded and documented for legal reasons; others can be captured by additional tools or changed processes.

Fig. 3 visualizes three major design decisions that have to be made to turn context captured in the *plan and do work* stage into visual support for the subsequent stages (*initiate reflection* and *conduct reflection session*):

- Which context should be captured?
- How can this context be captured?
- How can the context be visualized?

These decisions depend on each other and the targeted work context. The following sections describe our approach by describing promising options and highlighting related challenges for the three decisions.

4.1 Relevant Context

Depending on the workplace and use case, different types of data are relevant. Moreover, the relevance of context depends on yet unknown goals. This *relevance paradox* [30] complicates the decision on two levels by (a) the unpredictability of relevance of context and (b) the subjectivity and need for interpretation of context.

Unpredictability of relevance. Similar to the usage of QS tools [27], the outcome of reflection cannot be precisely predicted; (i) it is unclear which context is useful and (ii) more context information has to be captured than will probably be used afterward.

Subjectivity and need for interpretation. It is inherently difficult to identify data that relates to a particular experience. While hardware sensors and IT systems can capture a growing part of the context, the perception and interpretation of this context is hard to estimate. The user's perception depends on existing experiences and biases. Only the user can provide the necessary feedback to select the relevant subset of data for later reflection, and in many cases, this selection is already part of a reflective learning process. Hence, designers cannot solely rely on fully automated ways of capturing (such as hardware sensors or mining of existing data), but have to look at applications that involve the user into this process or combination of sensors that provide hints on the relevance.

Three types of context have been identified that may act as memory support or help to recognize relevant time spans for reflection at the workplace: task, affective and social contexts. *Task context* relates directly to the work process and is, therefore, easy to understand for employees. Used tools can be augmented by additional sensors or existing data from project management tools can be reused. For instance in crisis management, rescue-related devices like a stretcher could be augmented with sensors. Alternatively, in a care home the care documentation could be reused. However, there is the risk that this data could be seen as an undesired performance monitoring by employees. If the data is seen as only beneficial for the management board, the acceptance of the corresponding apps will be low.

The capturing of *affective context* can be applied in a broad range of workplaces, e.g. by using sensors [5]. If something important happens during the day, it will likely trigger an emotional reaction. Therefore, affective context data can act as a marker to recognize relevant time spans and relevant situations for reflection. Furthermore, emotional awareness and emotion regulation are desired goals in many workplace settings. However, this data is highly privacy sensitive.

Similarly broad in the application domain is the *social context*. Social contacts are a vital part of our work. Whether we talk to colleagues, customers, or partners, these interactions are often decisive parts of the daily work. In some workplaces, these social contacts will basically mirror the task context, e.g. nearly all tasks of a nurse are related to a patient. Hence, similar limitations related to task context mentioned above apply regarding the acceptance of the data.

4.2 Capturing Method

The decision about which context data should be captured in the *plan and do work* stage is closely tied to the possibilities of capturing this data. The preferred capturing method has to be as unobtrusive as possible while providing the desired amount of details. In-depth insights regarding long-term trends might only be possible after several months (or years) of data capturing. Employees receive the benefit for their capturing efforts only after a certain time. Moreover, this benefit is not guaranteed because of the unpredictability of relevance and the subjective interpretation of the data. The selection of the right capturing method is the key to the acceptance of a CSRL application. The options to obtain the desired data can be broadly classified into three methods:

- Data can be captured by the user, i.e. *self-reported*, thus providing a subjective impression of the current situation. The used tool can be a diary containing detailed personal notes or just a personal checklist.
- Data can be captured by *self-reporting from third parties* and made available to the reflecting person. This external perspective can be provided by single individuals or in an aggregated manner by multiple sources, e.g. in the form of a survey.
- Data can be captured *automatically* by sensors and applications, e.g. a simple log file recording all computer-based activity or an activity sensor.

These three methods have to be analyzed depending on the nature of the desired data as well as the environment where the data should be collected. The required effort by the user to obtain the relevant data for reflection varies across the three methods. Self-reporting apps rely on the user and therefore require their motivation, and this motivation has to be kept high over time. The Quantified Self community has presented a wealth of data and the possible insights that can be gained by highly motivated users. Accordingly, the integration into the existing work process is a key to success for self-reporting apps. An observer-based method distributes not only the required effort for data capturing to third parties, but the motivation challenges as well.

Automatic capturing methods shift the main effort from the employee to the investment and maintenance of technology. In many cases, additional software and hardware are required which might need experts to manage them. Automatic methods allow a wide range of granularity and precision, e.g. technology can be configured to capture data at any supported sampling rate. Often the main challenge is rather to filter the captured data or to find visualizations to aggregate large amounts of data. In contrast, constant self-reporting will interfere with the daily work.

Nevertheless, self-reporting apps can be applied across a wide range of workplace settings. In contrast, automatic methods are often tied to a particular tool, e.g. the computer, or a particular environment. Notable exceptions are wearable sensors and devices that can accompany an employee across different places and contexts. These wearable devices are well suited for dynamic work environments like care homes and crisis management where most employees are mobile and generally do not use smartphones or tablets in their daily work.

4.3 Visualization of Context

As suggested in [31], attractive and intuitive presentation and visualization forms for the users should be chosen, which at the same time foster the analysis of the data. Otherwise, this can become one of the major barriers in the *initiate reflection* and *conduct reflection session* stages. In addition, context visualization can benefit from the vast research visualization techniques, but further research is needed to assess the added value of these visual approaches in terms of effectiveness, efficiency, or other criteria that pertain to learning [32], especially in informal learning. Consequently, visualizations to support learning need to be developed by *using a user-centered design approach*, resulting in several prototypes and iterations which are affected by the feedback of end users. The concrete background of the learner, as well as her knowledge of the data, has to be taken into account.

Data can be visualized from several perspectives, depending on the criterion or criteria taken into account. Visualizations of surprising data or unexpected perspectives can lead to cognitive dissonance [17] and trigger reflection [24]. Hence, designers should aim to outline deviations and help to understand the underlying reasons. In [31] the following most *common visualization perspectives* were analyzed and summarized: Social perspective (comparing own performance/measures with others or aggregating data over multiple users), spatial perspective (the location of the user, allowing to understand the relation between place and behavior), historical perspective (comparison of current values to historic values), meta-level perspective (using item metadata that supports the understanding and interpretation of the data) and external perspective driven by other data sets (visualization according to data provided by other standard sources of information like e.g. the weather). In some cases, there are already established visualizations, which have proven to be intuitive and accepted, e.g. timelines for the historical perspective or social networks for the social perspective. However, other types of context can result in more complex visualizations, which have to be adapted to the type of captured data as well as to the learner's background.

For choosing the correct visualization, it is also important to *know from the end users which kind of questions they would like to get answered* by analyzing the data. This will guide the selection of the appropriate visualization. In the care domain, we have experienced in our studies that carers would like to know which patients they cared for and how long it took. Consequently, the time component should be easy to interpret in the visualizations. The studies conducted in the crisis management domain revealed that the exact time needed for each task compared to the optimum time was of most interest, so both values had to be easily and quickly comparable in the designed visualizations.

5 Research Approach

Many workplaces have benefited less from the developments in technology-enhanced learning because they are highly dynamic and rely on on-the-job-training. Two examples are care professions [33] and volunteers in crisis management [6]. Formal training material can provide guidance, but this education mainly trains the application of this knowledge in highly dynamic environments. Reflection on made experiences is crucial to draw as many insights as possible from every situation. Carers and volunteers have to work as a team to target the upcoming challenges and apply their knowledge to similar situations.

The following Chapters 6 and 7 describe two design studies in these work environments, i.e. dementia care and crisis management. Both chapters outline the specific challenges in the domain and motivate the resulting reflection practices before the developed application and its evaluation are presented.

5.1 Application Design

For each use case, one application was developed according to the design approach presented in Section 4. Two independent research groups designed and implemented the two applications. Both groups followed a user-centered participatory design process by iteratively creating prototypes and conducting preliminary studies. With this approach, we aimed to test our prototypes as often as possible in the target environment, as suggested by Rogers et al. [34].

Initially, developers visited the work environments to collect requirements and understand the needs of end users. Mock-ups and prototypes were iteratively refined in small studies with end-users and experts from the fields. In this process, sensor technology became more robust, and visualizations were tailored to end-user requests. The implementation resulted in two tailored solutions, CaReflect and

WATCHiT, that differ in their selected options depending on the use case. The preliminary studies in a care home have been presented in [35], and the studies in the crisis management domain have been reported in [36].

5.2 Evaluation Method

The evaluations reported in Chapters 6 and 7 tested the developed applications in the respective work settings to measure user acceptance, usability of the system, and impact on learning. We used a mix of qualitative and quantitative methods to account for the unpredictability in an in-situ study [34]. Hence, we combined sensor data, observations, questionnaires, and interviews to gain an in-depth understanding of the application usage and impact. Questionnaires offered a high-level quantification of feedback, while observations and interviews aimed to ground this feedback in the context of usage. Furthermore, researchers encouraged users to articulate insights and comment on their actions during the reflection.

The evaluation of CaReflect and WATCHiT was performed using the MIRROR evaluation toolbox [37], which provides questionnaires that measure reflective learning at work. These questionnaires are a generic instrument that has been developed through an extensive survey of literature on reflective learning and in cooperation with participants from different workplace settings. The resulting framework builds on the Kirkpatrick framework [38] and the theoretical understanding of computer-supported reflective learning described in Section 2.2. In this way, it is possible to study the impact on learning at different levels, e.g. perceived usefulness versus willingness to change. Renner et al. [39] describe the application of the toolbox in a workplace setting different than the two addressed in this paper. The resulting toolbox includes a core set of evaluation questions and a large set of optional and tailorable tools. In this paper, given our research focus, we only consider questions for measuring user acceptance, perceived learning success, and the intention to change behavior. User acceptance was measured using the *net promoter score (NPS)* [40] as to whether participants would recommend the used system to their peers. The questions regarding learning and intended behavior change had to be rephrased for the care home domain. Care home managers deemed the original wording as too complex. The questionnaire items used a five-point Likert scale (from 1 = strongly disagree to 5 = strongly agree) and are reported with mean and standard deviation (SD).

Interviews were used to follow up on the questionnaires, the observations regarding outcomes gained during tool usage, and the potential to use the application in the long term. The interviews helped to verify statements and ask for specific outcomes that can come in various forms according to Boud et al. [7].

6 Design Study: CaReflect

Carers in a care home rarely take the time to sit down and reflect, because the requests of the residents have always a higher priority. The CaReflect app was designed to support carers in care homes by reflecting on their daily interaction with residents and colleagues. A single sensor is used to capture the social context and provide an objective perspective on own care practices by visualizing the data captured to the care staff.

6.1 Dementia Care

As in the rest of Europe, the life expectancy of the average care home resident in the UK is rising, with a concomitant increase in the incidence of dementia, an age-related cognitive disability [41]. Around two-thirds of nursing and care home residents will have some form of dementia, putting additional strain on the care staff, due to the unique and complex challenges such a disability can cause.

Most staff members in a care home are care assistants. Except for recently qualified nurses, they are not educated to degree level and only have national vocational qualifications. As a result, staff without formal training can be confronted with complex situations to resolve. Work is organized in two day and one night shifts with handovers; protocols document every treatment and activity. A high turnover of care staff—around 20-25 percent annually is common for homes in the sector [42]—so most homes will always have a significant number of inexperienced and new staff.

Although often paid around the statutory minimum wage, a new care worker is expected to undertake an induction period and then training in some 13 or more mandatory areas of professional knowledge in their first two years of work, ranging from ‘manual handling’ to dementia care and ‘end of life care.’ Induction will involve the supervision of experienced carers as well as knowledge-based training. While e-learning is increasingly a part of this training, most training is still of the traditional small-group type with a specialist trainer presenting for a half-day or more. However, such general approaches cannot cover all the variants of challenges likely to be posed to the staff from the residents and their unique demands. These challenges often require some reflection and some help, for example, asking experienced staff.

A growing challenge for care homes is the higher proportion of increasingly elderly residents suffering from dementia when admitted to the homes. This can lead to instances of challenging behavior where the elderly residents are confused and react, sometimes aggressively and irrationally, to their unfamiliar surroundings. Reflective learning on the side of the carers and nurses working in the homes is seen as a potential, as there is no one-size-fits-all solution when dealing with personalities approaching the end of their lives with their individual and complex life-histories [33].

6.2 CaReflect

The system is based on proximity sensors as presented in [4], [35]. The proximity sensors are wearable devices—either in the form of a badge or wristwatch (see Fig. 4)—that capture the proximity between wearers of the sensors. Every 10 seconds the environment is scanned for other sensors that are worn by residents, carers, or placed at important positions, such as the documentation desk. The sensors store all contacts and can be read afterward by the CaReflect system. The data provides an objective perspective on the daily interaction by quantifying the contact times. Furthermore, sensors can be placed at critical locations like the office or on used devices such as the laptop that is used for documentation tasks.

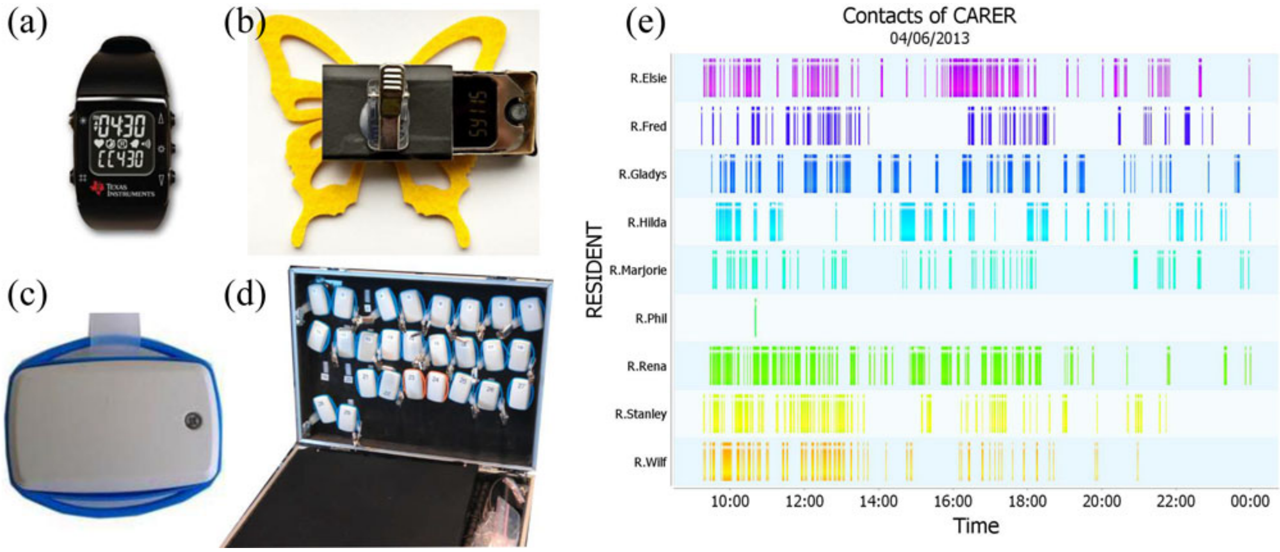

Fig. 4. CaReflect prototypes and visualization: (a) sensor original format, (b) first prototype, (c) final sensor hardware prototype, (d) mobile sensor station, and (e) visualized timeline showing the contacts of a carer with each patient.

The resulting data can be analyzed using the CaReflect platform. The platform is a Java-based application running on a laptop as part of the sensor station (Fig. 4c). Carers have only limited time to review the data and want to be able to check their work at a high level. Typical questions are: Who needed most time today? How does the effort for this resident relate to the time spend with other residents? Is there someone that I might not have seen at all? How much time did I spent on documentation?

Carers asked for a pie chart as a brief summary of their day. Only if the pie charts were surprising, carers would like to see additional visualizations to explore the underlying reasons, e.g. when did they spend time with a particular resident? For this purpose, the system visualizes the time spent with residents and colleagues in the form of timelines (see Fig. 4d) and pie charts that summarize the day. Carers can browse through these timelines individually. However, carers may ask colleagues about specific patterns. There are also separate tools to create custom timelines, e.g. a timeline showing all care that a resident received.

6.3 Evaluation in a Care Home

The CaReflect App was tested in a nursing home over four days during all three shifts. It was used by 40 carers (34) and nurses (six) mostly female (two male/38 female), with varying degrees of care experience (four months to 27 years), and coming from a wide range of age groups (<20 : 6; 20-29: 11; 30-39: 7; 40-49: 6; 50-59: 6; >60: 3). Each staff member was wearing a proximity sensor during the shift. Nine residents with different levels of dementia and different needs for care were selected by the care home staff. These residents were coming from all of the four wards of the care home. Further sensors were placed in the staff office and in the common rooms on each ward to obtain insights on the location of staff. Documentation is either done on a laptop in the common room or in the office.

At the beginning of each shift, care staff had to log into the CaReflect system to get a sensor at the sensor station, shown in Fig. 4d. On the first day, carers managed the distribution of sensors. During the study, they regularly checked if the sensors were still attached. After each shift, participants returned their sensors to load the data into the CaReflect system. They were asked to reflect on the recorded data directly after their shift and to complete a short questionnaire. One week after the study, a subset of the participants (17) were interviewed to provide additional qualitative feedback and fill a concluding questionnaire. The interviews were limited to 20 minutes because of work constraints. During this time, the aggregate data from the system was shown and participants provided feedback on the physical sensors, usefulness of the system for triggering reflection, and insights gained.

6.4 Results

User acceptance and usability was measured in the concluding questionnaire and interviews. Participants were satisfied with CaReflect (3.82, SD = 0.6) and 82 percent said they would like to use CaReflect again with their team. Only 24 percent said they would like to use it on their own. Every day seems different for the carers, dependent on the health, activities, and moods of the residents. The data, shown on a day-by-day view, often stimulates the carer to provide a narrative of this specific day (e.g. *"this was the day Allan died," "this was the day Doris didn't want to get up," "this was the day I spent ages in the office talking to John's daughter,"* etc.). The concluding interviews provided additional qualitative feedback to understand the results better. For most carers, the benefit was to see the measured and relative time given to residents, spent with other staff, and at various locations, particularly 'the office.' A number of carers said it was difficult to remember all their contacts over an 8-hour shift, particularly when encouraged to work in the 'butterfly' mode, i.e. a large number of small contacts rather than large blocks of single contacts.

The overall net promoter score was negative (NPS = −29%). This result is due to the many young detractors (5) among the inexperienced carers (nine of 17) that did not see any value in the collected data. Experienced staff members

TABLE 1
Responses Split by Experience of Participants

Question	All (n = 40)	Experience ≥ 5 years (n = 12)	Experience <5 years (n = 28)
I learned something by looking at this data	4.03 (SD = 0.55)	4.18 (SD = 0.39)	3.96 (SD = 0.60)
I have now an idea what I could change.	3.66 (SD = 0.85)	3.77 (SD = 0.91)	3.61 (SD = 0.82)

(eight of 17) were neutral (NPS = 0%). These experienced staff members include all nurses and care coordinators.

The knowledge of the individual needs of residents is used to evaluate the CaReflect data—this is where reflective learning occurs most clearly. The quantitative results of the questionnaires indicate that carers in general agree on the impact of CaReflect on learning (4.03, SD = 0.55). In individual reflection sessions, care staff reviewed the time shares allocated to each resident and came to outcomes. For example, one carer noted that a particular resident with a sensor seemed to receive more attention than usual, and responded by being more alert and brighter. When asked for examples of insights, carers talked about the time spent on documentation or the differences between residents. One carer was surprised how much time she needed to assist a resident with meals and wanted to discuss with colleagues about their experiences. While collaborative reflection was not planned as a formal session, individual reflection sessions motivated carers to reflect collaboratively during their daily care. However, fewer staff members felt that they had an idea how they could change their behavior (3.66, SD = 0.85). One example that was reflected even with the manager but did not yet lead to a decision was the need and amount of 'doubling up' given for heavy, difficult or highly dependent residents. Learning and reflection occurred at all levels, but insights and acceptance varied between participants. When the questionnaire feedback is split into experienced carers with at least five years of experience (12 out of 40), it becomes apparent that especially the experienced carers see more benefit in using CaReflect (see Table 1).

7 Design Study: WATCHiT

WATCHiT is a wearable computer for situated collection of data in crisis management. It allows emergency workers to capture information while being in the field and without interrupting the rescue work. Data captured might include self-reported information from the individual, for example, perceived stress levels; and automatic data captured from the environment, like locations, temperature, time, and radioactive exhalations. For a description of user studies and development of an early prototype, see [36].

7.1 Crisis Preparedness

Over the last 35 years, the frequency of natural and man-made disasters has increased five-fold and the damage caused has multiplied by approximately eight times [43], making preparedness to crisis management a priority for all European countries [44]. Public administrations at different levels (e.g. municipality, regions and national bodies) are facing growing responsibilities for preparedness, struggling with old and emerging risks and limited resources.

An important part of preparedness is proper training. Training for crisis preparedness is challenging not only because of the complexity of the work to be performed, but also due to its sporadic and discontinuous nature, which makes it difficult, if not impossible, to assure that workers gain sufficient experience. To compensate for the lack of real experience, drills and field tests to recreate realistic crisis experiences are often adopted. Drills and field tests are complex training activities that promote training of different skills for individual workers, as well as an occasion for organizations to test relevant procedures and their capability to apply them. Though learning from (simulated) experience is recognized as critical, it is expensive and thus important to optimize the impact. Additional problems are keeping motivation, lack of time, varied levels of initial competencies, and retaining personnel, especially young people [6], [45]. Reflective learning plays an important role in crisis preparedness, ranging from the sharing of war stories among field workers to highly structured debriefings involving multiple organizations. In our work, we focus on the learning of volunteers while training the execution of medical procedures.

7.2 WATCHiT

Capturing data, both by using self-reported and automatic methods, during crisis response is challenging. First, it is difficult to foresee the type of data that is relevant to be captured. For example, air quality information might be relevant during a wildfire but not during a flooding. Secondly, the introduction of new devices for data collection requires careful study to avoid interfering with highly standardized protocols for rescue operations. Most of the tasks a field worker is engaged in require both hands to be free, for example to carry someone on a stretcher or to break into a building on fire, thus making self-reporting difficult. Thirdly, in order to provoke reflection, the data acquired needs to be reviewed in a way that helps to make sense of the information, reconstruct original meanings, and reflect on alternative paths of actions. However, voluntary workers in crisis situations lack regular time and places of work when this can be done. In order to tackle these challenges, WATCHiT features a modular design based on sensor modules for transient customization of the types of data capturable in the field. The set of information WATCHiT captures is not defined a priori, but can be customized by plugging sensor modules on a technology-augmented wristband (Fig. 5a). In the current prototype, we built modules for sensing location, time, air quality, and to read RFID tokens.

WATCHiT includes a disruption-free user interface that allows the user to control data collection using RFID tokens to be embedded in uniforms or tools (Fig. 5b). Tokens are activated when waved in close proximity to the WATCHiT wristband (Fig. 5c). They can be programmed beforehand to control the activation of specific sensors or to bookmark raw data with predefined informational tags reporting on activity or feelings. For example, a worker could tag GPS coordinates captured by the location sensor module with labels like *injured person rescued* or *high stress*. Another example, as shown in the evaluation in Section 7.3, is the use of

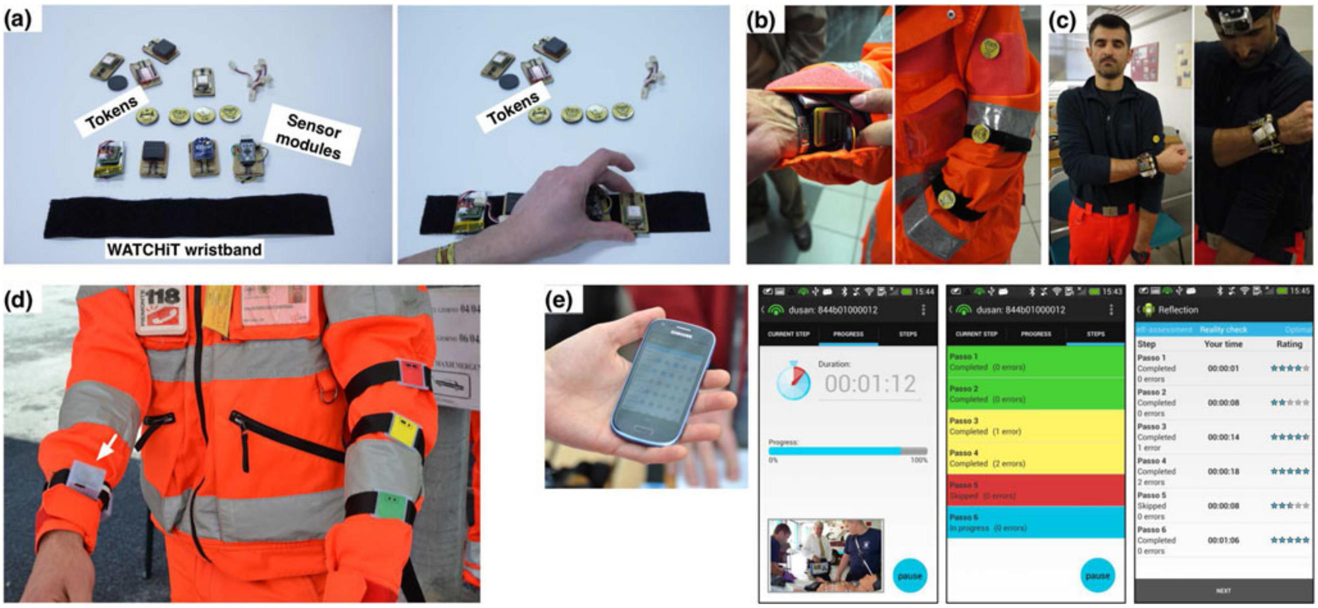

Fig. 5. Modular wearable WATCHiT hardware: (a) physical sensor modules and tokens, (b) WATCHiT and tokens on working uniform, (c) user interaction with the system (d) WATCHiT worn by a volunteer and (e) WATCHiT Procedure Trainer visualizations.

tokens for collecting the time and self-reported errors during rescue procedure training. The Bluetooth link and developer API enable data exchange with mobile apps than can support quick on-site reflection sessions.

Compared with the CaReflect study, with WATCHiT we investigate the capture of more than one type of context at a time; thanks to the modular design and APIs, WATCHiT can be configured to address the need for capturing different types of contexts in different work practices. Furthermore, using RFID tokens as informational tags, WATCHiT complements the automatic capture of quantitative data with the collection of self-reported qualitative data, leveraging the benefits of the two approaches. This aims at both increasing relevance of data and giving the user more control of the capturing device.

In this paper, we examine WATCHiT integrated with WATCHiT Procedure Trainer, a smartphone app that aims at promoting reflective learning using the data collected through WATCHiT. Workers use WATCHiT with RFID tokens to collect the time taken to complete each step of a rescue procedure and self-report their errors. The application promotes reflection by guiding users through a set of steps: (i) visualization of data captured (completion time and errors for each step) for performance self-assessment and rating, (ii) comparison of each own performance with best practices provided by experts and previous performances by colleagues, and (iii) collection of notes on possible improvements (see Fig. 5).

In this way, the app provides a more structured reflection session than CaReflect, where the reflection session is supported only by providing data visualization. On one side, this leaves less freedom to the users to explore the data, but can be more efficient under the strict time constraints of rescue work.

7.3 Evaluation in Crisis Preparedness

WATCHiT together with WATCHiT Procedure Trainer were evaluated by voluntary workers of an Italian emergency association while training for the 'Percorso Trauma,' a procedure to load an injured person onto a spinal board before ambulance transport, for which time and errors to completion are critical for the survival rate of the injured person. Indeed, it is important that the procedure is performed as quickly as possible, but without errors. The procedure is normally executed by a team of three members, where one acts as leader and has the responsibility to supervise the execution of the procedure and to keep the patient's head immobilized until the procedure is completed. The person wearing WATCHiT, which for this experiment was protected by a hard shell, also wore three tokens (Fig. 5d): one programmed for signaling completion of a procedural step with no error, one for signaling step completion with minor errors, and one for reporting competition with critical errors. Tags were color-coded respectively in green, yellow, and red for mnemonic aid. After the procedure, the whole team could navigate through the collected data using a mobile phone with the WATCHiT Procedure Trainer app (Fig. 5e).

The system was evaluated with nine teams of volunteers, all from different associations, encompassing 27 participants (16 male, 11 female). Experience as a volunteer varied significantly in both groups, ranging from one year to more than 20 years. Participants were from different age groups, with the majority between 20-30 (<20 : 1; 20-29: 14; 30-39: 7; 40-49: 3; 50-59: 2). The evaluation was conducted during a large training event and a national championship encompassing simulated rescue operations after an earthquake, where the registered teams were performing different procedures. This type of event is a core part of crisis and emergency workers training and is designed to resemble as much as possible real situations. We observed the teams while performing the procedure and we collected 27 questionnaires to gather feedback on perceived usefulness, usability, and impact on reflective learning.

7.4 Results

The respondents were overall satisfied with the use of the system (4.11, SD = 0.49) and perceived it as a useful tool for

TABLE 2
Responses Split by Experience of Participants

Question	All (n = 27[3])	Experience ≥ 5 years (n = 13)	Experience <5 years (n = 13)
I gained a deeper understanding of my work life.	3.96 (SD = 0.71)	4.15 (SD = 0.55)	3.79 (SD = 0.83)
I made a conscious decision about how to behave in the future.	4.07 (SD = 0.62)	4.08 (SD = 0.76)	4.07 (SD = 0.49)

3. One respondent has not reported experience.

training (4.22, SD = 0.62). The respondents also agreed that the system helped them to reflect on their work (4.00, SD = 0.6). The information collected with WATCHiT was perceived as accurate (3.90, SD = 0.6), relevant (4.03, SD = 0.50), and the collection of data was effortless (3.81, SD = 0.47). Respondents agree that the system has provided relevant content for reflection (4.23, SD = 0.50).

The net promoter score was fairly positive (NPS = +4%); interesting enough there was a large disagreement between the expert and novice groups. Seven out of 13 experts recommended the app (NPS = 41%), while we counted six detractors among novices (NPS = −38%). This result is in line with the CaReflect study, and it confirms the milder acceptance for the proposed capturing tools among novices.

The quantitative results of the questionnaires indicate that respondents agree on the impact on learning. After using the system, respondents made a conscious decision about how to behave in the future (4.07, SD = 0.62) and gained a deeper understanding of their work life (3.96, SD = 0.71). They were also motivated to change their behavior (4.11, SD = 0.49). The questionnaire also included some open-ended questions about what aspects one intended to change at the individual or team level. Intention to change included (i) the use of artifacts during the procedure, e.g. tightening the straps of the stretchers, (ii) the procedure, e.g. *"I need to understand better the different steps in the procedure"*, and (iii) higher level skills, e.g. *"more attention"* and more cooperation and coordination, *"for sure we need to cooperate more within the team."* These results are also in line with the observations conducted during the evaluation. While using the application, the teams discussed their performance, trying to make sense of the data in order to learn, for example, how the team should be positioned during the operation or the use of different types of stretchers.

The system stimulated knowledge exchange within the team (4.11, SD = 0.41) in the form of collaborative reflection. In particular, we observed that some of the teams discussed their performance while and after going through the steps of the mobile apps. Table 2 provides results from the questionnaires considering different levels of experience.

8 Discussion and Lessons Learned

With the evaluations of the two systems presented in this paper, we have shown that the reflective process can be supported if it is fed with relevant context captured from the work environment. In the following, we discuss the results, and present lessons learned related to the role of context in reflective learning and the three design choices identified in Section 4.

8.1 Learning from Context

Participants in both studies were able to learn from the visualized context. They quickly understood the visualized data and their narratives of events established a relationship between the new perspective and their own experiences. Carers and rescuers reconstructed specific situations and gained new insights while doing so. Consequently, as described in the CSRL model, sensor data can indeed be used for promoting the transition from working to learning.

However, learning outcomes varied within both groups. Volunteers using WATCHiT acquired knowledge about their behavior while performing their work, e.g. about the procedure (the steps to perform) and transversal skills, e.g. the importance of reflection. Carers using CaReflect learned about their work patterns as well as general organizational issues. In this perspective, our experience confirms that learning goals and expected outcomes are difficult to define a priori. Though both applications might be associated with the overall learning goal of getting a better understanding of work practices and behavior, the resulting outcomes depend on the particular work situations of individuals or teams. *It is therefore critical when designing tools for reflection to find a balance between defining an overall learning goal (e.g. reflecting on a particular aspect of a procedure) so to be able to identify relevant context data and visualization, and at the same time leaving enough space for exploration while reflecting ('conduct reflection session' in the CSRL model).*

The evaluation of both apps has shown that collecting data alone does not produce reflective learning but it requires time to understand the collected data. This becomes more pressing with growing complexity and richness of data, because learners will need more time for the initial interpretation, and the time to understand it from many different perspectives. From this point of view, it is important to carefully address framing of the reflection session. In the WATCHiT Procedure Trainer, for example, the framing of reflection is partly embedded in the application by implementing concrete reflection steps and enforcing a predefined way to analyze the data. On the contrary, in CaReflect, the framing is only provided in terms of visualization of data, but no predefined navigation steps are defined. This leaves more freedom to users, but it comes to an additional cost, because they need to organize the reflection session, for example how to navigate through the data. *Designing tools for reflection therefore requires a careful tradeoff analysis between providing a structured reflection session versus a more open-ended one ('initiate reflection' in the CSRL model). There is no one-fits-all solution, since the right type and degree of framing might depend on the type of work, the conditions under which reflection is performed, and the experience of the users.*

In both design studies, the participants engaged in making sense of the data, individually and collaboratively, and the data were compared and integrated with memories from the actual work. As memory fades away, it might become more difficult over time to make sense of the collected data. *Therefore, when designing tools for reflection providing for an option to record reflection outcomes becomes important, so that the gained insights can be used later* *(implementing the outcome arrow in the CSRL model). This can be done within tools, e.g. by adding functions for recording the outcomes of a reflection session, as in WATCHiT Procedure Trainer, or annotating the data.*

In both design studies, learning (as reported by users, see Tables 1 and 2) was higher for experienced workers. This is a counter-intuitive result, since one would expect that people with less experience are the ones who have more to learn. The results, however, show that more knowledge on the work process seems necessary to benefit from reflection. *This should be considered during the design, for example, by adding for less experienced users more knowledge of the process to reflect on, more guidance on the reflection session, or some form of coaching ('conduct reflection session' in the CSRL model).*

8.2 Context as Content

The selection of a context type as the content for reflection is mainly driven by the workplace-specific requirements. *Relevant requirements vary not only across domains but even within domains*, e.g. different care homes involved in the design process pursued different care philosophies. Some care homes strive for long in-depth social contacts, while others aim for many short contacts; known as 'butterfly' method. Therefore, *a user-centered design is required to select the relevant data, capturing method and visualization for the particular setting*.

In the evaluation of WATCHiT, we observed how sharing of visualization could trigger new reflection cycles, e.g. involving other teams or instructors. Nevertheless, *the design of CSRL applications for workplace-settings has to account for the legal and social implications*. For instance, employees may fear legal consequences, i.e. if captured data and annotations can be used against them. Especially in domains like healthcare, all documentation can be used if potential mistakes come to trial. However, participants in both studies lacked awareness of the possible legal and social implications of data sharing. Functionality that aims at enhancing the privacy is mainly seen as a barrier to usage of the system, e.g. anonymized visualizations were perceived as hard to understand during the usage of CaReflect. Especially in the care domain, not sharing data among colleagues is seen as an offense. *Privacy functionality has to be a central part of the systems but adapted to the needs of the particular context*.

Our evaluation pointed out that *by putting the focus on one aspect, there is a risk that the others are neglected*. For example, capturing times to perform a procedure rather than quality; or time spent with a patient rather than quality. The CaReflect results suggest that wearing a sensor and knowing that others are wearing one could affect a worker's behavior. Care staff suspected that it might lead to giving more attention to residents with a sensor. Carers asked to give a sensor to every resident to mitigate this problem. *It is therefore important to find the right set of data to collect, shading light on the different perspectives one should reflect on.*

8.3 Control and Adaptation

The two presented apps differ in their capturing method, but flexibility turned out to be a key design goal in both design processes. If users can modify a solution, they can build their "own" custom solution.

Capturing tools should be easy to adapt. If possible, users will customize and 'hack' the tools to meet their needs. The adaptation of hardware-based capturing methods (sensor devices) to the specific context requires more time, and changes are expensive. WATCHiT uses a modular approach to allow for the adaption to users' needs. Sensor modules can be added and exchanged to fit the crisis situation. Additionally, more data can be captured simultaneously. This allows users to deal with the unpredictability of relevance of the captured context.

Simplicity of capturing solutions can facilitate adaptation to a workplace-setting. CaReflect is based on a simple concept, proximity, which was easily understood by care home staff. Therefore, it allowed carers, who had no technical background or training, to modify the system by placing sensors not only on residents, but also at places that are relevant for their work. Hence, they could capture data not only about their interaction with residents but also about time spent on documentation.

Automatic capturing and self-reporting can be combined to balance effort and control. Using WATCHiT, users activate the data collection with a gesture. The user can control when and which data is captured. Furthermore, activating the sensor is increasing awareness about the work to be done. The capturing of context becomes itself a reflection session. In general, the interaction was not perceived as a problem. Still, it would require attention from the user and might increase errors in the collection of data.

8.4 Visualizing for Sense Making

Designers aiming at selecting a visualization that makes sense to the user and their work practices have to take into account users preferences, the nature of the work, and the intended learning goal in terms of expected outcomes of the reflection session. For example, in the care domain it is important to choose simplified visualizations, whereas, in crisis management details are important, and therefore these details have to be clear in the data visualizations.

During the iterative prototype development, *participants requested mainly three types of visualizations: status charts, comparison charts, and timelines*. The status chart was often the starting point for exploring the data, e.g. in CaReflect it was the first step to check quickly if something stands out. Comparisons were initially not included in CaReflect because of privacy concerns. However, participants demanded them to benchmark themselves against others in the sense making process. In WATCHiT, comparisons to a benchmark were a central element to reflect on training success. Intuitive timelines are useful for in-depth analysis what was happening at a particular time and often triggered participants to engage in storytelling about the experience behind the data. In general, it is important to identify a visualization that helps the users to make sense of the data considering that, as explained in the CSRL model, data is supporting the transition from working to learning.

9 Conclusion

In this paper, we presented an approach to record context from the workplace and visualize the data as content for reflective learning, by considering theory as well as available technology and its introduction in the work environment. The development of reflection support can be structured along three design decisions: selected data, capturing method and visualization. We provided an overview of possible options and corresponding design challenges. The iterative refinement of these decisions helped to design two wearable sensor systems that facilitate reflective learning by capturing and visualizing context. The evaluation of these two systems allowed us to validate the presented approach and derive lessons learned.

The articulated insights in our two studies highlight the potential impact of context on reflective learning. The participants used their experience and knowledge to analyze the visualized context and thereby learned and gained new insights about their work.

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