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Designing Smart Knowledge Building Communities

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Abstract. Knowledge building communities (KBCs) are environments where learning is continually occurring as a social process, and the collective knowledge base is gradually being expanded upon. Knowledge accessible to all members is produced in collaborative discourse, along with the development and the use of conceptual artifacts. This theoretical contribution discusses the possibilities to foster and design KBCs in a "smart" manner so that they can be connected to formal learning. Firstly, the paper identifies the characteristics of "smartness" for the context of KBCs: participants (individuals and groups), collaboration and convergence, as well as technology that may provide enabling and monitoring tools. Secondly, tools are suggested to foster and monitor the development and the use of collaborative discourse and conceptual artifacts. Thirdly, recommendations for the design of smart KBCs are provided. Finally, a research agenda is proposed based on the previous discussions.

Keywords: smart learning communities, student-centered open learning environments (SCOLEs), conceptual artifacts, discourse learning analytics

1 Introduction

In a recent IxD&A publication, Giovanella, Dascălu and Scaccia [1] address smart cities as communities of highly skilled people who are continuously motivated and challenged, while their basic needs are satisfied. The community members come together and collaborate, drawing each other to these collaborations and establishing what has been termed "flow". These people are represented by corresponding intellectual capital [2] enabling the social practice. Technology can be applied to empower people in their social practice, and to receive feedback on the state of their city.

In an analogous view, communities – and especially virtual communities [3] – can also be smart. Virtual communities are groups of people sharing in the long term some technology-based communication space (e.g., discussion forums, blogs, social media) along with specific goals or interests [3, 4]. Knowledge building is one of the most important activities of a virtual community [5–7]. In contrast to formal learning environments (such as schools), where knowledge building is tightly connected to formal learning and, as such, curriculum driven; knowledge building in communities is practice driven, largely spontaneous, and thus informal [4]. Nevertheless, learning in communities is strongly based on intrinsic motivation and results in applicable knowledge [4], therefore it can be regarded as a valuable complement of formal learning. Such assets raise the question how knowledge building in virtual communities can be supported or, more specifically, how it can be made "smart".

From an educational perspective, smart knowledge building communities (KBCs) may be regarded as open learning environments [8] in which community members determine their own learning goals, learning means, or both. Examining the process of learning, Wenger [9] identifies two interdependent components in communities of practice: participation and reification. In virtual learning communities, participation largely consists of discourse, and reification results in the discourse-based development and use of conceptual artifacts. Numerous examples and studies have shown so far how technology can support communication in virtual communities [4]. It is an open question how technology can enhance social practice in KBCs. In this realm, this paper suggests technological tools to foster and monitor the development, as well as the use of collaborative discourse and conceptual artifacts, based on characteristics of "smartness", concluding with recommendations for designing a smart KBC.

Given that knowledge building in communities takes place mainly in the collaborative discourse and the development of conceptual artifacts, fostering "smart" KBCs involves three elements: (1) analyzing and scaffolding collaborative discourse, (2) supporting the development and the use of conceptual artifacts; and (3) using technological tools to enable the previous elements (1) and (2), as well as using them to monitor and provide feedback on the state of the community (through discourse learning analytics [10]) to further aid its development and design.

Against this background, this paper presents the theoretical bases of student-centered open learning environments, KBCs, collaborative discourse and conceptual artifacts in this context, followed by an analysis of what makes an entity "smart". Based on this, technological tools are presented as part of a smart KBC design. Specifically, technological tools to support the development and use of collaborative discourse, and conceptual artifacts; furthermore, the monitoring of the community will be also presented. Finally, conclusions regarding the design of smart KBCs, future tool development and research questions for empirical educational research are drawn.

2 Student Centered Open Learning Environments (SCOLEs)

In the Student Centered Open Learning Environment (SCOLE) the student is considered a central actor, choosing his own learning path in the form of goals and/or means [11]. As opposed to traditional, direct instruction, the student can choose the resources which will aid him in his learning goals, transforming learning from an externally directed activity into an internally directed one [11]. The student's construction of meaning will be influenced by his prior knowledge and experiences. However, since SCOLEs also take elements from a situated learning perspective, collaboration is also important, with the student participating in socio-cultural practices within realistic contexts [12]. The inclusion of diverse perspectives and collaborations foster individual and shared understandings, which in turn contribute to the construction of community knowledge [12, 13]. SCOLEs also support the inclusion of different resources, such as tools (some of them technological) to support the student's construction of meaning [12].

SCOLEs provide frameworks for students as they engage in complex problem solving, such as scaffolds, serving as guidelines and prompts for students to check their progress on their learning goals and the effectiveness of their selected means [12]. An example of a well-known SCOLE is the Web-based Inquiry Science Environment (WISE) [12, 14]. In WISE, the student is treated as a scientific researcher, and is given the opportunity to use different technological tools, to raise questions, critique and review evidence, and work with classmates to build and refine knowledge. Students are presented with questions, and for answering them, they are using means such as collaborating with classmates. They can also receive hints, which could include questions directed at the student to evaluate personal progress, or to aid in connecting different pieces of knowledge seeking, or to seek outside knowledge [14].

It has been noted that certain other communities with a learning focus, like KBCs, share characteristics with SCOLEs such as keeping the student at the center, working collaboratively to build knowledge and share understanding; and the use of technological tools can play a large role in this [12, 13]. The student is empowered to determine his or her own learning path, at times aided by scaffolds, which both increase awareness of the learning process itself, and help the student relate apparently disparate knowledge. The student is provided with diverse tools and access to different perspectives, so that the student him/herself constructs meaning [12]. KBCs exist within this framework, adding a focus on this last point – the construction of meaning. KBCs go beyond "collaboration" to focus on long-term collaborative discourse, and the conceptual artifacts developed through discourse, which are then used to stimulate further discourse [13]. It is here that technological tools have their own role that can enhance social practice and aid in monitoring the development of KBCs, making them "smart".

3 Knowledge Building Communities (KBCs)

KBCs were introduced in the work of Scardamalia and Bereiter [5], where changes in education were advocated to turn schools into KBCs. The authors put forth the idea of schools as environments where learning is continually occurring, and the collective knowledge base is constantly being expanded upon as the result of a social process where knowledge is contributed and built upon as a group effort [5]. Since knowledge is socially constructed, the discourse, which takes place to produce it, is also a key element. Participants in the knowledge building activities should be able to access others' knowledge so that they can build on it. Participants also have the alternative to include "outside" knowledge, weaving it into the discussion and thus contextualizing discussions in "real world scenarios" [5].

Describing such processes, Wenger [9] emphasizes the interplay between participation and reification of knowledge, and their vital role in learning. It is through participation in community practice that community members co-construct knowledge and reify, i.e., transform it into cultural artifacts of the community. These, in turn, enhance further participation [9, 15]. Bereiter [6] describes conceptual artifacts as a subset of cultural artifacts, which are generally objects mediating the interactions between subjects (community members) and objects (products of the community interaction). Unlike cultural artefacts which encompass both material and immaterial objects, conceptual artefacts are immaterial; they are built on and added to through the knowledge building process which takes place in communities (based on the cycle of participation and reification) [6, 15].

Technology can play an important role in a KBC as a means to enhance collaborative discourse, and therefore stimulating conceptual artifact creation. Scardamalia and Bereiter describe their Computer Supported Intentional Learning Environments (CSILE) system, which supports collaborative discourse and knowledge building that can extend outside the classroom [5]. CSILE is characterized by community databases, where students can contribute to and store their knowledge. Its structure is such that knowledge can be distributed, which in turn also fosters collaboration; however, document and resource storage is centralized, so that access is not a problem [5]. A more recent technology based on CSILE is Knowledge Forum®, whose design moves away from thread like discussions; making both content and its organization more accessible to the community [13]. With Knowledge Forum®, users can organize their knowledge in the way they see fit, with others also able to view and contribute to it, with scaffolds available to users (but not mandatory) [13]. Additionally, offline activities, which provide a "real world" context, are brought into the Knowledge Forum®, thus making it the central place where discourse and knowledge building take place [13].

In the next section, the definition of a "smart" entity will be discussed and three main characteristics will be described in detail. Following this, the concept of KBCs will be tied together with that of "smart" entities, resulting in conclusions regarding the design of "smart KBCs." The following sections will further expand on these conclusions.

4 Smart Entities

What makes a community "smart"? "Smart" has been used as an attribute of spaces, such as classrooms, communities, and cities. Smart classrooms, for example, use technologies to assist in activities such as collaborative inquiries and knowledge construction [16]. Smart communities have also been described in a mobile multimedia context, defined as interconnected people and technological objects, to deliver "smart" services, made possible through monitoring, which then determines which kind of feedback is given to improve the community overall [17]. Smart city is another relatively novel concept uniting concepts from design, architecture, and analytics. A smart city has been defined as a city inhabited by skilled individuals, which can satisfy the needs of its inhabitants as well as stimulate them. Additionally, a state of "cooperative and convergent actions carried on by all stakeholders" is what will create a state of "flow" of a city; an example of a city in "flow" is Florence during the Renaissance [1, p. 85].

Smart cities emphasize the central role of the person, and therefore the importance of introducing bottom-up methods of evaluation of the city, as opposed to top down approaches, where pre-determined metrics are imposed and measured to determine a city's "smartness" [1]. These bottom-up approaches are enabled by technology, which enhances the possibility of data gathering and analysis. An example of technology as an enabler is given by Giovanella, Dascălu and Scaccia [1], where they ask people to answer a questionnaire on their conceptions of smart cities, and analyze their responses in terms of word occurrences, as well as demonstrating the potential of an automatic text analysis method to produce conceptual maps. In smart cities, the role of the individual is highlighted, but the role of collaboration and coming together of people does not fall far behind – this is part of the "flow" [1].

Smart classrooms focus on the individual student, but the interactions of groups of students are also highlighted in their participation in knowledge construction and collaborative activities, as well as the formation of knowledge communities [16]. In smart classrooms, these interactions are enabled by technology, which in turn also provides a way to collect data (on interactions, for example) [16]. Through the study of smart classrooms and their effect on students' learning, not only is learning being monitored, but it is also being analyzed, and can therefore be considered a bottom-up approach to improving learning.

In smart communities in a mobile multimedia context, the interconnection of people and technology provides the possibility to deliver "smart services", through the monitoring of the community, and feedback based on this monitoring [17].

Although these definitions of smart entities refer to different scenarios and applications, they share three common elements: participants (individuals and groups), collaboration, and technology both as an enabling tool and as a tool for monitoring the entity with bottom-up data (which can then prompt feedback or a response).

Looking back at SCOLEs, they are student centered, while keeping collaboration and community aspects, and providing students with resources and tools [12]. SCOLEs that are additionally KBCs have a focus on collaboration and convergence, through collaborative discourse and conceptual artifacts [5]. These characteristics are in line with those of a smart KBC. The first element of a smart KBC is present – participants, not only individuals, but also groups. Out of the social interactions and processes of these individuals and groups, their collaborative discourse, and cycles of participation and reification [9], and consequent knowledge building and conceptual artifact creation and use, comes the second element of a smart KBC: collaboration and convergence. The third element of a smart KBC, which has not been discussed thus far, is technology and its role.

Technology is important as an enabler of collaborative discourse and as a supporter of the development and the use of conceptual artifacts. This can be achieved through technologies such as the Knowledge Forum® [13]. However, another important element of a smart community technology in the role of a tool to both monitor and provide bottom-up feedback on the state of the community.

Having established that smart KBCs require participants and collaboration, with collaborative discourse and conceptual artifacts at the heart of their knowledge building, the focus will now turn to the third element at hand: technology as an enabling and monitoring tool. The addition of technological tools would effectively transform a KBC into a “smart” KBC in the following three manners: technology (1) as an enabler in the development and use of conceptual artifacts, (2) as a tool enabling collaborative discourse, and as (3) a tool to monitor learning and provide feedback for improvement in design. The following sections will address these three roles of technological tools.

5 Technological Tools Supporting Conceptual Artifacts in Smart KBCs

As previously mentioned, Bereiter [6] describes conceptual artifacts as a subset of cultural artifacts, which are generally objects that mediate the interactions between subjects (community members) and objects (products of the community interaction). Conceptual artefacts are immaterial; they are built upon and added to through the knowledge building process taking place in communities (based on the cycle of participation and reification) [6, 15]. The presence of adequate conceptual artifacts in a community can foster knowledge sharing, and more broadly, the socio-cognitive aspects of knowledge communities [4]. Additionally, in a KBC, conceptual artifacts are an essential part of the knowledge building process.

Nistor [4] has identified socio-cognitive processes present in the knowledge community taking place at three levels: information exchange, co-construction of knowledge, and collective memory [4]. The author has also identified the ways in which technology can foster these three different levels and how information exchange can be fostered through a variety of technologies enabling the sharing of text and images. These can also be used to foster co-construction of knowledge, along with different technologies supporting access to additional information (such as libraries and databases, for example) [4]. In terms of finding collaborators to engage in knowledge exchange, directories and social media are examples of tools [4]. Finally, collaborative tagging based on preferences and the corresponding use in automatic recommender systems represent a possible manner in which collective memory is fostered through technology [4].

Technology can also enable the co-construction of knowledge in the form of conceptual artifacts, by enabling collaborative tasks or tasks which allow the convergence of knowledge. One such example is that of shared annotations. Mazzei, Blom, Gomez and Dillenbourg [18] describe the implementation of a shared note-taking tool in a university class. The note-taking tool, annOot, a web based application accessed on a tablet, allowed students to take their own notes, as well as view others' notes, both during and after the class lecture [18, 19]. The study sought to answer three main questions: how browsing behavior was affected by the act of note taking, how the use of annOot affected student performance, and how social influence affected the flow of shared annotation material. This longitudinal study involving 20 participants was carried out in a university classroom over the course of a semester [18]. In order to answer the proposed research questions, the students' usage of the system was recorded, specifically the time they spent browsing annotated slides. Additionally, a survey centered on the perceived friendships was used to model a social network of the classroom, termed a "socio-cognitive structure". This network was later on used to determine if the browsed annotations were produced by the student's browsing, a "friend" or a "non-friend". Finally, performance in the final exam was measured [18]. The authors point to the following main findings: the time spent browsing annotations is positively correlated with both the number of shared annotations and the student's final exam grade; and that the students tend to click on their own annotations, followed by those of friends [18, 19]. In this study, the act of note-taking can be seen as a form of knowledge reification. Through the sharing of these conceptual artifacts, new ones were co-created by each student, and this process of knowledge building resulted in a higher final exam grade.

Another example of conceptual artifact creation and the negotiation of meaning through technological tools comes from the annotation of images with LabelMe, an image labeling tool [20]. In this image annotation study [21], which had a focus on sense of social identity and task continuance in a collaborative environment, participants were given different scenarios and were asked to outline and label what could see in a satellite image, and later organize their labels into a semantic tree. Participants collaborated on images asynchronously, with one participant beginning the labeling task, and the second continuing afterwards. In this setting, participants were using the image labeling tool to create meaning, and they reified this knowledge in the form of a semantic tree, an artefact later used and built upon by another participant.

Creating and sharing conceptual artifacts are a key point of KBCs. By using technological tools to enhance this process, a "smart" KBC is born. Technological tools, such as the ones indicated above, not only stimulate the development and sharing of conceptual artifacts (which make the KBC "smart"), but also stimulate other components of the knowledge building SCOLE, such as keeping the student at the center, to search for additional notes to complement personal ones, or to choose what is meaningful to take notes on or to label, for example.

6 Technological Tools Supporting Collaborative Discourse in Smart KBCs

As previously mentioned, KBCs go beyond "collaboration" to focus on collaborative discourse, and the conceptual artifacts developed through discourse, which are then used to stimulate further discourse [13].

Nistor and his colleagues present two examples of discourse analytics employed to identify potential learning environments. In a first study [22], automated discourse analysis tools assess discourse quality in online communities, and identify central community members as potential dialogue and knowledge building partners of the learners. In a follow-up study [23], similar tools were employed to predict how likely a blog-based community will be to integrate the learners as new members. It appeared that communities with a higher number of active members (as compared to the number of peripheral members) were more likely to integrate new members. In a further study on newcomer integration, authors use an automated text analysis tool "Important Moments" to analyze and compare the dialogues taking place in an integrative and in a non-integrative online KBC, delving into the relationship between newcomer integration and dialogue quality [24]. In this study, the authors suggest to make an online KBC "smart" by utilizing technological tools to predict the likelihood of newcomer integration [24]. As a consequence, from the huge number of KBCs on the Internet, those appropriate as SCOLEs can thus be selected. For more details on these studies, please refer to [22–24]. The following step consists of developing SCOLEs that have such KBCs as a central design element.

7 Technological Tools Monitoring Learning Activities in Smart KBCs

Technology can also be an enabling tool for smart KBCs to provide learning analytics, such as monitoring the discourse and collaboration, as well as delivering appropriate feedback.

An example of a technology that can provide monitoring and modeling of participants' interaction, as well as fostering collaborative discourse by finding resources for learners in SCOLEs (eg., finding external resources for students or appropriate virtual communities based on their discourse) is *ReaderBench*, an automated dialogue analysis tool based on natural language processing, polyphony and social networks analysis [25]. The analysis of underlying collaboration is performed in accordance to the polyphonic model [26] focused on identifying voices and on building the cohesion graph [27]. For this aim, links between utterances are analyzed considering adjacency pairs, repetitions, lexical chains, speech and argumentation acts [28] or cohesive links that reflect a high semantic similarity between the interventions. The resulting graph represents the starting point for the subsequent identification of discussion threads.

After uncovering the underlying discourse structure [27], topics are extracted as key concepts whose relevance score is reflected by the following factors: (a) statistical presence from information retrieval (term frequency – inverse document frequency)

[29], (b) semantic relatedness in terms of the cohesion with the specific analysis element and the entire document, and (c) overall coverage and linkage with the analysis element from the automatically generated lexical chains [30]. The initial individual assessment of each element is based on its topics coverage and their corresponding relevance, with respect to the entire discussion thread [31]. Therefore, topics are used to reflect the local importance of each analysis element and to indicate the covered concepts, whereas cohesive links are used to transpose the local impact upon other inter-linked elements.

Participant Involvement Evaluation. Participant interaction modeling covers a deeper qualitative dimension, obtained by considering the previously determined intervention scores. Internally, an interaction graph is built with participants as nodes and the weight of links equal to the sum of interventions scores multiplied by the cohesion function with the referred element of analysis, extracted from the cohesion graph and spanning throughout all the forum discussion threads. Therefore, by performing social network analysis on the previous participant interaction graph, the scale of analysis is shifted towards an individual perspective, centered on each of the participants. In the end, the size of each node in the interaction graph is directly proportional to its corresponding betweenness score [32]. Moreover a clear separation must be made: personal involvement is expressed as the cumulative utterance importance scores, whereas the interaction graph reflects the exchange of information through cohesive links, making the two perspectives complementary to each other.

Starting from the previous graph, the most important factors consist of measuring each participant's centrality derived from Social Network Analysis [33], as well as the quality of the dialogue deduced from the cumulative intervention scores of each virtual community of practice member [34].

Collaboration Assessment Through the Social Knowledge-Building Model. The actual information transfer through cohesive links from the cohesion graph obtains two valences by enforcing a personal and social knowledge-building process [35] at intervention level. Firstly, a personal dimension emerges by considering utterances with the same speaker, therefore modeling an inner voice or continuation of the discourse. Secondly, inter-changed utterances having different speakers define a social perspective that models collaboration as a cumulative effect. Although similar to some extent to the previously proposed gain-based collaboration model [36], the transition towards Stahl's model of collaborative knowledge-building [35] and the use of the multi-layered cohesion graph instead of the utterance graph enable a deeper and a more generalized analysis of collaboration in computer supported collaborative learning conversations [34].

Therefore, each intervention or utterance now has its previously defined importance score and a knowledge-building effect, both personal and social. The personal effect is initialized as the intervention's score, whereas the social effect is zero. Later on, by considering all the links from the cohesion graph, each dimension is correspondingly augmented: if the link is between utterances with the same speaker, the previously built knowledge (both personal and social) from the referred utterance is transferred through the cohesion function to the personal dimension of the current utterance; otherwise, if the pair of utterances is between different participants, the social knowledge-building dimension of the currently analyzed utterance is increased with the same amount of information (previous knowledge multiplied by the cohesion measure) [34]. In other words, continuation of ideas or explicitly referencing utterances of the same speaker builds personal knowledge, whereas the social perspective measures the interaction with other participants, encourages ideas sharing, fostering creativity for working in groups [37] and influencing the other participants' points of view during the discussion, thus enabling a truly collaborative discussion.

Collaboration Assessment Through Voice Inter-Animation. In order to achieve genuine collaboration, the conversation must contain a dense intertwining of voices derived from key concepts and covering multiple participants of the conversation [38]. Therefore, starting from voices computed as semantic chains containing highly cohesive concepts, a split per participant was performed in order to observe the corresponding coverage and distribution of dominant concepts per speaker, throughout the discussion thread.

Additionally, in order to identify the voice overlaps now pertaining to different participants, a change occurred from an ongoing longitudinal analysis derived from the cohesion graph following the discussion timeline, to a transversal analysis of a context in which multiple voices co-occur [39]. Subsequently, in order to evaluate collaboration following the conversation's timeline, a sliding window of five adjacent utterances (with a possible shortening of the window, if the pause between adjacent utterances is greater than an imposed threshold) was used in order to model, through its replication, the overlap of voices pertaining to different participants in different contexts. More specifically, collaboration is measured as a cumulated value of point wise mutual information [40] obtained from all possible pairs of voices pertaining to different participants (different viewpoints), within subsequent contexts of the analysis [25].

8 Conclusions

In summary, virtual KBCs share several characteristics of SCOLEs, while emphasizing collaborative discourse and conceptual artifact development and use. Virtual communities employ technological tools, raising the question of how to use them to support knowledge building, to enhance social practices and to turn them into "smart" KBCs. Moreover, a "smart" entity is composed of participants (both individuals and groups), collaboration among participants, and technology, both as an enabling tool and as a tool for monitoring the entity with bottom-up data (which can then prompt feedback or a response). A KBC will have both participants and collaborative discourse. Therefore, fostering a smart KBC involves using technological tools in three ways: (1) to analyze and scaffold collaborative discourse, (2) to support the development and use of conceptual artifacts, and (3) to monitor and provide feedback to aid the further development and design of the community. In this article, the theory leading up to this last point was developed, and technological tools supporting these three manners were presented. At this point, the elements of a smart KBC have been established, and conclusions can be drawn regarding their design.

Smart KBC Design. KBCs have the foundations of a smart entity; what they require is the leveraging of technological resources to make them "smart". Conceptual artifact development and use can be enhanced through the annotation of images or note-taking for a class, for example. Technologies can help make knowledge more visible, reify it, and make it accessible to others, who may then build upon or use it in their communication. In this way, the reach of knowledge is expanded in a community. In the same vein, collaborative discourse can also be leveraged through technology. Through tools such as *ReaderBench* [27], potential collaborators can be sought out, bringing different perspectives into a discussion going beyond the classroom walls, and really integrating them into the community discussion, as well as providing feedback on the state of the community's discourse. Taking this a step further, discourse analytics can also be implemented to assess the likelihood of blog based communities to integrate new members, and therefore assess which communities are appropriate as SCOLEs [23].

Further Tool Development. The technological tools described here have dealt with discourse analysis; future tool development could take the next step in seeking out the communities online. These tools could aid in the search for adequate virtual communities of different formats (not only blog-based). Future tools could also focus on the analysis of conceptual artifacts, on finding out text annotation connected to collaborative knowledge construction, and on extending this understanding to working with images.

Future Research. Future research can address new tools and their capabilities. The external resources made available to students and the collaboration frameworks provided in SCOLEs could be evaluated, in an effort to find ways to streamline tools (such as discourse analysis tools) and make them available to the student so they can find their own external resources (such as appropriate virtual communities). Potential further research questions are: How do students accept and use blog based communities as resources for knowledge sharing and construction? How does this discourse work and what is its effect on student's academic performance? In terms of image annotation and conceptual artifacts, a design based research model could change the design of the annotation collaboration framework to enhance the acceptance and continuance of the task, as well as stimulating a community.

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