Open Source Computer-Mediated Collaborative Community Learning

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Abstract—**The concept of Open Source dates back to early 1970s when IBM pioneered by releasing parts of its operating systems to the public. Since then, the Open Source (FLOSS) paradigm has and continues to significantly influence the software industry and the broader economic ecosystem. It has been diffused across numerous other sectors that adhere its philosophy, its open and collaborative model of design as well as its development and distribution model. In this paper we examine the OSS diffusion and impact in the educational context while we discuss the benefits emanated from its adoption that lead to the derivation of new dimensions of educational interactions, namely the community. We investigate how open source software contributes into bringing the learner closer to the *community*, which has evolved into a key actor in the online learning network. Anchored in this notion, we propose a holistic typology of learning interactions in distance education, which includes *four key entities* of knowledge manipulation: (a) *student/learner, (b) instructor, (c) knowledge/content,* and *(d) community*. We examine the notion of the *community* in the context of computer-mediated collaborative learning along one specific educational context, namely computer science education and in relation to one distinct type of learning application: collaborative development environments. Our analysis identifies the need for a community-centered, collaborative, knowledge management e-learning platform, aligned with the knowledge-management life-cycle model [13] and the needs of a knowledge management system. Aiming to fill this gap, we propose an open source, community-centered, collaborative knowledge management, e-learning platform that addresses the need for a knowledge sharing environment that supports advanced capabilities in distributed, collaborative engineering and management of software systems among students.**

Keywords-collaborative e-learning; community learning; open source e-learning platforms; knowledge-management platform

I. INTRODUCTION

Over the last two decades the open source phenomenon has evolved as one of the most significant community collaboration paradigms, having an amalgam of technical, organizational and cultural elements. Open source software (FLOSS) refers to a program or part of a program developed under an open, public and collaborative mode which provides access to the source code for use, modification (i.e., changes and/or improvements) and redistribution in compliance with the copyright license under which it has been distributed [12]. However, the concept of open source extends to other sectors beyond the software industry who adopt its philosophy [32], its open and collaborative model of design and co-creation as well as its development and distribution modes.

In the context of education, open source software can be seen as the natural environment for learning [6]. On the one hand, the open learning environment promotes the linkage and collaboration with the global community as well as the implementation of innovative teaching and learning practices, while on the other hand it enhances user access and control, encourages freedom to choose and endorses quality [7]; stimulating this way conceptual development.

However, despite the early signs of diffusion of open source software in the educational community, one can observe a tendency towards individual learning tools rather than collaborative ones that enable ubiquitous learning and knowledge sharing processes. To our knowledge, in the context of, collaborative development e-learning platforms, there are only a few such systems available in the current literature, which are mostly concerned with proprietary solutions. In order to fill this gap, we focus our analysis on open source products, placing emphasis on the development of a collaborative e-learning platform that aims at bringing learners closer to learners (i.e., learner-centered) and to the broader educational community (i.e., community-centered).

The remaining of this paper is organized as follow. Section II initially provides an introduction of the dimensions of learning and focuses on collaborative learning and computer-mediated collaborative learning processes. Subsequently, it details how the emergence of the open source paradigm stimulated new dimensions of e-learning and introduces the notion of the *community* as a key dimension in learning interactions. Finally, Section II examines the *community* dimension in the context of computer-mediated collaborative learning along one specific educational context, namely computer science education and in relation to one distinct type of learning application: collaborative development environments for software development activities. This section concludes with an overview of the existing collaborative development platforms and identifies the need for community-centered collaborative e-learning environments. Section III presents an open source, community-centered, collaborative e-learning platform (TeamWeaver) that supports the need for a knowledge sharing environment with advanced capabilities in distributed, collaborative engineering and management of software systems among students. TeamWeaver has a high educational potential as it provides a decentralized, personalized, context-sensitive and semantic-based framework for sharing knowledge, about software implementation that is seamlessly integrated into a software Integrated Development Environment (IDE). Finally, Section IV provides some concluding remarks and future research areas.

II. COLLABORATIVE COMMUNITY E-LEARNING

A. Collaborative Learning and Computer-mediated Collaborative Learning

Current theories of learning (i.e., constructivism) describe learning as the process of constructing understanding by dealing with problems, seeking solutions, and organizing knowledge. Constructivists and social constructivists [1] view knowledge as constructed by learners through social interaction with others [45], [46], [47] and argue that constructivism learning can also be applied in distance education and educational technology [43], [44].

Anchored in this notion we portray, learning activity in three dimensions describing distinct aspects of the learning process and context, (figure 1): the *learning mode* (individual, collaborative learning [15]), the *place dimension* (co-locative, distributed learning), and the *time dimension* (synchronous, asynchronous learning).

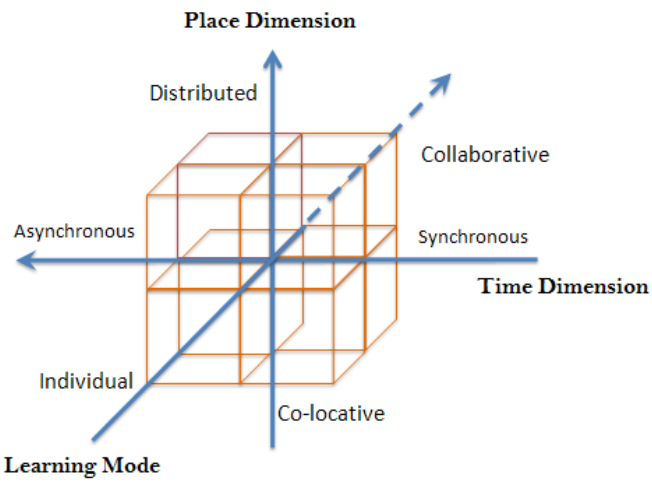


Figure 1. Dimensions of learning

Learning can be both an individual and a collaborative process[2]. The "manifestation of a culture of collaboration" [6] (p.47) has always been inherent in the sphere of education, which has a long tradition of collective development, review and distribution practices. Theories of learning support this notion and denote that collaborative dialogue is essential in engaging learners' conceptualizations towards directions that enhance the refinement of knowledge and advancement of understanding, both through instructor-led argumentation [30], [18], [31] and social interaction with peer learners [45], [46], [47].

Moving into the information technology era, new kinds of interactions have emerged through alternative arrangements of space, time, resources and collaboration for learners and teachers worldwide. Technology has profoundly impacted the learning paradigm and has strengthened the need for computer-mediated collaboration (i.e., synchronous and asynchronous). The Internet, from an ideal medium for learning content exposition (i.e., individual-asynchronous-distributed learning square in figure 1), has evolved into an ideal collaborative learning environment, which allows learning to be both time and place independent [48] while stimulating conceptual development via instructor-led, student-led and community-led collaborative dialogue.

Collaborative learning (CL) [3] is founded in the social constructivism theory of learning which places emphasis on the social context in which learning takes place [45]. Vygotsky [45] highlights the critical importance of the interaction with people including the community of learners and teachers. More specifically, he stresses that collaborative learning among students or between students and a teacher is critical for the advancement of each student [50]. CL is anchored in the attribute of effective learning, encompassing three distinct elements[4]: (a) *active learning and construction of knowledge*, (b) *cooperation and teamwork in learning*, and (c) *learning via problem solving* [1]. The benefits of this learning approach are:

- increased student involvement in academic tasks [41], which endorses the creation of problem solving and critical thinking skills [3], [24], [26], [27], [38];
- enhanced communication, which is equal in participation, since the traditional levels of exclusion from discussions are minimized [37], [28] and
- enhanced student learning and achievements [23], [36] and increased student satisfaction with the learning experience [3], [24], [41].

These benefits make CL a more effective instructional method than the traditional ones [22], [23], [36].

Computer-mediated collaborative learning (CMCL), on the other hand, realizes the benefits of collaborative learning (CL) via digital networks. CMCL fosters the development of critical thinking and problem solving across distributed learner groups by utilizing innovative technology-mediated learning

1 Social constructivism, a widely accepted constructivism learning theory, emphasizes that learners obtain knowledge and make sense of their experiences through collaborative communications [45], [50].
2 Following [15] we define "learning modes" as: (a) *collaborative* an instruction method in which students work in groups toward a common academic an academic goal; and (b) *individual* an instruction method in which students work individually at their own level and rate toward an academic goal.
3 Collaborative learning is defined as "an activity that is undertaken by equal partners who work jointly on the same problem rather than on different components of the problem" [42].
4 As such, CL is considered as the principal method of operationalizing them [21].

processes. Technology enables distant learners to collaborate effectively online both synchronously and asynchronously. Studies indicate that computer-mediated communications result in "communication that is more equal in participation than face-to-face discussion, with those who are traditionally shut out of discussions benefiting most from the increased participation" [49] (p: 473). This improved communication between learners and teachers can lead to improved learning practices [51]. As such, the effectiveness of collaborative learning over traditional methods [22] (depicted in enhanced student involvement [19], satisfaction [18] and engagement in the learning process [17]), can be further enhanced though digital networks.

However, despite the importance of collaborative learning (in both traditional and computer-mediated networks), one can observe a tendency towards individual, asynchronous online learning tools and platforms rather than collaborative (synchronous and/or asynchronous) ones that enable ubiquitous learning and knowledge sharing processes.

B. FLOSS and the notion of the "Community" in the learning process

The diffusion of open source software in educational institutions began during the mid-1970s as a result of the Unix movement [35] and its adoption is still growing aiming towards "revolutionizing education" [39]. As such, open source can be seen as the natural environment for education [6]. This community collaboration paradigm that enables users to access, modify and redistribute source code has successfully reached the early adopter segment of the educational community. The factors that endorse this acceptance range from economic and technological to pedagogical and philosophical ones [25], [35]. The premise behind open source and its inherent freedoms[5] harmonize with the basis of the educational core while it enables learners and instructors to become active participants of the learning and teaching process. For educators, FLOSS provides an exceptional innovative option in the teaching process while at the same time it acts as an enabler of knowledge sharing within an intra/inter-class and intra/inter-University level. For students, FLOSS acts as a medium for enhancing their active participation in the learning process both as knowledge builders and as creators via online distributed and collaborative networks.

Community: a key actor in educational interactions

The diffusion of open source software in the educational community has increased significantly collaborative learning and teaching practices, driven by social modes of interaction and knowledge exchange across the stakeholders of this community. The FLOSS paradigm has changed the relationship of knowledge creation and consumption, as well as the teaching and learning processes, bringing this way the learner closer to the *community*, which has evolved into a key actor in the online learning network, enabling "effective learning" practices [5]. As such, this new form of interaction in distance education can expand the existing typologies of [29], [2]. In 1989, Moore [29] introduced the first typology of interactions in distance education, presenting the three most common ones: *student-student*, *student-teacher* and *student-content*. Anderson and Garrison [2] expanded this typology by adding three additional forms of interaction: *teacher-teacher, teacher-content, content-content*.

In the context of this paper, we propose a holistic typology of educational interactions in distance education (see figure 2), which depicts *four key entities* of knowledge manipulation: (a) *student/learner*, *(b) instructor* and *(c) knowledge/content*, we propose the introduction of one additional stakeholder namely the *(d) community*. Figure 2 presents these actors and portrays their distinct educational inter-relationships as: *I-S, I-K, I-C, S-K, C-S, C-K, I-I, S-S, C-C* and *K-K*. As it can be seen, within these ten types of educational interactions, the following four new-additional *community-centered*, educational interactions[6] are being introduced, namely:

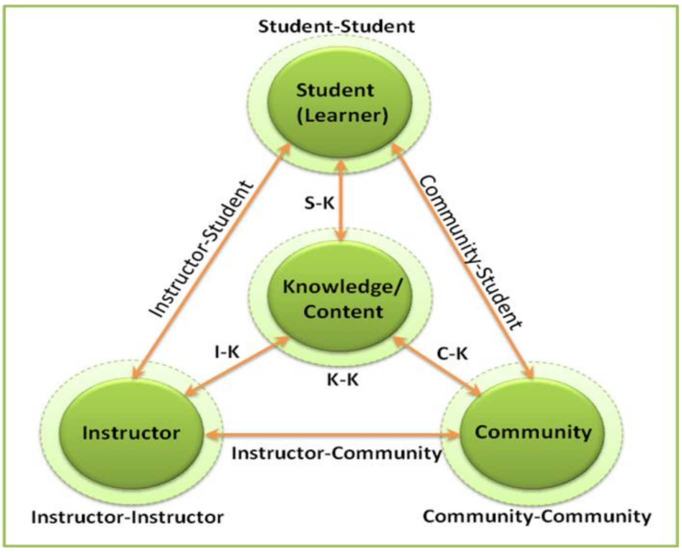


Figure 2. A typology of types of educational interactions in distance education

- *C-S: Community-Student interaction*

Online learning supports community-student interactions in a variety of ways, ranging from synchronous to asynchronous, utilizing different types of formats (i.e., text, audio and video) and across distinct online communities (i.e., theme-specific and broad-theme or multidisciplinary communities, intra and inter-University communities, local and global communities, communities with a small and large number of participants, formal and less formal, etc.). Anchored in the FLOSS paradigm, this form of interaction creates the opportunity for individual learners to enjoy enhanced knowledge consumption benefits while at the same time act as knowledge creators, reciprocating this way to the broader educational community. Community-student interactions enhance the interest and motivation of learners, which results in increased levels of involvement and engagement in the learning process, stimulating this way conceptual development.

[5] Free Software Definition [14].

[6] For detailed description of the remaining six forms of interactions, please refer to [29], [2].

TABLE I. COLLABORATIVE E-LEARNING TOOLS

Type of application	**Description**	**Type of interaction**										**Application Examples (*indicative list*)**	
		I2S	I2K	I2C	S2K	C2S	C2K	I2I	S2S	C2C	K2K	Open source or free software solutions	Proprietary solutions
1. Application sharing	enables two or more users to access a shared application or file repository from their respective computers simultaneously in real time	√						√	√			Remote Desktop, TeamViewer, Remote Administration	intelliAdmin, Box.net
2.Communication tools	communication channels established via instant messaging, IRC, web-conferencing applications, exchange of multimedia and mostly textual content via e-mails.	√		√		√		√	√	√		MSN, Skype, GoogleTalk, AOL, Gmail, Hotmail	WebEX, CuteCom, MS-Outlook, IBM Lotus Notes
3.Computer-based assessment tools	use of computer technology to enhance the assessment of the learning process	√										BTL Engage, DeL eTools, Onyx, TOIA, XQuestion, Hot popatoes	Questionmark Perception, Respondus, TCExam, e-Examiner, AQuRAte, Minibix
4.Collaborative development environment	an online virtual meeting space where classmates (users) can work together in a distributed, asynchronous and collaborative manner	√				√			√	√	√	Mylyn, Corona, Jabber, Nepomuk	IBM Jazz, Collb.Net, Novell, CollabVS
5.Discussion forum	online discussion site where people can interact with questions, answers and discussions on a given topic					√	√		√	√		phpBB, Vanilla, YaBB, SMF	vBulletin, Invision Power Board
6.e-learning platform	realization of an virtualized environment with real-time audio-visual support for conducting e-courses over the Web, usually offering immersive and application sharing facilities, knowledge creation and management modules, e-whiteboard functions, e-scheduling etc.	√	√	√	√				√		√	Moodle, Sakai, docebo, Claroline	Angel LMS, Blackboard, Centra
7.Knowledge management	a platform for storing, controlling, revising and publishing content; usually collaborative editing is also supported	√	√		√	√		√	√		√	Alfresco, GoogleDocs, MS-Office Live Workspace Subversion, Joomla	BSCW, HyperOffice, MS-SharePoint, JIRA
8.Knowledge creation and information sharing	Web application that allows the easy creation and editing of multimedia content i.e. Wikis, Blogs etc.	√	√	√	√	√	√				√	YourWiki, Blogger, WordPress,	-
9.Web/News feed	provision of frequently updated content over the Internet. Data are usually distributed in the form of Webcasts, Podcasts, RSS etc. or via newsgroups and mailing-lists	√	√	√	√	√	√			√		GoogleGroups, Yahoo pipes, RSS Bandit, iTunes, FreeForAll	FeedDemon

- *I-C: Instructor-Community interaction*

Instructor-community interaction via the Internet encourages the development of special online communities that enhance the knowledge exchange, provide deeper understanding and new insight across diverse thematic areas (i.e., existing and novel themes). Anchored in the FLOSS principles, this form of interaction supports the relationship between knowledge creation and consumption among the stakeholders of the educational community and individual instructors.

- *C-C: Community-Community interaction*

Anchored in the principles of the FLOSS paradigm and supported by online medium this form of interaction has emerged as a highly innovative model of peer-production. Community-community interaction enables cooperation and collaboration between and across digital networks, contributing this way to the development of online collaborative learning communities that unite interacting stakeholders (i.e., sharing a common thematic interest) all over the world. The significance of peer-to-peer interaction has been illustrated by many theorists in the area, depicting the emerging gains in the conceptual development of learners ([9], [34] among others) and in the development of communities of learning [40]. The communication of an idea in community-community interaction enhances the interest and motivation of interacting parties, resulting in enhanced levels of involvement and engagement in the learning community.

- *C-K: Community-Knowledge/Content interaction*

Supported by Web and stimulated by the FLOSS paradigm principles, the Community-knowledge/content interaction has emerged as a highly critical component of knowledge creation and knowledge sharing, based on large-scale collaborative activities of the educational and the broader community. This peer-production mode of knowledge and content generation facilitates the learning process; given the knowledge creation and diffusion that provides deeper understanding of the learning content across key actors of the educational community.

Currently, one can identify numerous e-learning software applications and tools. However, although they can be used for diverse educational purposes, ranging from general (i.e., word processing, presentation, etc.) and domain specific tools (i.e., statistical, engineering, medical applications, etc.), to collaborative ones; these tools enable only some of the proposed types of educational interactions. A classification framework of the existing e-learning tools, covering a range of educational modes and interactions, is presented in table I. This table classifies e-learning applications, based on: (a) *the (generic) type of application area* (i.e., communication tools, computer-based assessment tools, collaborative development environments, etc.) and (b) *the type(s) of interaction(s) that they enable* (i.e., based on the proposed ten types of educational interactions, see figure 2) and provides a number of examples of such collaborative e-learning applications, both proprietary and open source. As it can be seen, different types of e-learning applications address different forms of interactions. However, the majority of existing tools facilitate only a few of these forms of interactions, including community-centered educational interactions.

C. Open source computer-mediated collaborative community learning tools in computer science education

The introduction of FLOSS tools in education strengthens the concept of the "*community*" as a critical stakeholder in the e-learning process. In order to analyze its impact in the context of computer-mediated collaborative learning, we examine it along one specific educational context, namely computer science education and in relation to one distinct type of learning application: collaborative development environments.

In the context of ***computer science and software engineering (CSSE) education,*** the usage of FLOSS tools offers significant benefits across three areas [11], namely: *(i) channel:* expanding teamwork at an inter-community level; *(ii) method*: providing students with exposure to the peer-review and collaborative creation process; and *(iii) technology*: providing free (or low-cost mainly for supporting services) software technology to students.

However, in order to identify the benefits of FLOSS tools in education, one should also consider the *"level" of collaborative interaction* (i.e., from macro level: broad collaboration, to individual level: no collaboration). In the context of distributed software development, collaboration can occur not only at a micro level (i.e., intra-university (intra-class and inter-class) but also at a meso (i.e., inter-university) as well at a macro level (i.e., inter-community), providing students with tremendous benefits sought by their interactions and collaboration with the cross-institutional community as well as the broader open source community (see table II).

TABLE II. BENEFITS OF OPEN SOURCE IN EDUCATION ACROSS DIFFERENT LEVELS OF COLLABORATIVE INTERACTION

		Level			
		Macro	**Meso**	**Micro**	**Individual**
Aspect	*Type of collaborative interaction:*	Broad/open	Restricted/ closed (pre-specified)	Restricted/ closed (pre-specified)	No inter-action
	Channel Level of teamwork	inter-Community *(i.e., professional & academic community)*	inter-University	intra-University *(i.e., intra/ inter-class)*	No teamwork
	Method Peer review and collaborative creation process	√	√	√	-
	Knowledge sharing	√	√	√	-
	Level of Support	Community	inter-University student	intra/inter-class student	-
	Technology	Free (or low-cost) software technologies			

In CSSE education, software development is considered to be a collective, complex, and creative effort. Usually, computer science students rely on academic knowledge and personal experience. However, as software development projects/tasks grow larger and the discipline moves from craftsmanship to engineering, it becomes a group activity where individuals need not only to communicate but also to collaborate and share their knowledge. Specifically, in some cases individual knowledge might not need to be shared and leveraged only at a project level (i.e., intra-class and/or inter-class level) but also at a cross-institutional level (i.e. inter-Univeristy) and /or at a inter-community level as well.

Community-centered collaborative knowledge management e-learning platforms

Despite the fact that benefits may be derived from individual tools addressing separate software development activities, there is a need for community-centered collaborative knowledge development e-learning tools. It has been observed that by integrating Knowledge Management (KM) functionalities within the students' working environment contributes significantly in knowledge sharing, critical thinking towards problem solving and collaborative software development. An examination of the most well-known proprietary and FLOSS knowledge management platforms for collaborative e-learning utilized in educational institutes is presented in table III. These platforms have been examined along a set of features that comply with the knowledge-management life-cycle model [13] and which also address the needs of a knowledge management system.

TABLE III. EVALUATION OF COLLABORATIVE KNOWLEDGE MANAGEMENT E-LEARNING[A] PLATFORMS

	Open Source Platforms				Proprietary Platforms		
Features	Mylyn	Corona	Jabber	NEPOMUK	IBM Jazz	CollabNet	Novell
Context	No	No	No	No	No	No	No
(Semantic) Search	No	Yes	No	Yes	Yes	No	No
Recommendation	No	No	No	No	No	No	No
Knowledge Desktop	No	No	No	Yes	Yes/No	Yes	No
Focused UI	Yes	No	Yes	Yes	No	No	No
Task Model	Yes	Yes	No	Yes	Yes	No	No
Communication Tools	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Peer-to-Peer data exchange	No	No	Yes	Yes	No	No	-

a. Source: TEAM project.

As it can be seen, none of the examined platforms addresses all identified features. Although they all provide the necessary operations for supporting the complete Knowledge Management life-cycle via intuitive interfaces, only a few of them utilize complementary technologies (i.e. semantics, P2P) for enhancing knowledge searching, structuring and distribution. A common ellipse lays in the absence of innovative techniques that may inspect (without violating privacy issues) and interpret the students' interaction with their context environment and intelligently provide (proactively or on-demand) knowledge and/or recommendations on the task that a student is currently engaged with. As such, one can identify the need for a community-centered, collaborative, knowledge management e-learning platform, which addresses all identified features.

III. THE TEAMWEAVER COLLABORATIVE PLATFORM

Aiming to feel this gap, we propose an open source, collaborative knowledge management, e-learning platform that aims at bringing learners closer to learners (i.e., learner-centered) and to the broader community (i.e., community-centered). TeamWeaver[7] is an open source platform that has been developed to addresses the need for a knowledge sharing environment, supporting advanced capabilities in distributed, collaborative engineering and management of software systems among students. Although the software development process is unique in some sense, collaboration, sharing of knowledge and similar experiences can help students enhance their learning, critical thinking and problem solving abilities. For example, knowledge re-usage can prevent the repetition of past failures and guide students to resolve their recurrent software development problems.

As such it is critical to have a decentralized, personalized, context-sensitive and semantic-based framework for sharing knowledge about software implementation that is seamlessly integrated into a software Integrated Development Environment (IDE). Thus, the primarily goal of the TeamWeaver platform is to provide a KM system that supports computer science students in their coding activities while crowd sourcing knowledge. As such, TeamWeaver actively contributes to the knowledge creation and problem solving processes of concrete problems in coding, namely error handling and component reuse by enabling distributed teams to become more effective, learning from each other's experiences.

A. Conceptual architecture

The TeamWeaver platform is composed of a number of components addressing each of the phases of the KM life-cycle, seamlessly integrated within the Eclipse environment to provide a coherent collaborative toolkit that fosters knowledge sharing. A high level representation of TeamWeaver conceptualization architecture in relation to its surrounding environment (i.e. software and hardware) is illustrated in figure 3.

7 Please note that with reference to the features outlined in table III, an advanced context observer and automatic recommendation mechanism is, among others, the pre-eminence of TeamWeaver compared to the other existing knowledge management collaborative e-learning platforms. Despite the lack of a communication medium integrated to the platform for supporting online messaging between platform's participants and a focused UI, TeamWeaver (http://www.teamweaver.org) comes in the form of an extension that may seamlessly be integrated into an existing Integrated Development Environment (IDE) and inherit all the functionalities and operations provided by the latter.

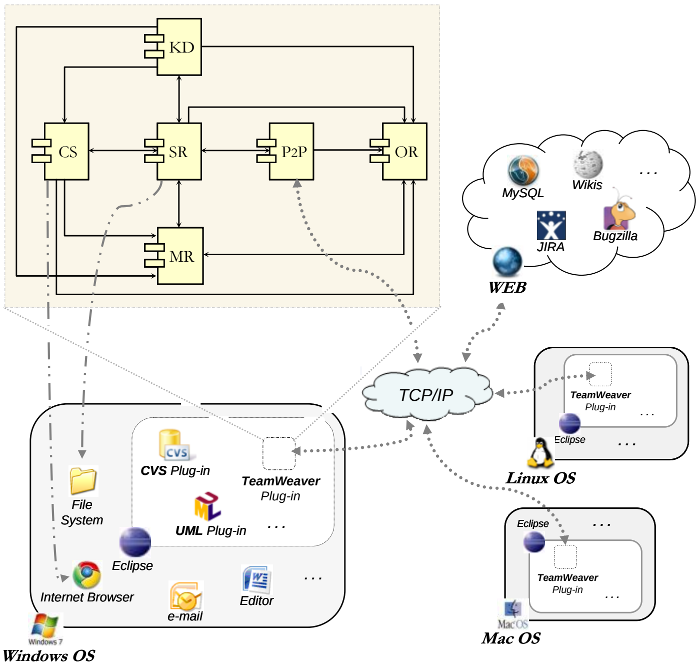


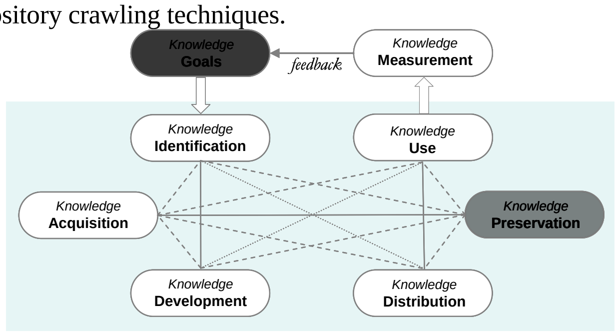
Figure 3. High level conceptualization architecture of TeamWeaver (Source: TEAM project)

The rounded box on the bottom-left corner of the figure represents a typical personal computer running Windows Operating Systmem (OS) with a number of applications installed – enclosed by the box. The inner rounded box positioned on top of Eclipse icon illustrates an indicative number of plug-ins (bundled with Eclipse), where one of these is the TeamWeaver of which its internal architecture is presented on the figure's top-left corner enclosed by the dotted box. The diagram depicts all of the six components that constitute the TeamWeaver platform and illustrates the interrelationships of those components between themselves and the rest of the system; such as OS modules and applications, other TeamWeaver platforms residing on different locations (e.g. Mac OS and Linux OS rounded boxes), and web applications (enclosed by the cloud icon named by 'WEB', positioned on the top-right corner of the figure).

The TeamWeaver components involve the: ***(i) Knowledge Desktop (KD)*** that stands as the platform's front-end for accessing its functionalities, providing knowledge articulation facilities and semi-automatic metadata creation, ***(ii) Context System (CS)*** that observes and interprets a student's interaction with the developing environment, utilizing data mining techniques on user interaction logs for enhancing predictions of behavior. ***(iii) Search and Recommendation (SR)*** that provides search functionality and recommendations to solve problems encountered during coding, ***(iv) Metadata Repository (MR)*** that stores schema information and metadata, ***(v) Peer-to-Peer (P2P)*** that handles the connection and information exchange with other TeamWeaver platforms in a network, and ***(vi) Ontology Repository (OR)*** that constitutes the glue that binds the TeamWeaver components together by defining the shared vocabulary used to facilitate annotation, communication, search, storage and representation of information.

B. *Toolkit exploitation*

TeamWeaver may be considered as an integrated collection of services that facilitate software development activities by capturing, storing, disseminating, and reusing knowledge created during software development as well as in integrating existing knowledge sources. The relationship of the TeamWeaver components with the different phases of KM life-cycle is visualized in figure 4. *Knowledge acquisition* is performed synchronously or asynchronously by: (i) on-line acquisition of problem/solution knowledge though the observation and the interpretation of student's interaction with the development environment, (ii) off-line acquisition of learning rules that help in detecting problems encountered by students by using machine learning and statistical techniques, enabling in this instance the provision of recommendation to specific activities, and (iii) knowledge aggregation of heterogeneous repositories such as file systems, email archives CVSs, JIRA, DBMSs, Wikis, Bugzilla etc. generated via repository crawling techniques.



Phases of Knowledge Management life-cycle

TeamWeaver components	Knowledge Goals	Knowledge Identification	Knowledge Acquisition	Knowledge Development	Knowledge Distribution	Knowledge Use	Knowledge Preservation	Knowledge Measurement
Context System			√			√		
Knowledge Desktop				√		√	√	
Search & Recommendation			√		√	√		
Metadata Repository							√	
Peer-to-Peer					√			
Ontology Repository	√	√	√	√	√	√	√	√

Figure 4. Representation of knowledge management life-cycle (top-part) [13], and TeamWeaver components in relation to phases of KM life-cycle (bottom-part) (Source: TEAM project)

Knowledge development is carried out in a manual or semi-automatic fashion. In the manual approach, students/instructors may utilize a Wiki-like knowledge editor or an advanced ontology-based knowledge editor. Semantically annotation of code segments is also possible by highlighting the desired part of code and choosing one of the aforementioned editors for knowledge creation. Since manual creating knowledge is a time-consuming and error-prone activity, TeamWeaver takes advantage of information extraction techniques to propose annotations. As such, a student/instructor may select a single or groups of files to be automatically annotated by TeamWeaver; where manual-triggered threshold switches determine the level of annotation. The two editors are also used for knowledge visualization purposes as well; in addition, a graph ontology-based visualization environment is supplied for representing knowledge in a different dimension.

Knowledge searching is conducted by: (i) taking into account different types of searching, namely keyword, structured and semantic search, (ii) integrating results from different repositories i.e. local and P2P storage, and (iii) including user feedback and similarity in the search process to refine information needs. While keyword-based search represents the standard model for search interfaces, structured search allows more precise queries, which in turn yield more precise results. Novelty of the search in TeamWeaver lies in the combination of keyword and structured queries and in the usage of the context information to restrict the search space. Context information is automatically derived directly from students without extra effort (i.e., on describing (i) what they have been doing, (ii) which problem they encountered and (iii) how they have solved this problem), resulting in a "semantic context log", which contributes on a better processing, interpretation and aggregation of information.

In relation to *knowledge sharing*, TeamWeaver offers students/instructors the possibility of defining the knowledge that they are willing to share over the (S2S, S2C) network and explicitly define the network members (i.e., individual or group of students operating TeamWeaver) by whom this knowledge will be accessed. TeamWeaver is coupled with a configuration console for the parameterization of the: (i) network sharing policies, (ii) integration of external knowledge repositories, (iii) activation/deactivation of monitoring sensors that control what and how a student's activity is monitored by the CS; with respect to privacy issues and (iv) the way in which recommendations are generated/ranked; based on a number of configurable parameters such as taxonomy level and metric value, feature threshold, size and level.

TeamWeaver was initially evaluated by four European leading IT companies; it is now being sustained by an Open source community and may be accessed directly via http://www.teamweaver.org. The piloting phase was conducted in a distributed offshore software development environment under realistic conditions by INTRASOFT International S.A., THALES, Linux Industrial Association-LIPSZ, and TXT e-solutions. The utilization of TeamWeaver in this demanding environment, where commercial software applications are being produced, yielded positive results, and contributed to the increase of the piloting participants' productivity.

IV. Conclusions and Recommendations

Collaborative learning constitutes a key learning mode which is critical in engaging learners' conceptualizations, enhancing the refinement of knowledge and advancement of understanding [30], [18], [31]. During the last two decades, the emergence of Internet and evolution of technology has stimulated the transformation of the educational sector. Digital networks that were initially utilized simply for the dispersal of learning content, have now evolved into an ideal collaborative learning environment which stimulates conceptual development via collaborative dialogue. To this end, the emergence of the open source paradigm stimulated new dimensions of e-learning. The epitome of *community collaboration* has changed the relationship between knowledge creation and consumption as well as teaching and learning processes driven by social modes of interaction and knowledge exchange. As such, open source software has actively contributed in bringing the learner closer to the *community*, which has evolved into a key actor in the online learning network, enabling effective learning practices. In this context, we propose a holistic typology of learning interactions in distance education, which includes *f*our key entities of knowledge manipulation: (a) *student/learner, (b) instructor, (c) knowledge/content,* and *(d) community* (figure 2). Our analysis indicates that most of the online collaborative e-learning tools (both proprietary and open source) across a range of types facilitate only a few of these forms of interactions.

In order to further explore the notion of the "community" in the context of computer-mediated collaborative learning, we examine it along one specific educational context, namely computer science education and in relation to one distinct type of learning application: collaborative development environments. On the one hand, our analysis indicates that the notion of community and the level of collaborative interaction (i.e., with the intra-university community (micro-level), the cross-institutional community (meso level) and the broader open source community (macro level)) are critical in CSSE[8] education. On the other hand, our examination of collaborative knowledge management e-learning platforms utilised in CSSE education, identifies the need for a community-centered, collaborative, knowledge management e-learning platform, which addresses all the features of the knowledge-management life-cycle model [13] and the needs of a knowledge management system.

Aiming to feel this gap, we propose an open source, collaborative knowledge management, e-learning platform that aims at bringing learners closer to learners (i.e., learner-centered) and to the broader community (i.e., community-centered), in an efficient and innovative way. TeamWeaver is an open source collaborative platform developed for addressing the need for a knowledge sharing environment that supports advanced capabilities in distributed, collaborative engineering and management of software systems among students. It provides a decentralized, personalized, context-sensitive and semantic-based framework for sharing knowledge, about software implementation that is seamlessly integrated into a software Integrated Development Environment (IDE). Although the software development process is unique in some sense, collaboration and sharing of knowledge and similar experiences can help students enhance their learning, critical thinking and problem solving abilities.

TeamWeaver enables knowledge re-usage that can prevent the repetition of past failures and guide students to resolve their recurrent software development problems. More specifically, in relation to knowledge sharing, the proposed system offers

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students the possibility of defining the knowledge that they are willing to share over the (S2S, S2C) network and explicitly define the network members (i.e., individual or group of students in the platform) by whom this knowledge will be accessed.

A potential extension of TeamWeaver could be integration of a communication medium in the platform for supporting online messaging between platform's participants and a focused UI.

Future research directions embrace TeamWeaver and foster the notion of community-based learning interactions by introducing concepts from the social media paradigm [53], [54], [55].

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