Organizational Learning from the Perspective of Knowledge Maturing Activities

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Abstract—The level of similarity of knowledge work across occupations and industries allows for the design of supportive information and communication technology (ICT) that can be widely used. In a previous ethnographically informed study, we identified activities that can be supported to increase knowledge maturing, conceptualized as goal-oriented learning on a collective level. The aim of this paper is to investigate the current state of support and success of these knowledge maturing activities and to contrast them with their perceived importance, to identify those which have the highest potential for being supported by ICT. Quantitative and qualitative data were collected through telephone interviews with representatives from 126 organizations throughout Europe in a sample stratified according to size, sector, and knowledge-intensity. The activities that appear to be most promising are "reflecting on and refining work practices and processes," "finding people with particular knowledge or expertise," as well as "assessing, verifying, and rating information." Rich empirical material about how these activities are performed and also the issues that emerged and need to be managed were collected. Three clusters of organizations were identified: best performing organizations, people- and awareness-oriented organizations, and hesitant formalists. It was found that a balanced knowledge strategy that leaned toward personalization outperformed a codification strategy.

Index Terms—Collaborative learning, ICT-based support, knowledge work, knowledge management

1 Introduction

The share of knowledge work [1] has continuously risen over recent decades [2]. Knowledge work can be found in all occupations and industries with sufficient similarity to allow the design of instruments to foster knowledge, independently of occupations or industries.

The systematic design of interventions aiming at increasing the productivity of knowledge work [3] needs more information about how such work is actually performed in organizations. In clear opposition to the abundance of concepts, models, methods, tools, and systems suggested for such interventions [4], many of which have failed to achieve their goals [5], recent information on how knowledge work is actually performed is scarce. Blackler et al. [6] recommend studying knowledge work by focusing on work practices or activities and on the interactions between humans and computers, frequently referred to in the context of knowledge and learning management [7], [8].

This paper presents an activity perspective toward knowledge work. We are not interested in integrated systems for workplace learning or knowledge management that support a prescribed, comprehensive process of handling knowledge and learning in organizations in their entirety. Instead, we focus on loosely coupled arrangements of services that support selected activities and are well aligned with the context of the work environment, i.e., the "spirit" [9] of the digital artifacts and tools available in the work environment that are adopted by a community of knowledge workers who are jointly engaged in knowledge handling. In this paper, so-called knowledge maturing activities are defined. The goals of the paper are threefold: 1) to contribute to knowledge in the field about the current state of perceived importance, support, and success of knowledge maturing activities in European organizations; 2) to analyze the knowledge maturing activities in more detail and describe how they are supported by organizational and ICT-based measures; as well as 3) to identify those knowledge maturing activities that might benefit most from support by ICT. We report on a broad empirical study involving telephone interviews with representatives from 126 European organizations. The data are analyzed

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Manuscript received 1 Mar. 2012; revised 19 Oct. 2012; accepted 7 Feb. 2013; published online 6 Mar. 2013.
For information on obtaining reprints of this article, please send e-mail to: lt@computer.org, and reference IEEECS Log Number TLT-2012-03-0039.
Digital Object Identifier no. 10.1109/TLT.2013.14.

with a mixed-method approach using quantitative and qualitative methods. Section 2 of the paper introduces the context in which the study was conducted and details the study design. Section 3 elaborates on the results, utilizing a portfolio approach (Section 3.1) and an approach for clustering organizations (Section 3.2). Section 4 discusses the results and their implications. In particular, interviewee responses together with concepts found in the literature for the four most interesting activities are reflected upon in Section 4.1. Following this, different types of organizations identified with respect to knowledge handling are characterized (Section 4.2). Section 4.3 discusses implications for the design of information systems, while Section 4.4 acknowledges the limitations of the approach. The conclusions and implications from the paper are presented in Section 5.

2 Background to the Study

This section defines the concept of knowledge maturing, discusses related work on activity theory, boundary objects, and practices of knowledge work and describes the design of the study and the sample of organizations.

2.1 Related Work

The study has been conducted within the context of the MATURE Integrating Project,[1] which is based on the concept of knowledge maturing [10], [11], defined as goal-oriented learning on a collective level. While there are a number of models and theories for describing, analyzing, and studying knowledge handling in organizations, e.g., Nonaka's [12] SECI model, Wiig's [13] model for situation handling from a knowledge perspective or Sveiby's [14] knowledge conversions to create business value, to the best of our knowledge none has an explicit focus on knowledge maturing. Therefore, we focus on topics including the practices of learning and knowledge development in organizations.

Our project investigates how knowledge maturing takes place in organizations, what barriers are encountered, and how socio-technical solutions can help to overcome those barriers with a particular focus on bottom-up processes. These range from informal, individual learning in organizational contexts via community-based learning to formal, organizational learning. The project is characterized by four strands: the empirical strand for which a series of studies building on each other were undertaken, i.e., an ethnographically informed study, an interview study (which is reported here), and an in-depth empirical study; the conceptual-technical strand designing knowledge maturing support and implementing tools; the integration strand developing a flexible infrastructure and enabling loosely coupled solutions; and the evaluation strand consisting of participatory design activities, formative and summative evaluations.

Knowledge maturing has been analyzed in terms of identifying the different phases of knowledge development, specifically "expressing ideas" and "appropriating ideas" on an individual level. This includes developing new ideas by individuals, personalizing and marking them as individual contributions. These ideas are "distributed in communities," through the sharing, codevelopment, and refining of highly contextualized knowledge in a collective of knowledge workers who share a common understanding of the topics involved. "Formalizing" involves the creation of purpose-driven, structured documents in which knowledge is desubjectified and the context is made explicit, and the provision of "ad hoc training" through the refining and didactic preparation of a topic to improve comprehensibility and ease its consumption or reuse in workplace learning. "Standardizing" involves solidifying formalized knowledge and implementing it in the organizational infrastructure, e.g., in the form of processes, business rules or standard operating procedures, which are described in the knowledge maturing (phase) model [15]. In the first year of the project, an ethnographically informed study [16] was conducted to understand real-world maturing practices and activities as well as a series of design studies that explored different approaches to support knowledge maturing activities.

The idea of knowledge maturing corresponds with Vygotsky's [17] thinking. Leontev [18], drawing on Vygotsky's foundational work, points out that there is a crucial difference between individual action and collective activity, and extends Vygotsky's original model as a collective activity system model. Leontev's conceptualization includes the division of labor, which helps to differentiate between what is accomplished collectively or individually. Leontev further adds a distinction between activity, action, and operation, as three different levels of human practice to delineate an individual's action from a collective activity [18]. Leontev's work has given rise to Activity Theory. The Activity Theory model contextualizes the interaction between humans and computers with activity systems in which they take place, recognizing the mediation of instruments and tools, rules, communities, and divisions of labor [19]. The latter three have been reconceptualized as control, context, and communication as a broader perspective on the factors influencing informal learning to account for the specifics of knowledge development "on the move," switching between diverse semiotic and technological spaces and stressing the importance of learning as conversations [20].

Although Vygotsky's work is considered as sociocultural, activity theory arguably provides a more rigorous account of relations between learners and their social and cultural context, for example, as it is conceived in MATURE. It is a development of Vygotsky's [17] work that provides a framework for learning and development, which accepts that meaning arises and evolves during interactions influenced by the social relations within a community of practice. Hence, human practices are conceived as developmental processes "with both individual and social levels interlinked at the same time" [21]. An activity is considered the minimal meaningful context for individual actions and is not rigid and static, but continuously changing and developing. Activities are related to various artifacts, such as signs, methods, machines, and computers that serve as mediation tools. The concepts provided by activity theory help to analyze the creative, unstructured, and learning-oriented practices of knowledge work [1], and to guide the design of information systems and specifically knowledge infrastructures [8], [21], [22], [23], [24]. We use these concepts to detail our lens on knowledge development on a collective level that

1. http://mature-ip.eu.

is supported by organizational and ICT-based measures and help interviewers in their engagement in and reflection of critical discourses with interviewees.

Another way of thinking about the relationship between knowledge maturing and organizational learning is to look at the boundaries between different communities of employees in an organization and the artifacts, e.g., documents, graphs, computer software, that are used to communicate between communities [25]. These help to overcome barriers that arise between knowledge maturing in communities of practice, conceptualized with the knowledge maturing phase "distributing in communities," and across communities on the level of organizations, conceptualized with the knowledge maturing phases "formalizing," "ad hoc training," and "standardizing." Bowker and Star [26] highlight how boundary objects inhabit several communities of practice, thus making possible productive communication and "boundary crossing" of knowledge. Hoyles et al. [27] developed an approach to learning based on the design of symbolic boundary objects that were intended to facilitate communication across community boundaries, between teams and specialists or experts. Effective learning could result from engaging in activities that embedded models and representations of knowledge, which were supported and made more visible and easily manipulated through software and services. Such an approach, further expanded in the MATURE project, linked ideas of boundary crossing and tool mediation [28], [29], and situated learning with a close alignment to the importance of a focus upon practice [30], [31]. Summing up, this approach informed considerations of knowledge (maturing) activity in different contexts, thus detailing an activity theoretic stance toward knowledge work.

Knowledge activities in general have their roots in the perspective of the practice of knowledge work as described above. Practice is the source of coherence within a community due to mutual engagement, joint enterprise, and a shared repertoire [32]. Practices performed by individuals that are part of semipermanent work groups are examples of how knowledge work can be framed as a social process [33]. Knowledge work is characterized by the use of knowledge in the workplace that encompasses practices such as acquiring, creating, gathering, organizing, packaging, maintaining, systemizing, communicating, and applying knowledge [34], [35], [36]. Schultze [37] identifies informing practices in an ethnographic study of knowledge work in a large Fortune 500 manufacturing firm:

1. expressing, i.e., self-reflexive converting of individual knowledge and subjective insights into informational objects that are independent of knowledge workers,
2. monitoring, i.e., continuous nonfocused scanning of the environment and the gathering of useful "just-in-case" information, and
3. translating, i.e., the creation of information by ferrying it across multiple realms and different contexts until a coherent meaning emerges, and later adds
4. networking, i.e., the building of relationships with people inside and outside the organization that knowledge workers rely on [38].

Informing practices have been detailed in 12 knowledge actions described as sequences of steps, which were classified into 15 types of steps on the basis of a series of 31 interviews with knowledge workers [39]. A 10-country European study highlighted actions and attitudes toward learning in a wide variety of forms, including on-the-job training; self-directed learning inside or outside the workplace; learning from networks, working with clients; learning through life experience; learning through work by carrying out challenging tasks; learning from others at work; and learning through participating in seminars and conferences [40].

The interaction between learning, development and knowledge maturing and work practices has been mapped by Eraut [41] who highlights how learning linked to work practice can result in improvements in task performance, role performance, situational awareness and understanding, teamwork, personal and group development, decision-making and problem-solving, academic knowledge and skills, and judgment. The development of an individual's capabilities in relation to each component could be represented as a separate learning pathway in itself, but also these separate learning trajectories can intersect in moves toward holistic high-level work practice [41]. Furthermore, the transfer of appropriate knowledge between contexts (including from learning to work) is not a straightforward process, as knowledge maturing linked to work practice depends upon

- understanding the new situation, a process that often depends on informal social learning;
- recognizing which areas of knowledge are relevant to the new situation;
- focusing more precisely on what knowledge is needed for a particular decision or action;
- interpreting and/or transforming that knowledge to suit the new situation and context; and
- integrating the relevant aspects of knowledge prior to or during performance [41].

At work, knowledge maturing involves taking advantage of learning opportunities helpful for individual development and can include a willingness to engage in a wide range of activities such as asking questions, getting information, finding key people to support you, listening and observing, learning from mistakes; giving and receiving feedback, trying things out, independent study, and working for a qualification [41].

The activities proposed so far need to be detailed to offer starting points for information systems design. The knowledge actions and activities of varying levels of granularity from the literature were fed into an analysis of results from our previous ethnographically informed study [42] as well as the creation of use cases for the MATURE project.

In this ethnographically informed study, data were collected from seven European organizations. Over the course of five weeks, 18 ethnographers participated in the daily work lives of 31 employees comprising different tasks and project phases. The collected data were transcribed and coded. Each researcher coded the data individually which led to 322 distinct codes. In a joint workshop, all researchers then consolidated the code set into 65 code areas that everybody agreed upon. Following this, the data

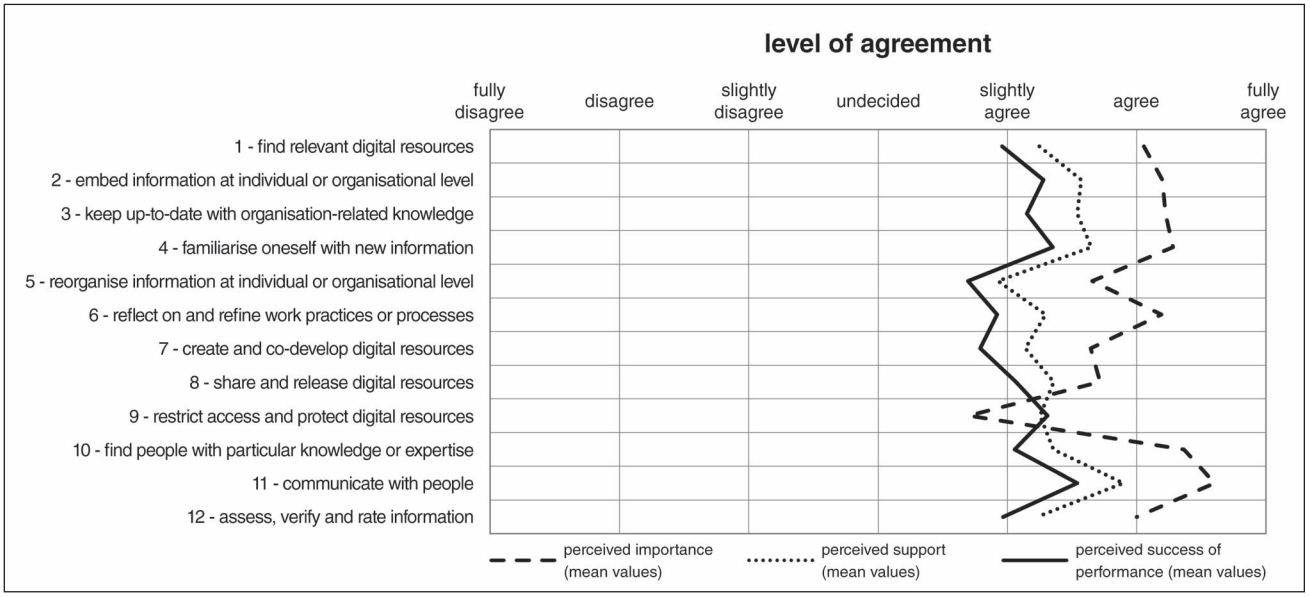

Fig. 1. Knowledge maturing activities—level of agreement.

was recoded. In essence, we performed an informed coding comprising six dimensions to put individual actions into a collective context of who (i.e., subject, community, division of labor) performed what (i.e., activity, actions), how (i.e., instruments, rules), why (i.e., occasion, objective), where (i.e., work space), and when (i.e., sequence of actions). We observed each knowledge activity several times, and we described each situation in which a knowledge activity was performed in a comparable way, relying on these six dimensions. For example, the activity "create and codevelop digital resources" has been observed in the following situation (dimensions and assigned codes are given in brackets):

> *[...] S1 (who: one actor internal) reserved one work day to prepare training material for a course she will give to users of software she codeveloped. S1 works at her desk in her office (where: own office). She intends to hand out material and use it in her presentation about the software (why: task-oriented occasion; preparing for formal training). She opens an already existing presentation (when: step1, how: presentation software) that was created and further developed by her and another colleague in software development (who: codevelopment with colleague; community of software developers) and selected out of a pool of presentations in the document store built on top of the enterprise resource planning system (when: step2, how: document management system); she goes through all the slides, inserts screenshots, and adds or alters bullet points on different slides (when: steps 3-5, what: create and codevelop; how: product knowledge, training material; guidelines for corporate presentations). [...]*

This resulted in a list of 12 knowledge maturing activities, which can occur in each phase of the knowledge maturing model and are seen as individual or group activities that contribute to the goal-oriented development of knowledge within an organization. These knowledge maturing activities (as listed in Fig. 1) were then subjected to the study described in the following sections.

2.2 Study Design

In contrast to the ethnographically informed study in which we investigated seven organizations resulting in the identification of 12 knowledge maturing activities, we aimed for a broader scope of organizations to be investigated to gain a rich picture of the perceptions held in organizations—of different size, sector, and knowledge intensity—regarding the results of the former study.

The knowledge maturing model provides a new and distinct lens for studying phenomena of knowledge conversion. Consequently, the empirical studies conducted in MATURE are exploratory. The study combines quantitative with qualitative elements in a mixed-method approach, so that phenomena of knowledge maturing, specifically about phases and knowledge maturing activities, were investigated in more detail. However, some initial assumptions about relationships between concepts were also studied.

We conducted telephone interviews in European countries for which language skills were available in the project team, namely Austria, Belgium, France, Germany, Greece, Hungary, Ireland, Italy, Poland, Portugal, Spain, Switzerland, and the United Kingdom. We defined three criteria that were transferable between the countries for our sampling approach: size, type of the sector, and knowledge intensity [43]. We aimed for an equally distributed sample according to our strata. Based on the assumption that medium and large organizations support knowledge maturing activities more systematically and may have dedicated roles that can provide qualified responses, we excluded small organizations.

Contacts were gained using a mixed approach of purposeful, convenient sampling and cold calling with stratified random sampling [44]. Some organizations were selected due to preexisting relations with the researchers and their interest in the topic. With cold calling, we made sure that our sample was evenly distributed and that we collected opinions from individuals who were new to the topic of knowledge maturing.

For each organization, we interviewed one representative who had work experience of at least three years and had been employed in the organization for at least one year.

Furthermore, interviewees had to have responsibility for, e.g., knowledge management, innovation management or personnel development. We made substantial effort to attract interviewees with responsibility and knowledge in the domain as well as a good overview about knowledge handling in the organizational unit they represented.

Telephone interviews were conducted and lasted at least one hour. Interviewers engaged in a discourse with interviewees and, early on in the interviews, jointly created a knowledge maturing story for their organization, so that the knowledge maturing model was instantiated and applied in the organizational context. By following this procedure, we made sure that we created a common understanding between interviewee and interviewer that was based on an actual case from the organization and, thereby, received meaningful and qualified responses.

The interviews were based on a common guideline and were partly structured and partly semistructured, reflecting the mixed method approach that was chosen because the study was exploratory and, in part, built on artifacts created in previous studies, specifically the knowledge maturing model [15] and the list of knowledge maturing activities. With respect to the knowledge maturing model, information was sought on the perceived importance, support from organizational and ICT-based measures, tools and infrastructures, barriers, and motivational factors involved as well as perception of success.

The concepts "perceived importance," "perceived support," and "perceived success" were investigated with respect to each knowledge maturing activity. Knowledge maturing activities were explained to interviewees as the activities of individuals or groups of individuals that contribute to the development of knowledge, which can occur within one knowledge maturing phase, e.g., "distributing in communities," or as a transition between two knowledge maturing phases, e.g., from "distributing in communities" to "formalizing." Importance relates to the extent to which interviewees think that a knowledge maturing activity is important for increasing knowledge maturity in their organization. Support refers to organizational or information and communication technological instruments that help individuals or groups of individuals perform an activity in such a way that it contributes to the development of knowledge. Finally, success captures to what extent interviewees believe that a knowledge maturing activity has been performed successfully in their organization or organizational unit. Each concept has been operationalized with the help of one statement per activity for which interviewees could indicate to what extent they would agree to this statement on a seven-point Likert scale. Besides reflecting on each of the 12 proposed knowledge maturing activities with respect to the three concepts, interviewees were also asked about additional activities. Moreover, the comments of interviewees regarding the knowledge maturing activities were collected. A prestudy was conducted with six individuals representing heterogeneous organizations, which helped to improve the understandability of the questions.

2.3 Sample

In total, 939 organizations were contacted. Out of these, 139 participated in the study, which translated into a response rate of 14.8 percent. Of the interviews, 128 fulfilled the selection criteria: the organization was of medium or large size, and the interviewee had sufficient experience in his/her profession and within the current organization (Section 2.2). After conducting a missing value analysis, two[2] interviews with more than 50 percent of missing data were excluded [45]. Outliers were analyzed among variables related to knowledge maturing activities with univariate and multivariate methods. All potential outliers were investigated in detail taking into account the comments made by interviewees. All seemed to be similar to the remaining observations to be retained.

TABLE 1
Sample—Size, Sector, and Knowledge Intensity of Organizations

Stratification		Number (percentage) of organizations
size	medium	42 (33.3%)
	large	84 (66.7%)
sector	industry	42 (33.3%)
	service	76 (60.3%)
	n/a	8 (6.4%)
knowledge intensity	low	39 (30.9%)
	high	79 (62.7%)
	n/a	8 (6.4%)

The final sample contained 126 organizations. Two-thirds of organizations were large ($n = 84$; 66.7 percent) and one-third ($n = 42$; 33.3 percent) were medium sized (Table 1). Using the NACE code [43], [46], 42 (33.3 percent) organizations were situated in the industry sector and 76 (60.3 percent) in the service sector. The majority ($n = 79$; 62.7 percent) can be classified as highly knowledge-intensive[3] organizations and 39 organizations (30.9 percent) as less knowledge intensive. Finally, eight (6.4 percent) organizations could not be assigned to a sector or knowledge intensity.

Data were also collected on interviewee's positions and fields of work. As job positions and descriptions could be characterized as having a certain degree of ambiguity, it was decided to rely on a collaborative coding procedure for handling the information provided. The coding procedure was performed jointly by all interviewers and was revised during team discussions.

With respect to their field of work, most of the interviewees ($n = 36$; 28.6 percent) worked in human resources (Table 2). The area of business and administration was used as a general classification for interviewees working in fields like customer relation management or controlling; this accounted for 26 interviewees (20.6 percent). Additionally, 18 (14.3 percent) interviewees worked in information systems and technology; and 15 (11.9 percent) in change management. In eight cases (6.4 percent), interviewees did not specify any details about their field of work.

2. The two interviews that were not completed had 56 and 74 percent missing values.

3. Eurostat refers to knowledge intensity for service sectors and technology intensity for industry sectors. For this paper, we will refer to both as knowledge intensity.

TABLE 2
Sample—Interviewees' Field of Work

Field of work	Number of interviewees
human resources	36 (28.6%)
business and administration	26 (20.6%)
information systems	18 (14.3%)
change management	15 (11.9%)
research and development	13 (10.3%)
knowledge management	9 (7.1%)
innovation	1 (0.8%)
unspecified	8 (6.4%)

TABLE 3
Sample—Interviewees' Position

Position	Number of interviewees
head	61 (48.4%)
executive	22 (17.5%)
employee	22 (17.5%)
project manager	11 (8.7%)
unspecified	10 (7.9%)

Aggregations for levels of positions were created with respect to the rank or level of the respondent within the organizational hierarchy. Department heads (e.g., head of human resource management) were mapped to "head" (Table 3). With 61 occurrences, this code represents nearly half of all interviewees (48.4 percent). Top-level positions such as chief information officer were assigned to "executive" and mapped to 22 interviewees (17.5 percent). "Employee" was used for the 22 (17.5 percent) interviewees who did not supervise others. All interviewees who were mainly responsible for projects were mapped to the position "project manager" that accounts for 11 (8.7 percent) of the interviewees. The code "unspecified" was used 10 times (7.9 percent), when it could not be determined whether the interviewee was in a management position or just described as being responsible for a specific topic.

In total, the participants matched the target group aimed for; they had sufficient experience and most were in high-ranking positions. All interviewees were capable of speaking for large parts or even for the entire organization they represented during the interview.

3 Results

This section presents the results of the study, focusing on those activities for knowledge maturing deemed to have the highest potential to be supported with respect to the three concepts described earlier, i.e., being important and at the same time less supported and less successfully performed. Differences between organizations that could be traced back to strata are also investigated and results of clustering organizations according to their performance of knowledge maturing activities are presented and described according to size, industry sector, and level of knowledge intensity.

3.1 Knowledge Maturing Activities—Descriptives and Portfolios

Here, the interviewee perceptions of the importance, support, and success of the activities are descriptively analyzed and interesting facets of individual activities are highlighted. This detailed information is then further investigated with the help of portfolios to map importance and support as well as importance and success of performance.

3.1.1 Importance, Support and Success of Knowledge Maturing Activities

A relatively high mean value of agreement can be observed with respect to all three questions. Fig. 1 shows the mean values of the level of agreement for the three questions for each knowledge maturing activity.

Perceived importance. According to the median, at least 50 percent of respondents agreed or fully agreed that all 12 knowledge maturing activities are important for increasing maturity of knowledge in their organization (see Table 9 in the Appendix, available in the online supplemental material, which can be found on the Computer Society Digital Library at http://doi.ieeecomputersociety.org/10.1109/TLT.2013.14). The agreement to the importance of the following knowledge maturing activities was particularly high, as according to the median, at least 50 percent of the respondents fully agreed (exact percentages are provided in brackets): *"11—communicate with people"* (70.6 percent); *"10—find people with particular knowledge or expertise"* (54.0 percent); *"1—find relevant digital resources"* (51.2 percent); and *"6—reflect on and refine work practices or processes"* (50.4 percent). The knowledge maturing activity with the highest standard deviation (2.15) is *"9—restrict access and protect digital resources."* Twenty-six percent of respondents "fully disagreed" or "disagreed" on its importance, indicating two different interpretations of this knowledge maturing activity.

Perceived support. Agreement with the statement that the respective knowledge maturing activity is supported in the respondents' organizations (see Table 10 in the Appendix, available in the online supplemental material) is not as high as the agreement of the importance of the respective knowledge maturing activity. However, for 10 out of 12 knowledge maturing activities, according to the median, at least 50 percent of interviewees "agreed" or "fully agreed." With respect to knowledge maturing activity *"5—reorganize information at individual or organizational level"* (66.4 percent) and *"12—assess, verify, and rate information"* (69.9 percent) "slightly agreed," "agreed" or "fully agreed." Again, the most heterogeneous answers were given to knowledge maturing activity *"9—restrict access and protect digital resources"* (standard deviation is 1.81).

Perceived success of performance: the level of agreement is lower compared to the agreement to support knowledge maturing activities (see Table 11 in the Appendix, available in the online supplemental material). However, more than 50 percent of interviewees "agreed" or "fully agreed" that the knowledge maturing activities *"9—restrict access and protect digital resources"* (61.0 percent), *"11—communicate with people"* (58.7 percent), *"4—familiarize oneself with new information"* (54.4 percent), *"10—find people with particular knowledge or expertise"* (52.4 percent), and *"8—share and release digital resources"* (51.2 percent) are performed successfully in their organization. For the remaining seven knowledge maturing activities, a median of five indicates that at least 50 percent of respondents "slightly agreed,"

"agreed," or "fully agreed." The knowledge maturing activity *"8—share and release digital resources"* has the highest standard deviation (1.67) closely followed by *"9—restrict access and protect digital resources"* (1.63).

For 11 knowledge maturing activities, the mean values of given answers decrease from importance over support to success (see Fig. 1). Hence, though these knowledge maturing activities are perceived to be important, they are actually less well supported. This might result in a less successful performance. For the remaining knowledge maturing activity *"9—restrict access and protect digital resources,"* the opposite is true. For this knowledge maturing activity, the success of performance is perceived as slightly higher than the perceived support and in turn perceived importance (see Section 4.1).

3.1.2 Portfolios

To set priorities on knowledge maturing activities with a perceived high potential, it is of interest to identify those knowledge maturing activities that are, first, deemed important for increasing knowledge maturity but perceived as less supported and, second, deemed important but perceived as less successfully performed. In such cases, software or services could be (further) developed to enhance the support of such activities, aiming at a more successful performance in organizations. To perform this analysis, the mean levels of agreement were employed. To avoid influences of the absolute mean values, it was decided to concentrate on the relative values, i.e., mean level of agreement to one knowledge maturing activity relative to the mean levels of agreement to other knowledge maturing activities. This also has the advantage of retaining information about the relative mean agreement of each concept with respect to a specific knowledge maturing activity, instead of reducing it to one single difference score. Therefore, mean values for perceived importance, support, and success are divided into quartiles, comprising three knowledge maturing activities each. These are then contrasted. Applying this approach explicates that knowledge maturing activities are deemed more important, and at the same time, less supported or successfully performed than others. Each of the portfolios displayed in Fig. 2 opposes two dimensions. The focus was on the deemed importance of knowledge maturing activities and related it to the perceived support and success of performance.

The "importance-support" portfolio displayed in Fig. 2 depicts on its x-axis the mean values of perceived importance and on its y-axis the mean values of perceived support. As quartiles were used for placing knowledge maturing activities within the portfolio, the mean values of both perceived support and importance are arranged relative to each other.

The higher the perceived importance and the lower the perceived support, the higher the potential is for supporting this knowledge maturing activity. Following this, the background of the importance-support portfolio shown in Fig. 2 is colored in different shades to show the strategy of investing into those activities that are in the lower right corner of the portfolio. The darker the background color, the higher the importance and the higher the assumed lack of software or services that provide functionalities to support the knowledge maturing activity.

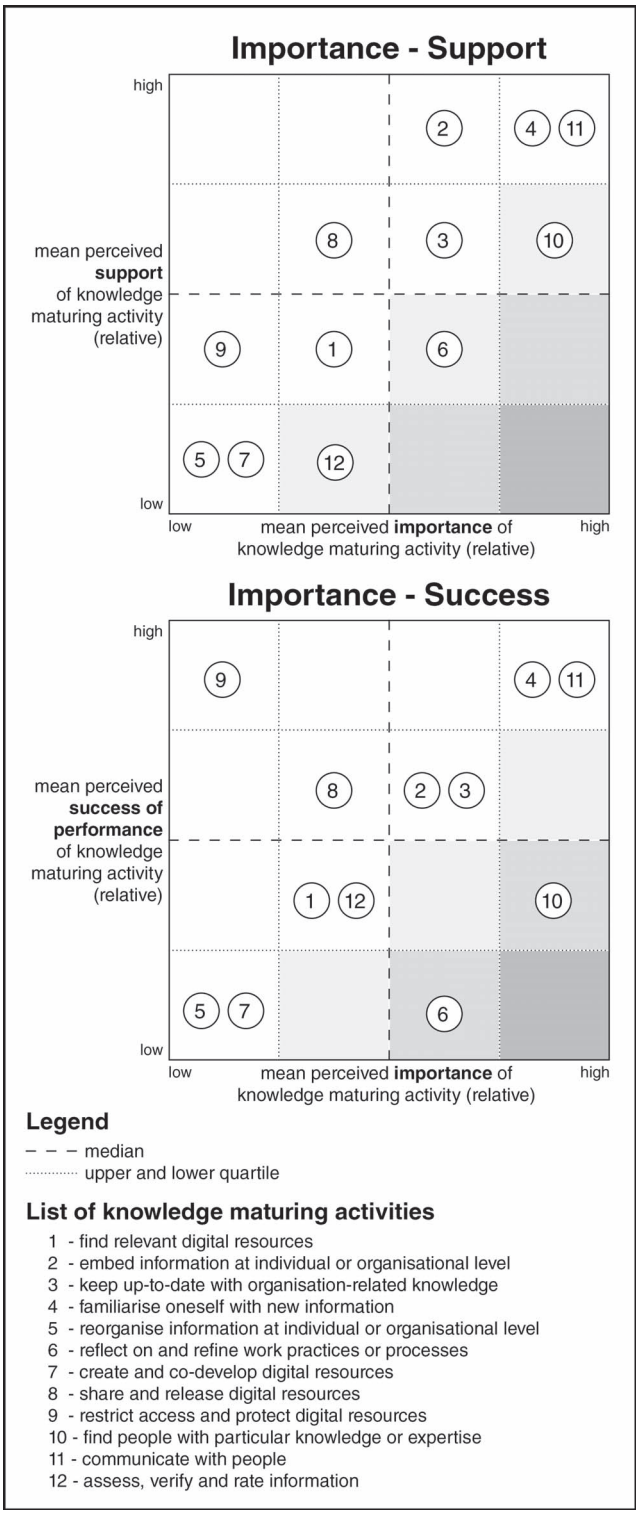

Fig. 2. Knowledge maturing activities—portfolios.

Relative to the others, the knowledge maturing activities *"4—familiarize oneself with new information," "11—communicate with people"* and *"10—find people with particular knowledge or expertise"* are deemed most important for increasing knowledge maturity in the interviewee's organizations. The latter is less supported, and hence would be most interesting. The knowledge maturing activities *"2—embed information at individual or organizational level,"*

"3—keep up-to-date with organization-related knowledge," and *"6—reflect on and refine work practices or processes"* are deemed to be of secondary importance. The latter knowledge maturing activity is deemed less supported, and additionally is the only one in this portfolio that belongs to 50 percent of knowledge maturing activities that are deemed more important and 50 percent of knowledge maturing activities that are deemed less supported than others. Hence, this knowledge maturing activity would be of high interest for further consideration. With respect to perceived importance, the knowledge maturing activities *"1—find relevant digital resources," "8—share and release digital resources,"* and *"12—assess, verify, and rate information"* would fall into the third group. The latter of this group is less supported and would be a candidate to be facilitated with the help of software or services. The knowledge maturing activities *"5—reorganize information at individual or organizational level," "7—create and codevelop digital resources,"* and *"9—restrict access and protect digital resources"* are part of the group that is deemed least important.

The "importance-success" portfolio depicted in Fig. 2 displays the mean values of perceived importance on its x-axis and the mean values of perceived success of performance on its y-axis. Those activities deemed important and at the same time perceived to be performed less successfully would be most interesting for further consideration. Again, this area of interest is shaded differently to show the norm strategy of investing in those activities that are in the lower right corner of the portfolio.

According to the "importance-success" portfolio *"10—find people with particular knowledge or expertise"* and *"6—reflect on and refine work practices or processes"* would be most interesting. The former falls into the group of most important knowledge maturing activities and, at the same time, is part of the 50 percent of knowledge maturing activities that are less successfully performed. The latter is deemed to be one of the 50 percent of knowledge maturing activities that are more important and, at the same time, is perceived to be one of the three less successfully performed knowledge maturing activities.

3.2 Types of Organizations

In this section, we investigate whether organizations differ with respect to knowledge maturing. First, we concentrate on differences that can be traced back to the stratification, i.e., sector (industry versus service), size (medium versus large) and knowledge intensity (low versus high). Therefore, statistical tests can be performed. We chose the Kolmogorov-Smirnov test for two independent samples, as it is applicable to the data that are conceptualized as an interval scale and because it has less stringent assumptions (e.g., according to the underlying distribution) than the t-test for two independent samples (for more information see [47]). To assess differences, interviewees' perceptions of groups of variables are focused upon. On the one hand, these are directly related to knowledge maturing, i.e., support of knowledge maturing phases (six variables), successful performance of knowledge maturing phases (six variables), and overall success of knowledge maturing (one variable). On the other hand, these are related to knowledge maturing activities, i.e., importance (12 variables), support (12 variables), and successful performance (12 variables). In total, 49 variables are investigated with respect to three strata, resulting in 147 statistical tests. An excerpt of results showing only the lowest level of statistical significance per group of tests is presented in Table 12 (see Appendix, available in the online supplemental material).

At a statistical significance level of $\alpha \leq 0.05$, a single test result indicated a significant difference between organizations in the industry and service sector with respect to the perceived importance of one knowledge maturing activity, i.e., *"5—reorganize information at individual or organizational level."* Nevertheless, as groups of tests were performed, the level of statistical significance using a Bonferroni correction was adjusted [45]. To assess whether certain strata of organizations differ with respect to a group of variables (e.g., 12 variables in case of perceived successful performance of knowledge maturing activities), at a statistical significance level of $\alpha \leq 0.05$, the Bonferroni correction requires performing each of the n individual tests on a $\alpha_{\text{corrected}} = \alpha/n$ level. Hence, according to the number of tests performed, for importance, support and successful performance of knowledge maturing activities a level of $\alpha_{\text{corrected}} \leq 0.0042$ and for support and successful performance of knowledge maturing phases $\alpha_{\text{corrected}} \leq 0.0083$ is used.

Considering the Bonferroni correction, no significant differences were found with respect to knowledge maturing between organizations of different strata. Thus, the organizations in the sample are considered to be similar with respect to knowledge maturing across size, sector, and knowledge intensity.

As no differences between strata were found, the potential groupings of organizations were further explored. Therefore, a hierarchal cluster analysis to research groups of organizations regarding performance of knowledge maturing was undertaken. Variables for assessing the similarity of organizations with respect to the successful performance of knowledge maturing were selected. This is a critical step as the resulting clusters are highly dependent on these variables [48]. Aldenderfer and Blashfield [48] recommend selecting a set of variables that best represents the concepts of similarity under which the analysis operates and at best can be related to a theory supporting the classification. The underlying theory in our case is represented by the knowledge maturing model and corresponding concepts (see Section 2.1). Respondents' evaluations of successful performance of knowledge maturing were collected from three different perspectives, i.e., knowledge maturing activities (12 variables), knowledge maturing phases (six variables), and overall (one variable). Out of those, perceptions of successful performance of knowledge maturing activities were selected as variables for cluster analysis for several reasons. First, they represent the finest level of granularity allowing for rich interpretation. Second, the interviewees turned out to be very interested in the activities. This is, for example, manifested in a large number of additional statements that were analyzed (see Section 4.1). Third, interviewees' perceptions of successful performance of knowledge maturing activities are most closely related to the potential support that software and services could offer, thus informing design and development in the MATURE project. Fourthly, the knowledge maturing activities are grounded in qualitative

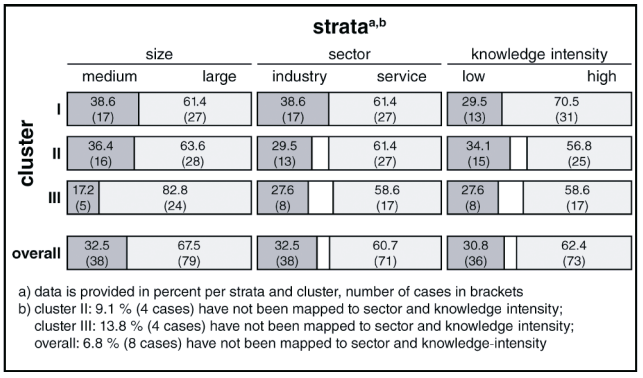

Fig. 3. Clusters in relation to strata (117 out of 126 cases covered).

data gained from an ethnographically informed study (see Section 2.1). Each of the 12 knowledge maturing activities is rated by interviewees with respect to 1) importance for increasing knowledge maturity, 2) support in their organization, and 3) successful performance in their organization (Section 3.1). As we concentrate on the latter, 12 assessments were measured using a seven-point Likert scale fed as attributes into the cluster analysis.

Cluster analysis [48] maximizes the similarity of objects in the same cluster while similarity to objects in other clusters is minimized. The data set has to be described as a matrix X_D consisting of n cases (the rows) and a attributes (the columns). Each variable $x_{i,j}$ represents the assessment of interviewee $i(i = 1, 2, \ldots, n)$ with regard to attribute $j(j = 1, 2, \ldots, a)$.

In our case, all attributes are measured on the same seven-point Likert scale. Any case with missing data in one of the 12 variables is excluded from the cluster analysis, so 117 out of 126 cases were subjected to the cluster analysis.

There are several methods that can be used to conduct cluster analysis [48]. We compared results of different clustering methods performed on the data set and relied on a cluster solution gained by a hierarchical agglomerative cluster analysis performing Ward's method using squared euclidean distance. This method was chosen because it is applicable to the sample data; it creates clusters of relatively equal sizes and it is widely used in the social sciences [48], [49].

Several approaches supporting the determination of the number of clusters are available. Heuristic procedures are by far the most commonly used [45], [48]. As no standard objective selection procedure exists, a more formal, but still heuristic method that maps the number of clusters implied by the dendrogram against the agglomeration coefficient was adopted [45], [48]. The resulting diagram shows the growth of the agglomeration coefficient dependent on the number of clusters. If the curve progression shows a so-called "elbow," this can be used as a decision criterion to determine the number of clusters. In our case, a three-cluster solution was suggested, which was supported by other heuristics, such as the structure of the dendrogram.

Fig. 3 shows the three identified clusters in relation to our three strata variables. For each of the clusters, the cases belonging to different strata are depicted in relation to each other. Additionally, absolute values are displayed in brackets representing the numbers of cases per strata for each cluster.

Clusters I and II of the three-cluster solution are of equal size, containing 44 cases each. In comparison, cluster III that comprises 29 cases is smaller. This can be seen as a well-balanced cluster solution with regard to the number of cases per cluster.

To study whether the clusters contain a well-balanced set of organizations, i.e., whether the distribution of organizations in the clusters corresponds to the distribution in the entire sample with respect to size, sector, and knowledge intensity, chi-square tests were employed [47]. Concretely, we tested whether the observed frequencies shown in Fig. 3 differ significantly from the expected frequencies that were calculated based on the overall sample. The results of the tests are shown in Table 13 in the Appendix, available in the online supplemental material.

The cross tabulation of clusters and size shows that the actual distribution is very much in line with the distribution in the sample for clusters I and II with the exception of large organizations that are overrepresented in cluster III in which 24 out of 29 organizations are large, compared to 19.6 expected organizations. These 24 organizations account for 82.8 percent of organizations in cluster III compared to shares of 61.4 and 63.6 percent for clusters I and II). This deviation is not significant, however.

Concerning sector and knowledge intensity, the cross tabulations show that the actual distribution is very much in line with the overall distribution in the sample for all clusters (the differences between expected and actual values are 1.8 at most). As all results are not significant, the alternative hypotheses (i.e., one or more observed frequencies differ from expected frequencies) are not supported. Thus, the clusters were built independently from sector, size, and knowledge intensity and are composed of sets of organizations that are representative of the sample.

4 Discussion

This section interprets the results presented in Section 3, enriched by additional insights that emerged from a qualitative analysis of the responses collected during the interviews, and discusses the implications of the results for knowledge handling in organizations.

Section 4.1 interprets the portfolios presented in Section 3.1 and discusses selected knowledge maturing activities in light of qualitative data gained from the interviews and related work. Section 4.2 interprets and describes the clusters presented in Section 3.2 and relates them to knowledge strategies. Section 4.3 reflects on implications for the design process of the MATURE project. Finally, Section 4.4 discusses some limitations that need to be acknowledged.

4.1 Knowledge Maturing Activities

The comparison of both portfolios (depicted in Fig. 2) leads to the conclusion that the knowledge maturing activities *"6—reflect on and refine work practices or processes," "10—find people with particular knowledge or expertise,"* and *"12—assess, verify, and rate information"* are the most interesting ones to be supported.

TABLE 4
Characterization of Participants Cited

Part. ID	Size; NACE description; knowledge-intensity; field of work; position
P1	medium; education; high; knowledge management; employee
P2	large; manufacture of motor vehicles; high; human resources; unspecified
P3	large; computer programming, consultancy and related activities; high; research and development; project manager
P4	large; activities of head offices; management consultancy activities; high; unspecified; employee
P5	large; wholesale trade; low; human resources; head
P6	large; manufacture of computer, electronic and optical products ; high; knowledge management; head
P7	large; manufacture of computer, electronic and optical products ; high; knowledge management; head
P8	large; computer programming, consultancy and related activities; high; organization; head
P9	medium; computer programming, consultancy and related activities; high; organization; chief
P10	large; manufacture of other transport equipment; high; information systems; head
P11	large; manufacture of computer, electronic and optical products; high; knowledge management; head
P12	large; scientific research and development; high; research & development; project manager
P13	medium; computer programming, consultancy and related activities; high; organization; head
P14	medium; computer programming, consultancy and related activities; high; organization; chief
P15	medium; scientific research and development; high; information systems; head
P16	large; manufacture of computer, electronic and optical products ; high; knowledge management; head
P17	large; land transport and transport via pipelines; low; information systems; chief
P18	medium; scientific research and development; high; research & development; project manager
P19	large; other manufacturing ; low; business; employee

TABLE 5
Relevant Statements for "6—Reflect on and Refine Work Practices or Processes"

- **low support**: *"No one feels responsible for this activity."* (P1)
- **critical reflection**: *"That is difficult. Increases knowledge if I organize myself better?"* (P2)
- **recurring evaluation**: *"We are doing such meetings every three months, such strategy meetings, and discuss about the current situation - they are organized topic-specific. We are reflecting. And when someone has a new idea for a new internal process, we are doing it for half a year and look at it whether it has delivered what was expected, then it gets adapted."* (P3)
- **level of analysis**: *"That very much depends on the level. In the small group […] internally it works. On the next level 100-120 (employees) in the organization, processes are much slower and to change a process in the company takes 3-4 years."* (P4)
- **importance for processes**: *"Process optimization is nearly a buzz word in our company now (because it is so heavily performed)."* (P5)

TABLE 6
Relevant Statements for "10—Find People with Particular Knowledge or Expertise"

- **use of software:** *"My company supports this activity with a software application and furthermore, after the recent organizational structural change, this activity has become more important and more* supported." (P6); *"They are used as expert to solve specific issues and to provide the required knowledge."* (P7)
- **no need for support:** *"It is not individual knowledge that makes the difference."* (P8)
- **dependence on size**: *"We are too small to formalize this […] Over 50 people is then too large to know everyone, that's then the problem."* (P9)

TABLE 7
Relevant Statements for "12—Assess, Verify, and Rate Information"

- **use of software:** *"This activity is very important for the company and it is also supported by digital workflows that are used to share, verify and approve documents."* (P10); *"A Wiki and a Virtual Room for each single project. It is used to support the team creativity and collaboration."* (P11)
- **importance**: *"There is always this activity, before we make documents and information official."* (P12)

TABLE 8
Relevant Statements for "9—Restrict Access and Protect Digital Resources"

- **relevance:** *"This activity is not relevant for my company. There are some privacy issues but at a general level."* (P13); *"Not all digital resources - I would here (and above) say all resources that influence the work process, the product, the organizational goals, here I would always say yes. If it is not influencing the work process, then it is stupid."* (P14)
- **data security:** *"I fully agree for security reasons."* (P15); *"We work also for the military sector and the information protection is crucial."* (P16)
- **trust**: *"You wouldn't share anything if you couldn't restrict it to certain persons."* (P16); *"That's important because of trust. I think it is important to develop trust. There are people who will share only in a limited way if they have trust that not everyone can see it."* (P17)
- **information overload**: *"Knowledge is not something that has to be always distributed. With this activity the knowledge is channeled to the right users."* (P18)
- **barrier**: *"We are destroying knowledge in this area - clearly - when restricting access and only allow persons to do what they are supposed to do - then I exclude him from other knowledge."* (P19)

Narrative analysis was used for evaluating and integrating stories and their connections to the study. Stories were collected from the interviewees with qualitative open-ended interviews [50]. Narrative analysis has also been employed in management research [51], where it was considered useful for providing organizational understanding [44]. A collaborative narrative analysis can be applied combining the interviewees' stories with the experiences of the researchers [52].

A collaborative narrative analysis for presenting short quotations about the interviewees' experiences about the knowledge maturing activities was used. It is used as a complementary method combined with the quantitative results to explain the perceptions of importance, support, and success of knowledge maturing activities and enriched the view on those activities that were found to be most interesting in the quantitative data analysis.

For each of the selected knowledge maturing activities, we characterize the activity; present interesting aspects highlighted by our interviewees and relate them to literature. The origin of the citations is characterized in Table 4. The participant ID is used in the citations in Tables 5, 6, 7, and 8 as a key for identification. For each Participant ID, the organization is characterized with

respect to its size, the NACE description of its primary field of work and the knowledge intensity. Furthermore, the field of work and position of the interviewee is given.

The knowledge maturing activity *"6—Reflect on and refine work practices or processes"* is perceived of high importance but is perceived as less successfully performed and a less well supported. Hence, actions oriented to improve its efficiency are of high interest. This activity comprises the exploration of past experiences toward new understandings and appreciation [53] with respect to the tasks that people are engaged in. Tasks can be semistructured or unstructured denoted as work practices or structured within processes. This includes both elements of reflective practice [54]; the contemporaneous reflection-in-action and the retrospective reflection-on-action. The perceived importance is in line with results obtained by Brown et al. [40], who reported an increased role for reflection and reflexivity as individuals shape their work trajectories (i.e., choices and possibilities have expanded, and structural, organizational, and technological change have added complexity to work trajectories). Table 5 lists statements collected on this activity.

The findings in Section 3.1 suggest that the activity *"6—reflect on and refine work practices or processes,"* although deemed important, is comparably less well supported, which also holds when focusing on interviewee statements. While one interviewee mentioned that no one in the organization was assuming the responsibility for it (Table 5, P1), several organizations, directly supported this activity, e.g., by workshops with external organizations after completing a project and recording them with video to analyze later (Table 5, P3). It also became evident that this activity is quite complex and highly dependent on its context. One interviewee also highlighted that the level, i.e., whether an individual, a community, or an organization is targeted, is important and requires an adequate level of analysis (Table 5, P4). However, responses show that organizations supporting this activity focus on team reflection. No evidence was found that organizations support this activity solely at the individual level.

Reflecting on and refining processes is also a common practice in organizations that need certificates for their activities. One organization was found to take this knowledge maturing activity very seriously to ensure customers' requests are satisfied and for international certification requirements. But, there were also doubts about the connections between individual practices and knowledge maturing (Table 5, P2).

This activity is also related to processes and on their improvement (Table 5, P5). The redefinition of work practices and processes can be supported by the business process management (BPM) techniques starting from the analysis to the modeling and optimization of the organizational processes. An essential part of BPM is business process modeling that is based on business process identification and a representation useful to reflect on practices and impacts of a process [55], [56]. Knowledge is embedded in the organization's processes and has to be widely distributed and used daily. Organizational knowledge is thus captured, structured, and formalized in the organization's business processes [57], [58]. The correct identification of processes and practices and tools and initiatives to improve their performance can be useful for effective knowledge distribution amongst employees and to mature the organizational knowledge, learning how to apply it in work practices and processes.

The knowledge maturing activity *"10—Find people with particular knowledge or expertise"* is perceived of high importance, but initiatives to improve the success of their performance are needed, particularly for larger organizations (Table 6, P9). The knowledge maturing activity relates to identifying people who can help and provide support for carrying out work activities. Knowledge, especially in its tacit nature, is socially constructed, and collectively held by individuals throughout the organization [59].

The interviewees believe that it is important to find the most appropriate people for certain tasks and also for specialist help to complete specific daily tasks. Some initiatives are undertaken by the organizations.

One organization introduced a competence management Roadmap. It developed a methodology and software to trace the employees' competences, to elaborate the state of each activity to highlight gaps in the needed competences, and to simulate and forecast the situation of the organizational activities assuming changes in the team. Another organization used software to collect and manage the employees' CVs and skills for supporting and facilitating the link between the knowledge base available and the employees' skills (Table 6, P6). In the same organization, the director and the high-level managers met a group of employees to know their work and activities because they owned the core knowledge. The initiative aimed to specify the employee's activities and their knowledge to facilitate possible task rotation and their involvement in different projects, and also improve employees' creativity and productivity.

The analysis of processes and practices and identification of "super users" and "key users" that are not the process owners, but highly reputed experts coming from different areas was also a means for supporting knowledge maturing activity *"10—find people with particular knowledge or expertise"* (Table 6, P7). Not every interviewee considered supporting this activity as very useful, especially where individual knowledge was regarded as less important (Table 6, P8).

Therefore, mechanisms supporting knowledge sharing are important and are based on the correct identification of people and their expertise. There are key people inside the organization who have high levels of knowledge and expertise concerning a given activity. They are considered as "experts" to solve specific issues and to provide the required knowledge in the organizations' activities [60].

Approaches to making employee's capabilities visible use the notion of competencies [61]. In their view, individuals are described by their competencies impacting on the organizational activities and on patterns of organizational evolution and change [62]. In fact, an activity needs specific competencies to be executed and to optimize its performance. The application of the same competencies in two different activities can lead to different level of results. In this perspective, competencies are defined as "effective performance within a domain/context at different levels of proficiency" [63]. The identification of people with specific

competencies to be involved in the most appropriate organizational activities is of high importance to achieve good results.

Competency modeling, competency diagnosis, and competency gap analysis are key elements of competence management approaches, and are informed by performances in normal working tasks [64]. They can support [61] the planning of training, finding people to allocate them to appropriate activities, or experts and talents location and, thus, optimization of knowledge sharing [65], [66].

The activity *"12—Assess, verify, and rate information"* is considered as a third interesting knowledge maturing activity, because it is one of the least supported and less successfully performed activities. It involves evaluating content with respect to certain quality criteria, like accurateness, up-to-datedness, usefulness, or for people with respect to their capacity or behavior, and allows the organization to make the right and correct information available for organizational activities. Mechanisms to verify and validate the information can be useful to improve the quality of diffused information and to allow only the "right" knowledge to mature.

Information is, in fact, required to create knowledge. Information provides a meaning or an idea about something [67], knowledge enriches the information contextualizing it [68]. In the literature, different information and data quality assessment tools, frameworks and metrics are available [69], [70].

In some participating organizations, workflows are available to share, verify, and approve documents. One of the organizations developed a workflow for product design information. The files are verified and shared with other employees after approval (Table 7, P10). This workflow supports the activity *"12—assess verify and rate information"* and allows employees to learn from and apply the most adequate knowledge, reducing time caused by wrong information and related errors. Therefore, this activity provides a clear view about which information is correct for others to learn from, and allows the most valid knowledge to mature. Another organization used an open-source system that integrated a wiki and a virtual room for each project to support team creativity and collaboration, and also to specify authors and revisions and to provide a common workflow for the documents and actions (Table 7, P11). Using this system, the information exchanged and applied during the work activities are validated by the team, assuring the quality and relevance of information. In a further organization, a document's structure is discussed in a team to guide the right information to be used and workflows are used to share, verify, and approve documents (Table 7, P12) based on evaluating the available information.

The knowledge maturing activity *"12—assess, verify, and rate information"* is useful to drive information sharing, especially strategic information related to the organization's core business. In those processes, such as for new product development, the information flow follows a horizontal and vertical path amongst the different activities and tasks [71], and appropriate techniques are applied by organizations to adequately direct the most appropriate information to reduce errors and improve the quality of the product [72].

Organizations share their information and knowledge with the aim to create a strategic value for their activities [73]. Hence, the sharing of information between organizations calls for accurate policies to evaluate and channel their use. Information systems are useful to provide access to strategic information that create efficiencies and create more value to the organization based on a check mechanism to evaluate the information quality. Therefore, information systems enable the sharing of transaction data and strategic knowledge, and provide strategic advantages and opportunities to organizations [74].

Although being in the group deemed to be least important, the analysis of the frequencies of and comments to the activity *"9—Restrict access and protect digital resources"* calls for a more detailed discussion. This knowledge maturing activity is about limiting access to content and is the most controversial activity, as was shown in the previous section. The appropriateness and need for knowledge protection is recognized in literature. In the knowledge-based view of the firm [75], [76], protecting knowledge becomes critical [77], because a competitive advantage is determined by knowledge rather than tangible resources, thus increasing the relevance of focused knowledge sharing and protecting.

Generally, organizations are reluctant to share knowledge because of the threat of industrial espionage and are careful to guide employees' attention toward these issues [78]. Therefore, knowledge acquisition and application have to be protected from unauthorized dissemination or modification [79]. The notion of secure knowledge management has recently emerged, that is knowledge management practice based on principles of security and privacy [80]. Secure knowledge management has become a more critical practice for interorganizational collaboration, and has to be shaped with respect to each specific collaboration, regulating the exchange of data, designs, and documents that generally contain confidential data [81].

In the qualitative data collected in this study, evidence for a mixed picture emerged. Some organizations, with an open organizational culture, had very few restrictions (Table 8, P13), while others gave high priority to restricting access. In some cases, this was due to the fact that organizations are required to protect the information, e.g., data related to their customers (Table 8, P16-data security).

In fact, several organizations recognized the importance of this knowledge maturing activity. In those organizations, this activity is perceived as normal practice, and knowledge is channeled through appropriate users to avoid dissipating it. Three reasons emerged from the data to justify restricting access. The first is that trust is considered a prerequisite for knowledge sharing and collaboration. Two interviewees mentioned that they consider restricting access as a measure to create a protected space in which they can more freely exchange knowledge because they trust each other (Table 8, P16-trust and P17). This is in line with findings from Politis [82] who stated that a "*trustworthy*" intention among coworkers was key for knowledge acquisition and sharing. The second is to channel information and to avoid information overload. Intensive sharing of knowledge and information might lead to a counter-productive overload situation in which the users are not able to find the right

information and knowledge (Table 8, P18). This resonates well with issues already raised by Toffler [83] that are present in researched organizations. In many cases, considerations of data security motivated by the fear of losing competitive advantage are seen as important (Table 8, P15). Finally, interviewees also gave reasons against restricted access to resources (from the perspective of knowledge maturing). In total, 14 comments suggest that restriction means obstructing people's access to knowledge, which they view as a prerequisite for knowledge maturing to happen. They even see the current level of support for protecting and restricting access as a barrier for knowledge development in the organization (Table 8, P19). There was also the notion of differentiating this activity with respect to the actual contents (Table 8, P14).

The issue of how to cope with cases where expertise is distributed across organizations is an interesting challenge, as treating knowledge as something to be matured separately in single organizations could itself be problematic. Several organizations also saw a movement toward more collaborative knowledge maturing processes as part of a "bundle" of practices, inevitably bound up with the "management of change" and significant shifts in organizational culture.

Overall, the stories told were from a wide variety of organizations align with the view that the knowledge maturing model is one of a number of possible perspectives for engaging people in discussions about organizational change, learning, and development. Furthermore, some participants could see how collaborative knowledge maturing processes could be a key part of achieving a more fundamental transformation, where the quality of choice, information, and commitment are improved in a move toward double-loop learning, where broader questions about organizational goals are also addressed. Interorganizational learning and knowledge development can be a particular challenge in this respect.

Innovation, learning, and knowledge maturing activities within and across organizations are essentially social processes and that both personal networks and cross-organizational networks need to pay attention to building relationships to support development, as well as focusing upon substantive issues. There is also a need to consider the interaction between formal and informal approaches to learning, skill development, and knowledge creation as a particularly effective way forward, not only for enhancing personal professional development, but also as a means to improving organizational effectiveness.

Finally, there were some clearly differentiated comments related to the tension around external collaboration. Already identified as part of the ethnographically informed study, knowledge and information exchange with external contacts in an individual's social network was a very essential part of everyday work (even to an unanticipated degree). Also, external sources were seen by interviewees as essential for triggering change in an organization. Organizations tend to be very cautious toward external collaboration, as they see the risk of losing competitive advantage, or need to ensure compliance to externally induced regulations for data protection.

Summing up, the use of interviews instead of surveys not only proved necessary to create a common understanding of knowledge maturing activities so that interviewees could assess their importance, support, and success with respect to their organization or organizational unit. This approach also provided us with further insights concerning the following questions: 1) Why do organizations deem the knowledge maturing activities important, e.g., securing organizational resources that are of high relevance as an object, which is pursued when participating in the activity *"9—restrict access and protect digital resources,"* (P14); or to increase knowledge sharing as an expected outcome that is intended when allowing the knowledge to reach only specific target groups (P16). 2) How do organizations support knowledge maturing activities with organizational and ICT-based measures, e.g., in the form of explicit rules to support *"6—reflect on and refine work practices or processes"* through a recurring evaluation (P3); or in the form of tools established to support *"12—assess, verify, and rate information"* by using supportive software (P11). As our main focus was to inform the design of supportive ICT-based measures, we took a closer look on the tool dimension and found a large number of software tools that supported knowledge maturing, e.g., the usage of wikis and virtual rooms for supporting *"12—assess, verify, and rate information"* in communities (P11). 3) In what contextual settings do knowledge maturing activities thrive in organizations. For example, it seemed easier for our interviewees to support the activity *"6—reflect on and refine work practices or processes"* in smaller settings with fewer employees than in larger ones (P4). The approach also helped us in structuring information on what division of labor, i.e., what roles, were relevant for knowledge maturing activities and how they could be identified, e.g., the identification of experts via process analysis (P7).

4.2 Organizations and Knowledge Handling

The findings show that knowledge activities were perceived as being similarly important, supported, and successful in all organizations independent of the strata, (i.e., the organizations' sizes, sectors, and particular interest the level of knowledge intensity). This is in line with previous results as described by Felstead, et al. [84] and Holsapple and Joshi [85]. Table 14 (see Appendix, available in the online supplemental material) presents the mean values of perceived importance, support, and success of the 12 knowledge maturing activities for the three clusters.

Clearly, clusters were separated from each other with respect to the perceived success of knowledge maturing activities. With the exception of the two activities *"3—keep up-to-date with organization-related knowledge"* and *"9—restrict access and protect digital resources,"* both success and support are perceived as being quite different in all three clusters. Cluster I receives the highest perceptions of success and support for all knowledge maturing activities. Cluster III receives the lowest perceptions of success and support for all knowledge maturing activities. The mean values for organizations allocated to cluster II lie in the middle between the values for cluster I and cluster III, with a fair distance to either. The two exceptions are activities *"3—keep up-to-date with organization-related knowledge"* for

which clusters II and I have similar mean values and *"9—restrict access and protect digital resources"* for which clusters II and III show similar mean values.

This pattern, cluster I with the highest values, cluster III showing the lowest values, and cluster II lying between the two, also holds for the two sets of questions on perceived support and perceived success concerning knowledge maturing phases (see Table 15 in the Appendix, available in the online supplemental material) as well as the estimated overall success of knowledge maturing (mean values: I: 6.11, II: 5.20, and III: 4.34). Cluster I, thus, comprises the *best performing* organizations, cluster II *people- and awareness-oriented* organizations, and cluster III comprises *hesitant formalists*.

The *best performing* organizations in cluster I can be characterized as highly successful with respect to the support for and the success of knowledge maturing. This holds true for all phases and all activities and both the fostering and support they give, as well as how successful they are perceived. Compared to organizations in the other two clusters, they seem to be particularly successful with respect to the phases *"distributing in communities"* (mean difference cluster I-II: 1.16) and *"formalizing"* (mean difference cluster I-II: 1.00) and, thus, in both informal and formal phases of the knowledge maturing model, as well as the activities *"1—find relevant digital resources"* (mean difference cluster I-II: 1.54), *"5—reorganize information at individual and organizational level"* (mean difference cluster I-II: 1.20), and *"8—share and release digital resources"* (mean difference cluster I-II: 1.50).

People- and awareness-oriented organizations in cluster II perceive themselves as lying in the middle between *best performers* and *hesitant formalists*. With respect to the success of the performance of individual-oriented maturing phases *"expressing ideas"* (mean difference cluster I-II: 0.65; II-III: 0.81), *"appropriating ideas"* (mean difference cluster I-II: 0.75; II-III: 1.08) and *"ad hoc training"* (mean difference cluster I-II: 0.82; II-III: 1.24) as well as with respect to: awareness-oriented activities, such as *"3—keep-up-to-date with organization-related knowledge"* (mean difference cluster I-II: 0.18; II-III: 1.86) and *"12—assess, verify, and rate information"* (mean difference cluster I-II: 0.66; II-III: 1.30); and people-oriented activities, such as *"10—find people with particular knowledge or expertise"* (mean difference cluster I-II: 0.91; II-III: 1.40) and *"11—communicate with people"* (mean difference cluster I-II: 0.95; II-III: 1.48), they are closer to the best performers. With respect to the phase *"formalizing"* (mean difference cluster I-II: 1.00; II-III: 0.41) as well as with respect to the activity *"1—find relevant digital resources"* (mean difference cluster I-II: 1.54; II-III: 1.21) oriented toward the handling of digital resources, they are particularly close to the laggards.

Although this group also has the largest variance, the *hesitant formalists* in cluster III are organizations that perceive themselves as performing the worst with respect to all the activities and phases of knowledge maturing and also with respect to the perceived overall success. They perceive themselves as comparably supportive and successful with respect to the *"formalizing"* phase (mean: 4.52) and the activity *"9—restrict access and protect digital resources"* (mean: 4.55). With respect to the *"ad hoc training"* (mean: 3.59) and *"distributing in communities"* (mean: 3.86) phases as well as the activities *"1—find relevant digital resources"* (mean: 3.45), *"8—share and release digital resources"* (mean: 3.31) and *"6—reflect on and refine work practices and processes"* (mean: 3.41), they perceive themselves as performing particularly badly compared to interviewees' perceptions in the other two clusters.

In clear opposition to the comparably large differences between the clusters with respect to perceived support and success of most knowledge maturing activities and phases, the clusters score similarly concerning the perceived importance of knowledge maturing activities. Somewhat pronounced differences can only be seen with respect to activity *"1—find relevant digital resources."*

These results, of generally close perceptions of the importance of activities, underline the differences between the clusters with respect to support and success as being particularly pronounced. The results, thus, strengthen our general impression that the interviewees' reflections about the organizational units they represented were thorough.

The cluster solution, therefore, allows us to separate organizations by their perceived support and success of knowledge maturing. It is particularly interesting to remember that the distribution of organizations with respect to size, sector, and knowledge intensity is fairly balanced between the clusters (see Section 3.3), so that we have high performers as well as *hesitant formalists* in every industry and every size of organization, no matter whether the industry is considered knowledge intensive or not.

Viewed in the light of Hansen et al.'s [86] differentiation of knowledge strategies into codification and personalization, the *hesitant formalists* (cluster III) can be circumscribed as pursuing primarily a codification strategy, while the *people- and awareness-oriented* organizations (cluster II) can be circumscribed as pursuing primarily a personalization strategy. The *best performing* organizations (cluster I) could be assessed as pursuing a well-balanced mix of codification and personalization. The particularly high scores concerning support of people-oriented activities such as *"11—communicate with people," "10—find people with particular knowledge or expertise," "4—familiarise oneself with new information,"* and *"6—reflect on and refine work practices or processes"* in this cluster indicate that the *best performing* organizations lean toward personalization. Thus, in the sample, organizations that opted for a personalization strategy, i.e., *people- and awareness-oriented* organizations in cluster II, or a well-balanced mix of personalization and codification strategy with a slight emphasis on personalization, i.e., *best-performing organizations* in cluster I, presumably outperformed organizations that primarily relied on a codification strategy.

4.3 Implications for Design

Knowledge maturing (i.e., collective knowledge development) occurs in activities that are deeply embedded in work practices, which makes it difficult to produce generalizable approaches to designing systems that support it. This is even more important when moving away from (prescriptive) enterprise top-down system toward (enabling and personalized) learning and maturing environments, which give more flexibility for different patterns of tool appropriations.

A key role of the knowledge maturing activities described in this paper was to pave the way toward systematic engineering of such learning and maturing environments by

- identifying meaningful activities (i.e., clear focus on knowledge maturing, and on the right level of abstraction) that can be used as design categories;
- prioritizing activities that need support based on the organization context and problem analysis; and
- analyzing varying characteristics of such activities along different levels of maturity of the knowledge that is dealt with and possibly other contextual factors.

The latter was a major insight from the first design iterations: Technical support for activities needs to take into account the maturity of the knowledge to which the activity contributes. *"1—find relevant digital resources"* has exploratory, inspirational characteristics at an early stage, while becoming more targeted and focused at later stages (in line with findings from library science, such as [87]). Similarly, support for "*12—assess, verify, and rate information*" can range from (individual) selecting and filtering, via collaborative rating functionality, to formalized approval workflows at later phases of knowledge maturing.

Toward that end, the empirical study about knowledge maturing activities reported in this paper has been embedded into an iterative (four year) design process, intertwining empirical, and design-based research as part of the MATURE project [88]. In this project, several design studies have been conducted (as "critical experiments in design"), which in turn have evolved into four demonstrators, each focusing on different strands of knowledge development: knowledge about tasks and processes (process management); factual knowledge (content management); knowledge about other people (competence management); and knowledge how to describe and organize things (taxonomy/ontology management). In each of these demonstrators, the activities have been used to 1) define and refine the use cases of the system to be designed, and to 2) elicit specific characteristics of these activities.

As one example, this was a key to understanding and designing novel approaches such as the people tagging driven approach to competence management [89]. "*2—find people with particular knowledge or expertise*" is important for individuals finding solutions to the problem at hand, but also for finding candidates for forming communities, or for composing project-specific teams with a certain competence profile. However, each of these cases operate at different levels of maturity and, thus, need different levels of formality of the underlying data. Through a clear conceptualization of the same activity with distinct characteristics, MATURE has been able to provide tool support that links these different formality levels so that neither users are scared off because of overformalization, nor that lack of precision limits the usefulness of more complex functions.

While the activity-oriented design approach toward reusable design solutions has turned out to be more complex than originally envisioned, the knowledge maturing activities as design concepts for knowledge maturing were highly useful. They were a useful dimension for a general design framework for knowledge maturing support, but it was crucial to include other dimensions, such as the maturity of knowledge. Furthermore, they were used as the basis for activity-related indicators that make knowledge maturing traceable through logging the interactions of the user with the system. As the knowledge maturing activities are meaningful not just from a technical perspective, this enables learning analytics at the workplace, where the interpretation log data can be tied to findings from other fields (such as HR).

4.4 Limitations

The concept of knowledge maturing is complex. This was known in advance, as it is a distinct and new lens through which to look at the phenomena surrounding knowledge handling in organizations, and thus the concept was new to all interviewees. This was also a primary reason why it was decided to conduct interviews in the first instance. Thus, the interviewer-interviewee relationship and the interviewers' competence in appropriating an understanding of knowledge maturing in the context of the organization represented by the interviewee were crucial. This required substantial effort in preparing clearly defined concepts, with further explanations and examples to ease the task for the interviewer. Moreover, the study coordinators offered intensive interviewer training and kept in close contact with interviewers to transfer lessons learned and to help overcome barriers toward understanding. When interviews were conducted by different interviewers, there may be differences in answers [90]. However, no significant differences between cases with respect to the interviewers were found.

The research team was well aware that the concepts of importance and, in particular, support and success would deserve a thorough investigation, utilizing a number of variables that should be questioned for each, see, e.g., [91], [92]. However, we are confident that the depth of these concepts has been explored in the course of the interviews through interviewer-interviewee dialogues, which appropriated the concepts to the context of the organizations that the interviewee represented, and which were documented for each activity.

Although the interview aimed at (parts of) organizations, the personal scope (responsibility, interests) of the interviewee may have had an influence on the interviewees' perceptions. Statistical tests were performed and allowed to conclude that personal background, e.g., technical versus business or HR, had no influence on participants' answers.

As we conducted one interview per organization, different interviewees within the same organization might have given different answers. However, potential influences could at least be minimized as interviewees who had a good command of the knowledge and learning management in their organization were selected. A follow-up in-depth study with six organizations and one network of organizations in which we employed a multistakeholder perspective with interviewees representing several organizational units confirmed that the selected informants had a well-balanced overview of their organizations and were able to concentrate on the similarities between organizational units.

Our sample size ($n = 126$) certainly cannot represent the enormous variety of organizations across Europe, which is why we concentrated on medium-sized and large organizations that are supposedly more similar than small organizations, with respect to their way of handling knowledge maturing. Conducting interviews by telephone or in person certainly limited the number of organizations that could be investigated, but enabled us to choose interview partners carefully. Thus, we are confident that by adopting this approach, we created a common understanding of the complex phenomenon of knowledge maturing between interviewees and interviewers, and therefore gained robust data.

5 Conclusion

This paper presented the results of a qualitative and quantitative empirical study of the complex phenomenon of knowledge maturing, which was described with the help of knowledge maturing phases and 12 knowledge maturing activities that were studied in detail. All but one of the knowledge maturing activities were deemed important for increasing knowledge maturing in the interviewees' organizations. The interviewees attributed high importance to the knowledge maturing activities and to knowledge in general, which is perceived as a strategic resource to improve organizational practices and obtain competitive advantage. The knowledge maturing activity *"9—restrict access and protect digital resources"* was controversial. Some organizations deemed it very important to ease free knowledge sharing within the organizational boundaries, while protecting valuable knowledge assets from diluting to competitors. Other organizations found it generally detrimental to the process of knowledge maturing. For the other 11 knowledge maturing activities, importance was perceived as significantly higher than support, and support was perceived as significantly higher than success of performance. Based on these results, portfolios contrasting importance/support and importance/success were created. In this analysis, the knowledge maturing activities *"6—reflect on and refine work practices or processes," "10—find people with particular knowledge or expertise,"* and *"12—assess, verify and rate information"* were identified as being the most interesting. All three were deemed to be important, but were less supported and less successfully performed, and thus carry the highest potential when designing organizational and information and communication technology support for knowledge maturing.

Hence, these results encourage organizations to support those knowledge maturing activities that are deemed to be most critical through organizational and ICT solutions. These can be determined on the level of perceived importance and on the level of the existing initiatives within these organizations, which can be compared to the results of other organizations presented in this paper, as they seem to be valid across organizational size, sector, and knowledge intensity. We have further investigated these results and provided services, which aim to improve the support of knowledge maturing activities. The support and success of knowledge maturing activities allow organizational learning to improve, because the right knowledge is disseminated and employees are able to connect to each other, share and codevelop knowledge, acquire content and information, and apply it in their work.

However, knowledge management initiatives were not widely available in all organizations, and thus effective and broader support is needed. Several interviewees affirmed that their organizations were only starting to think of knowledge as a strategic resource. They were actually working to improve knowledge management and to diffuse a culture based on the sharing of appropriate knowledge, to capture what exists in the organization and learn how to apply it within daily work practices, thus capitalizing on their own intangible assets and resulting in higher profits. According to the interviewees, many organizations worked in value networks and share knowledge, risks, costs, and tangible assets with external actors who require a better and broader focus on the knowledge maturing activities involving these external actors. In fact, the establishment of consortia or project collaboration permits the development of a network with other actors, thus increasing the maturing of knowledge within a single organization. Working together, the knowledge is mutually influenced, and consequently the potential to mature knowledge could increase. The exchange of good practices and initiatives with other actors can allow individual organizations to learn from others and to improve the application of organizational knowledge, creating new linkages between internal and external knowledge.

The concepts of knowledge maturing, specifically the phases and activities, have proven to be suited for investigating processes and practices of knowledge development. Interviewees found it easy to identify cases of knowledge maturing in their organizations. An interesting avenue for future work could be to map the concepts of knowledge maturing against other models on knowledge development [12], [93], and reflect on their contributions. The concepts 1) offer an inclusive view on collective learning and knowledge practices traversing the levels of individuals, communities, and organizations and 2) are geared toward designing organizational and ICT-based measures supporting knowledge activities.

Confronted with the decision of which knowledge strategy [86] to pursue within an organization or in a partnership or network of organizations for knowledge cooperation, our results indicate that organizations opting for a personalization strategy or in particular a mix of personalization and codification strategy with a slight emphasis on personalization, might expect to perform better with respect to knowledge maturing than organizations choosing a codification strategy. The concept of knowledge maturing activities, as presented in this paper, can guide organizations in implementing ICT-based or organizational measures to improve goal-oriented organizational learning and knowledge handling. This can be achieved by focusing on the changes in maturity and in the type and nature of knowledge from emerging ideas via informal and formal sharing, and the further development and refinement of the knowledge in collectives within and across organizations until it is institutionalized through new products, services, processes, and practices. This focus

on knowledge strategy, the phases of knowledge maturing, and the key knowledge maturing activities identified, *"6—reflect on and refine work practices or processes," "10—find people with particular knowledge or expertise,"* and *"12—assess, verify, and rate information,"* helps organizations to revisit their initiatives and organizational and ICT-based support for organizational learning and knowledge management, and can inspire them to further develop.

ACKNOWLEDGMENTS

This work was cofunded by the European Commission under the Information and Communication Technologies theme of the Seventh Framework Programme, Integrating Project MATURE (Contract No. 216356, http://mature-ip.eu).

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