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DOI:10.1108/DTA-02-2017-0008



(Article begins on next page)

Received 27 February 2017
Revised 8 August 2017
Accepted 30 August 2017

# Cultivating virtual communities of practice in KAFKA

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## Abstract

**Purpose** – The purpose of this paper is to present a framework for cultivating virtual communities of practice in distributed environments. The framework is based on the integration of knowledge artifacts and wearable technologies.

**Design/methodology/approach** – The proposed knowledge artifact is based on the correlation between conceptual and computational tools for the representation of different kinds of knowledge.

**Findings** – In this way, it is possible to make deeper the collaboration between knowledge seekers and contributors within the community, given that seekers and contributors share, at least in part, design choices at the knowledge modeling level.

**Originality/value** – A practical application of the framework has been described, to show its originality with respect to traditional knowledge management systems. In particular, it has been demonstrated how lurking phenomenon inside communities of practice can be significantly reduced. To this aim, opportune indexes have been defined from existing ones in literature.

**Keywords** Bayesian network, Knowledge artifact, Rule-based system, Sense of virtual community, Virtual communities of practice, Wearable technologies

**Paper type** Research paper

## 1. Introduction

Communities of practice have been defined as groups of people bound by informal relationships sharing common practices (Brown and Duguid, 2001). The notion of CoP has been used in the past to define the spontaneous arising of knowledge centers in organizations, which overcome the traditional division into business units.

Pan and Leidner (2003) pointed out that CoPs are important as they weave the organization around competencies without reverting to functional structures. They facilitate an environment of "structured informality" supported by knowledge, people, organizational processes and infrastructure. Finally, the importance of CoP emerges from the fact that knowledge cannot be considered apart from the context where it develops. In all types of knowledge activities, knowledge contributors as well as seekers require a community in order to share general conversation, experimentation and experiences with other people carrying out the same kind of activities.

This last point brings us to the identification of two distinct roles in the CoP knowledge generation process: contributors and seekers. According to Sutanto and Jiang (2013), knowledge contributors must be willing to part with their knowledge and share it via a knowledge management system. For instance, knowledge contributors log into the system, fill out a form describing their contribution, and either attach a document or post content into a text box: this can be a one-time or a repeated action. Having invested funds in a KMS, organizations promote a continued inflow of knowledge. Knowledge seekers typically log

Data Technologies and Applications
Vol. 52 No. 1, 2018
pp. 34-57

2514-9288
DOI 10.1108/DTA-02-2017-0008

into the system, type keywords to search for the knowledge they require, and then retrieve and examine the results.

This conception of the relationship between the two roles suggests that knowledge contributors are active entities and knowledge seekers are passive entities in the knowledge management system development; the way knowledge is modeled within the system is unknown to the knowledge seeker, who is not responsible for its modification or maintenance. Indeed, this is a big limitation to the CoP potentialities in developing knowledge models: in particular, the principle of legitimate peripheral participation (LPP) (Lave and Wenger, 2002) is not satisfied. LPP consists in the possibility for newcomers to enter the CoP actively, contributing to its growth by means of their competencies. To do so, they should be enabled to transform the underlying knowledge bases by means of proper artifacts and interfaces. In this way, the transition from the role of knowledge seeker (typical of early stages in attending the community) to that of knowledge contributor could be more effective and rapid.

LPP is the key aspect to keep in consideration when developing KMS for CoPs promotion; it is important to avoid that newcomers become passive lurkers instead of contributors. As pointed out in Yeow *et al.* (2006), lurkers are participants who persistently refrain from engaging in the core activities that sustain a virtual community. Arguably, as the perceptions of both periphery and participation are context-specific, the identification of a behavior as lurking is dependent upon technology constraints and group-specific norms.

In this paper we propose the adoption of a framework (Sartori and Melen, 2015) based on the knowledge artifact notion (Salazar-Torres *et al.*, 2008) for building up virtuous relationships between knowledge seekers and contributors. This framework, namely, Knowledge Acquisition Framework based on Knowledge Artifact (KAFKA), implements knowledge contributors as Knowledge Artifact Developers (KA-Developers) and knowledge seekers as Knowledge Artifact Users (KA-Users). KA-Developers are responsible for the definition of conceptual and computational elements of the knowledge artifact, while KA-Users exploit the knowledge artifact to solve problems, according to the actual conditions of the target environment. In this way, the successful development of a KMS depends not only on the capability of the KA-Developer to model involved knowledge by means of a suitable knowledge artifact, but also on the capability of the KA-User to adopt the proposed knowledge artifact in real application scenarios, possibly identifying new potential sources of knowledge to be included in the model. For instance in Pinardi *et al.* (2016), the KA-User may intervene in the knowledge artifact development cycle thanks to its peripheral reasoning strategy, the capacity to detect and elaborate on the field the data included as inputs, partial elaborations or outputs, in the knowledge artifact model by the KA-Developer, exploiting inertial measurement unit sensors provided by wearable devices. Thus, the KA-User is made capable to evolve in the KA-Developer role by its active participation in the knowledge artifact definition instead of remaining indefinitely in a lurker condition.

The rest of the paper is organized as follows: Section 2 briefly reviews the literature about virtual communities of practice and knowledge artifacts. Section 3 introduces KAFKA, focusing on knowledge seekers and contributors and LPP in knowledge artifact management. Section 4 introduces a case study to show in practice how KAFKA works. The case study is related to the development of mobile apps for the promotion of physical activity (PA) in people potentially risking heart diseases. Section 5 briefly evaluates the theoretical and practical applicability of KAFKA in the virtual community development research field, presenting the preliminary results of tests conducted on a small community of users in the case study domain. Finally, the paper concludes with some considerations about future works.

## 2. Related work

As highlighted by Sutanto *et al.* (2011), virtual communities of practices have been developed as useful alternatives to company information and commerce websites. Although many tools are available for promoting such communities, the real challenge is how to keep the community alive. Preece and Shneiderman (2009) pointed out that, although billions of people participate in online social activities, most of them participate as readers of discussion boards, searchers of blog posts, or viewers of photos. Few users become contributors of user-generated content by writing consumer product reviews, uploading travel photos or expressing political opinions.

Many researchers have debated about the methods to improve the capability of participants to contribute: Ma and Agarwal (2007) found that "A variety of information technology (IT) artifacts, such as those supporting reputation management and digital archives of past interactions, are commonly deployed to support online communities. Despite their ubiquity, theoretical and empirical research investigating the impact of such IT-based features on online community communication and interaction is limited." Zhang and Zhang (2005) observed how the development and maintenance of active and successive communities must consider the following factors:

- the participant is the foundational factor of a community;
- participants are influenced by each other unequally in a community;
- individuals who can significantly influence others in a community play the most important role on community's effectiveness and success; and
- since participants play different roles on the activeness and success of a virtual community, it is valuable for companies and organizations to treat these participants differently.

Blanchard and Markus (2004) introduced the term sense of virtual community (SOVC) to measure the degree of involvement of people in a community. SOVC has been defined as the hierarchy of feelings of belonging of members toward the community. When SOVS is present, many processes and behaviors should also be guaranteed, like providing support, developing and maintaining norms and boundaries, and so on. Thus, the question is if the processes of SOVC cause feelings, or the contrary. The authors assume the first alternative to be correct. This means that the feeling of belonging to a community is not innate, but it must be developed within the community structure goals and rules.

Indeed, technology plays a crucial role in improving SOVC. A person starting the collaboration within a community as a lurker could become a knowledge contributor in the future, if and only if he/she will be guided to understand the community structure, to share its goals, boundaries and rules. For instance, as it emerges from the literature (see Sutanto and Jiang, 2013), rating-based rankings positively influence knowledge seekers' attitude to access and comment on the knowledge shared in the KMS. Moreover, algorithm-based approaches to evaluate the quality of knowledge shared by contributors positively influence them to continue sharing knowledge through the system.

Wang *et al.* (2008) introduced three key aspects concerning successful CoP implementation:

(1) remove barriers to individual participation;

(2) support and enrich the development of each individual's uniqueness within the context of the community; and

(3) link that uniqueness with the community's purpose.

They underlined how technological supports for CoPs are traditionally centralized architectures that do not fit knowledge contributors' and seekers' behavior well, although they facilitate easy control and management of knowledge. For this reason, they designed and implemented a P2P knowledge sharing architecture, namely, KTella, where a user is both a seeker and a contributor: as a seeker, he/she browses KTella for knowledge objects of interest; as a contributor, he/she publishes and forwards knowledge object to others.

In this paper, we present a unifying approach to the involvement of knowledge seekers and contributors based on their co-participation to the knowledge model development and maintenance. The approach is based on the knowledge artifact notion. According to Holsapple and Joshi (2001), a knowledge artifact is an object that conveys or holds usable representations of knowledge. Salazar-Torres *et al.* (2008) argued that, according to this definition, KAs are artifacts which represent executable-encodings of knowledge, which can be suitably embodied as computer programs, written in programming languages such as C, Java or declarative modeling languages such as XML, OWL or SQL.

Knowledge artifacts can be exploited to support the development of virtual communities of practice: the main aim of our study is to use them for building up shared knowledge models between knowledge seekers and contributors. While traditional KMSs are only focused on the sharing of knowledge model content, which is populated by contributors and accessed (and eventually rated) by seekers, we have developed a knowledge management framework where both knowledge contributors and seekers are aware of the knowledge organization. Moreover, the typical task of a knowledge seeker, that is querying the KMS to learn something new, is strictly connected to problem-solving activities, that means a knowledge seeker uses the knowledge model to obtain opportune outputs depending on given inputs. A knowledge seeker is important in the virtual community founded on knowledge artifacts, being the entity responsible for testing the model of knowledge created by the contributors, since he/she has full understanding of its application domain. In this scenario, knowledge seekers and contributors are complementary; the framework presented in this paper aims to overlap their roles in the generation and maintenance of communities, to improve their SOVC.

## 3. Knowledge contributors and seekers in KAFKA

In this section, we will describe the main methodological issues of our research. First of all, we will offer a conceptual introduction to KAFKA, focusing on the components involved in the virtual community promotion. Then, we will discuss on the role of KA-Developers and KA-Users in KAKFA adoption. It is important to notice that deeper information about KAFKA are out of paper scope: further details can be found in Sartori and Melen (2016, 2017).

### *3.1 KAFKA*

KAKFA is a computer-aided knowledge engineering tool aiming at reducing, and possibly deleting, the knowledge engineering role in complex decision-making processes representation. The main idea (Sartori *et al.*, 2013) behind KAKFA was focusing on domain experts and users providing them with automatic and semi-automatic methods to develop complete knowledge models and use them in concrete scenarios. To this scope, opportune conceptual and computational artifacts for the acquisition and representation of involved kinds of knowledge were used and correlated (Sartori and Grazioli, 2014). The higher-level knowledge artifact (HLKA) notion (Sartori and Melen, 2016, 2017) has been introduced to describe the correlation of knowledge artifacts, thanks to opportune equivalence relations.

Figure 1 shows a diagram of the HLKA concept in KAFKA. KAFKA focuses on functional knowledge, procedural knowledge and experiential knowledge. The knowledge artifact to model functional knowledge is ontology. This choice is coherent with the state of the art (Kitamura *et al.*, 2004). In the current version of KAFKA, we adopt taxonomies, linking the different elements of the problem to be solved by means of is-a and part-of relations. The taxonomy allows us to identify the inputs (nodes B, D and E in the figure) and outputs (node A in the figure) of the problem to be solved and the values they can assume, as well as possible partial elaborations (node C in the figure) necessary to move from inputs to outputs. Conceptually, inputs are observations on the field, they are valued by the knowledge seeker by hand or by means of sensors; partial elaborations are the result of a reasoning process, but they should not be presented to the user, except for explanations (i.e. to make evident the different steps of a knowledge-based activity); outputs are the results of a complete decision-making process, obtained from a given set of inputs and partial elaborations. The taxonomy in the figure says us that node A is the process output, depending on the values of input B and partial elaboration C, whose value is determined starting from inputs D and E.

Depending on the specific application, the procedural knowledge may be modeled by two kinds of artifact: influence networks or Bayesian networks. The procedural knowledge goal is to link inputs, partial elaborations and outputs by means of causal relationships, in order to identify the problem-solving strategy. Influence networks allow creating such causal relationships by means of affects and is affected by relationships, which permit to browse the causal dependencies from inputs to outputs and backward from outputs to inputs.

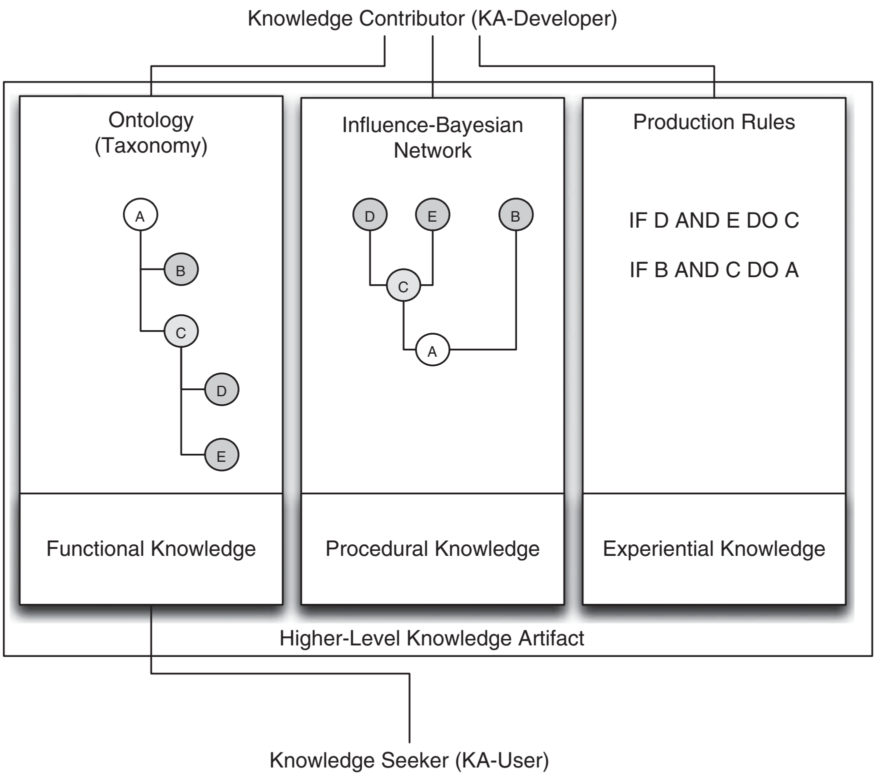



**Figure 1.**
KAFKA scenario: knowledge seekers and contributors virtually communicate to solve a problem in a given domain

The Bayesian network model in KAKFA is, instead, founded on the parent relationship which binds networks nodes from outputs to inputs. A conditional probability table for each node is provided to automatically detect the most probable decision-making strategy to follow depending on the problem state. To design the network, the taxonomy is browsed from inputs to outputs, grouping the nodes according to their level (i.e. inputs, partial elaborations or outputs), as shown in the figure.

Finally, the experiential knowledge is captured by production rules. Each directed link in the influence or Bayesian networks is associated to one or more production rules where the origin node acts as the left hand side, while the destination node serves as the right hand side. Such rules can be either manually designed by the domain expert, guided by the KA-Developer, if the influence network artifact has been adopted (Sartori and Melen, 2015), or automatically by the KA-Developer in case of Bayesian network exploitation (Melen *et al.*, 2015). The final output of KAFKA is a rule-based system written in JESS[1].

Recent developments have allowed us to include time-dependent scenarios in the rule-based systems generation, through the management of shadow facts (Sartori and Melen, 2016) and wearable devices (Pinardi *et al.*, 2016) in KAFKA.

Shadow facts are JavaBeans objects. Being JavaBeans a kind of Java object, shadow facts serve as a connection between the working memory and the Java application running JESS. From the KAFKA development point of view, their most interesting feature is the possibility to choose between their static or dynamic representation in the working memory. A shadow fact is static if its representation changes infrequently or according to an explicit request by the user. On the contrary, a dynamic shadow fact is characterized by a frequent variability over time, with the need for the working memory to keep trace of its changes immediately. Dynamic shadow facts have been used in KAFKA to implement evolution of facts' bases according to the real-time detection of information.

For example, let us suppose we have implemented a rule-based system to support users in taking decisions about patients affected by heart diseases. This application will check heart rate continuously, to be able to recognize possible critical situations. Hopefully, the heart rate will be normal for the most time, causing the activation and firing of standard rules. But the system should be able to detect immediately possible significant up and down oscillations of the heart rate values, and to recognize possible critical situations, avoiding them to become irreversible through the execution of proper actions. Dynamic checks on other parameters of the patient allow us to distinguish such critical situations from non-alarming heart rate variations.

The adoption of dynamic shadow facts to represent such kinds of variables enables a KAFKA-based rule-based system to manage such cases: a state of the system is represented as a collection of shadow facts, whose values can change unpredictably from a time-instant $t_i$ to the next one $t_j$. If the current value of the shadow fact is already known, i.e. rules are available in the system to deal with it, proper actions will be taken on time. Otherwise, new actions will be promoted by the expert through the rules' set extension to take care of the new state.

### *3.2 LPP in KAFKA*

The typical KAFKA domain is shown in Figure 1, which represents two kinds of roles: a KA-User supporting a generic operator solving problems and a KA-Developer, supporting a domain expert in the elaboration of decision-making processes.

The KA-User is a knowledge seeker in the KAFKA scenario: it is characterized by a state, a collection of quantitative and qualitative parameters (observations on the domain) that can be measured by wearable devices or manually inserted to be evaluated by the expert according to a given reasoning. This state can change over time; thus, it is continuously checked by the system in order to discover modifications and take proper actions.

The KA-Developer is a knowledge contributor in the KAFKA scenario: its main role is to support the domain expert in the definition of the three knowledge artifact correlated in the HLKA notion.

In both cases, KA-User and KA-Developer share information about the domain ontology: typically, the KA-Developer designs it supporting the related domain expert, but the KA-User is responsible for its use in the problem scenario. Thus, the KA-User can detect mistakes made by the KA-Developer and suggest how to update the ontology. Typical cases are the detection of new values for an input, or the need for adding new nodes to take care of new events in the problem scenario.

Figure 2 shows the implementation of LPP in traditional KMSs (on the left) and KAFKA (on the right). Knowledge contributors and KA-Developers are responsible for the maintenance of the knowledge model involved. Knowledge contributors feed the KMS with documents or rules to represent their knowledge; KA-Developers modify the KAFKA knowledge artifact structure, by the addition/modification/deletion of nodes in the ontology, new relationships in the influence or Bayesian networks and rules in the rule-based system. Both knowledge contributors and KA-Developers are fully involved in the CoP growth: the main difference between them is that KA-Developers are connected to KA-Users by a direct communication channel, while knowledge contributors and knowledge seekers are not.

Looking at LPP of the other roles involved, both knowledge seekers and KA-Users are on the boundary of the community of practice. Knowledge seekers query the KMS to obtain answers to their problems, being not involved in the knowledge model update. As presented in Sutanto and Jiang (2013), they can exploit recommendation mechanisms to highlight the importance of some parts of the system with respect to others, suggesting (implicitly) possible modifications to the knowledge model. KA-Users, instead, can participate actively in the modification of some parts of the HLKA model (see action 2 in the figure), for example, suggesting the addition of new nodes to the ontology. A new node in the ontology corresponds to the discovery of a potentially important event in the application domain.

Shadow facts may be employed to support also this more complex modification of the HLKA model. By means of the shadow fact execution, the KA-Developer will be notified of

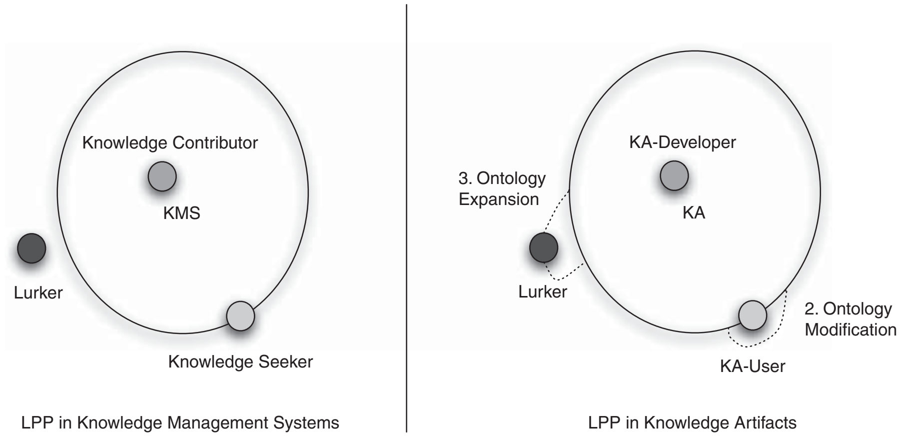



**Figure 2.**
Legitimate peripheral participation in traditional KMS and in KAFKA

the new relevant event. The KA-Developer will be then responsible for the linking of new nodes in the influence or Bayesian network. From this point of view, the CoP boundaries dynamically vary according to the KA-User discoveries: when new nodes are added to the ontology, KA-Users become developers, being involved in the HLKA structure modification. Of course, this change of role is implicit and temporary for most of them.

Lurkers will probably be not fully involved in the CoP, since they are interested in adopting the system to find immediate solution to their problems. For this reason, they will neither be involved in recommendation activities using the KMS nor in suggesting modifications to the ontology within KAFKA. Anyway, being modeled as KA-Users in KAKFA, they will be able to detect new facts (i.e. new values for existing events in the HLKA ontology) in their day-by-day activity supported by the HLKA (see action 3 in the figure). Doing so, thanks to the adoption of the shadow fact construct, the KA-Developer will be notified to consider such detection on the HLKA model.

## 4. Case study: promoting PA in potentially risky subjects

The proportion of the population over 60 is growing rapidly, as highlighted in the United Nations' report on world population aging[2]. Consequently, the Public Health will have to face significant improvements of costs in the next future, primarily related to non-communicable diseases (NCDs) such as cardiovascular and respiratory malfunctions, cancer, diabetes and obesity. PA has been identified as a crucial protection factor against NCDs; despite this, large part of the population does not know and/or follows the suggested PA guidelines, continuing to conduct a sedentary life (Hallal *et al.*, 2012). While traditional behavioral interventions have produced scarce results from the PA promotion point of view (Conn *et al.*, 2011), the availability of new technologies, in particular wearable technologies, can be exploited to develop new applications to support people in modifying their PA behavior.

### *4.1 Virtual communities in PA*

As stated above, a virtual community of practice is characterized by three kinds of roles: knowledge contributors, knowledge seekers and lurkers. In the PA promotion domain, knowledge contributors are domain experts, i.e. professionals in the medical and psychological fields. They are involved in the definition of the knowledge domain structure.

Knowledge seekers are people corresponding to the identikit defined above: they are 35-45 years old persons with a sedentary lifestyle, and no particular physical disease. They know that PA could be useful to improve their general physical and psychological well-being, but they are not able to involve themselves in regular activities. They are not interested in using commercial apps for PA promotion (like Runtastic, Runkeeper, and so on), given that they are not looking for hard, competitive, PA increasing plans, nor for tools to share their personal information with peers. On the other hand, they could be interested in accomplishing group activities. They are interested in the use of tailored applications that can be extended on the basis of their goals, according to their attitudes.

Lurkers are knowledge seekers who prefer to make exercises on their own, without sharing them with others. Moreover, they will not be interested to extend the knowledge model. This means that they will accept the possibility of having no answers to their problems, i.e. the possibility that the system would not be able to produce opportune outputs according to certain inputs.

In the following, we will use the terms KA-Developer and knowledge contributor as synonyms, as well as the terms KA-User and knowledge seeker.

*4.2 Building the knowledge model: the knowledge contributor role*

As specified above, knowledge contributors are domain experts in the PA promotion domain. Given that the scope of experts is to help people to improve their physical and psychological states, the knowledge model should involve both kinds of variables. From the physical point of view, the metabolic equivalent of task (MET) variable is used to estimate the amount and quality of PA accomplished. By definition, MET is defined as the ratio of the metabolic rate (the rate of energy consumption) during a specific PA to a reference metabolic rate:

$$1\ \text{MET} = 1\frac{\text{kcal}}{\text{kg} \times \text{h}} \tag{1}$$

MET is used as a mean of expressing the intensity and energy expenditure of activities in a way comparable among persons of different weight. Actual energy expenditure (e.g. in calories or joules) during an activity depends on the person's body mass; therefore, the energy cost of the same activity will be different for persons of different weight. Here, we are interested in exploiting the relationships between MET and heart beat rate (HBR), given by the following formula (Armstrong and Bonita, 2002):

$$\text{MET} = 4 \times \text{Time}^{\text{MPA}} + 8 \times \text{Time}^{\text{IPA}} \tag{2}$$

where $\text{Time}^{\text{MPA}}$ and $\text{Time}^{\text{IPA}}$ are the periods of time the subject is involved in moderate and intense PA, measured in minutes.

A PA session is defined moderate if the registered HBR values are in the range $(((6 \times \text{MHR})/10), ((7 \times \text{MHR})/10))$, with $\text{MHR} = 220 - \text{age}$ is the subject maximum heart rate, depending on his/her age. A PA session is defined intense if the registered HBR values are in the range $(((7 \times \text{MHR})/10), ((8 \times \text{MHR})/10))$.

According to the general guidelines for PA promotion, a person should be capable to reach 600 METs per week of PA, possibly distributed over two or three days, where 120 METs correspond to 30 minutes of moderate PA.

To take care of psychological well-being, the self-efficacy variable (Bandura, 1977) has been considered. Self-efficacy, also referred as personal efficacy, is the extent or strength of one's belief in his/her own ability to complete tasks and reach goals. Psychologists have studied self-efficacy from several perspectives, noting various paths in the development of self-efficacy; the dynamics of self-efficacy, and lack thereof, in many different settings; interactions between self-efficacy and self-concept; and habits of attribution that contribute to, or detract from, self-efficacy.

Self-efficacy affects every area of human endeavor. By determining the beliefs a person holds regarding his or her capacity to affect situations, it strongly influences both the power a person actually has to face challenges competently and the choices a person is most likely to make. These effects are particularly apparent, and compelling, with regard to behaviors affecting health (Luszczynska and Schwarzer, 2005).

Physical and psychological variables must be homogeneously merged into a unique conceptual framework, in order to build up tailored PA plans. The plan should be developed for several time scales: single session, whole day and whole week of activity.

Figure 3 shows the decision-making process about a single training session. The cycle checks continuously the person HBR to be in the ranges above; in case of positive matching, the time-stamp of moderate or intense activity is updated. The cycle ends when the individual stops the session, and the MET value obtained is calculated according to Equation (2).

A day of PA can be considered as the aggregation of one or more training sessions, as shown in Figure 4. Each of them contributes to the overall MET amount. At the end of the day, the total amount of METs is used to update the week situation. Moreover, the

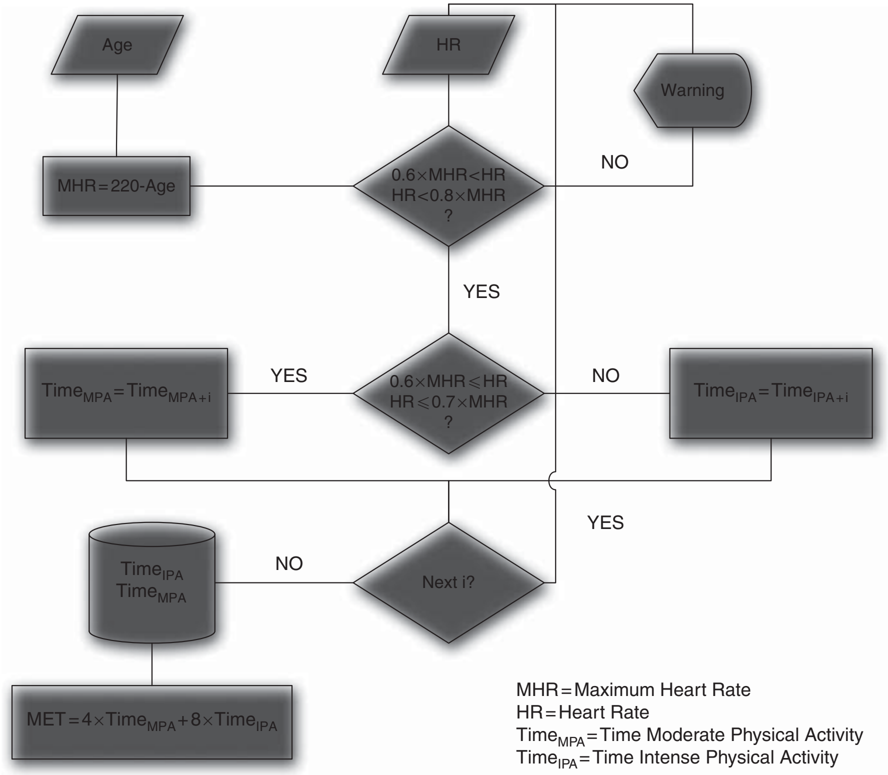



**Figure 3.**
The flow diagram of a PA session

self-efficacy value should be evaluated through a set of questions to the person, each concerning a specific aspect of the PA. The self-efficacy of the day is given by the arithmetic mean of the provided answers:

$$\mathrm{SE}_i = \frac{\sum_{i=1}^{n} \mathrm{answer}_i}{n} \qquad (3)$$

where $n$ is the number of questions posed to the user; and $\mathrm{answer}_i$ the value given by the user, usually an integer value in the range [1-4].

Currently, two questions are proposed to the user to evaluate his/her self-efficacy about the suggested physical activity:

(1) How much do you feel able to do similar training next week, despite its duration?

(2) How much do you feel able to do similar training next week, despite its intensity?

Finally, Figure 5 shows the evaluation of a training week results, as the sum of METs accomplished in the planned daily activities as well as the self-efficacy perceived by the person. The latter is calculated as the arithmetic mean of daily self-efficacies based on Equation (3). At the end of the week, the new plan of training for the next week can be produced, putting together METs and self-efficacy. Self-efficacy must be equal to or greater than a given threshold, that is three in our case study: in case of success, if the total amount of METs produced in the current week was equal to or greater than the required one, an increment of

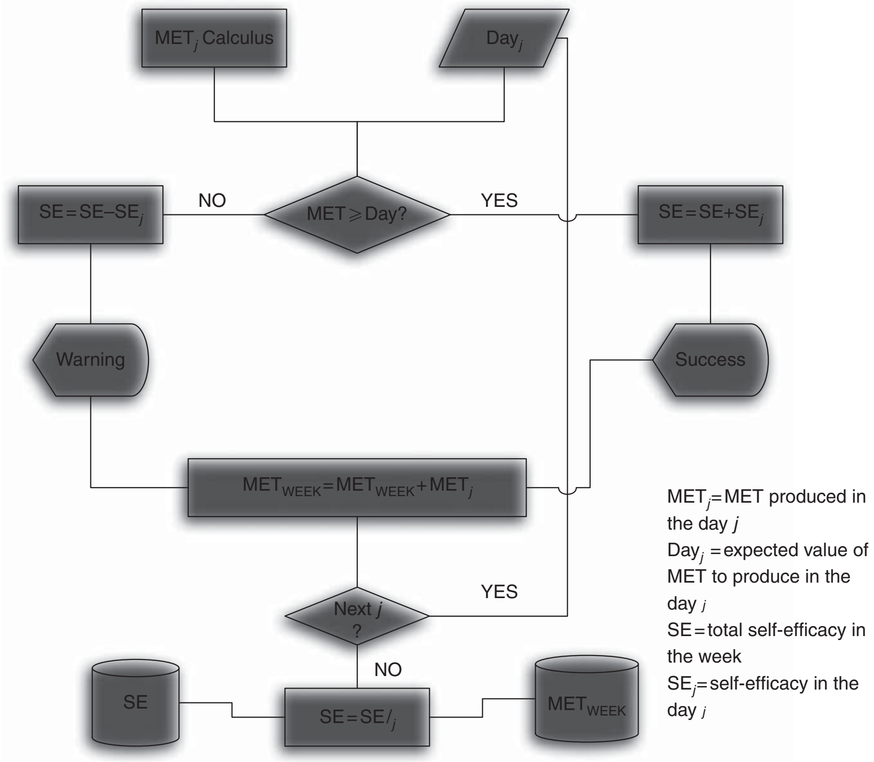



**Figure 4.**
The flow diagram of a day of PA

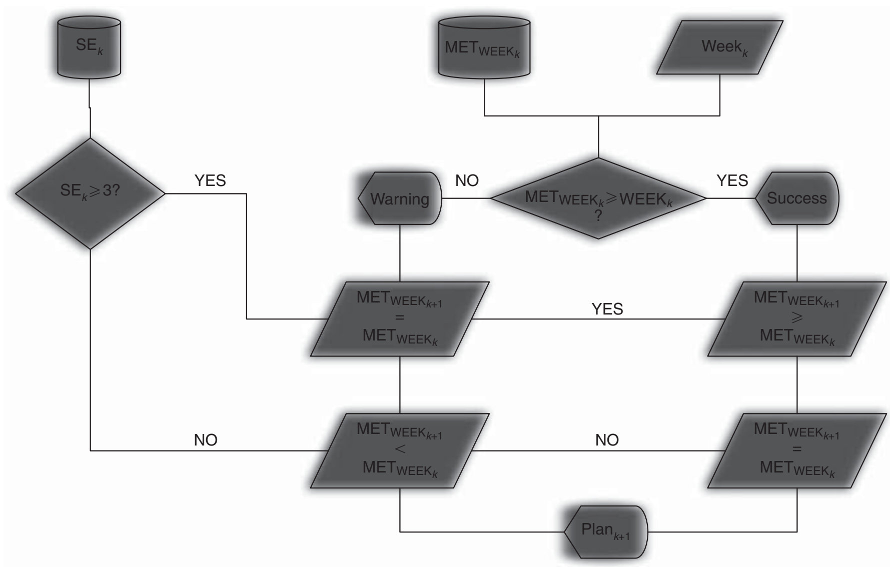



**Figure 5.**
The flow diagram of a week of PA

METs to reach in the following week is proposed. This increment is equal to 120 METs in our case study; otherwise, the number of METS will remain constant, given that the person shows a psychological state too optimistic with respect to his/her physical capabilities. In case of unsuccessful results from the psychological point of view, i.e. the self-efficacy is less than the threshold, the new plan will be the same as the week before if the person has obtained the required amount of METs, meaning that the psychological state of the person is too pessimistic with respect to his/her physical conditions; otherwise, it will be decreased by a 120 METs factor, supposing that the person should be involved in simpler activities.

All the procedures described insofar are implemented by the rule-based system, namely, the KA supporting the experiential knowledge model.

*4.3 Using the knowledge model: the knowledge seeker role*

Today, wearable devices and smartphones offer a great variety of sensors on board: ambient and body-temperature sensors, HBR sensors, light presence sensors, barometric pressure sensors and also inertial measurement units (IMUs) sensors. IMUs have shown to be of particular importance in the field of situations assessment to determine body movements and type of executed actions (Bao, 2003; Avci *et al.*, 2010). Via the IMUs sensors, it is possible to determine: the angular movements of a joint of the body and its geometrical trajectories, having some a priori determinants, i.e. knowing which portion of the body the sensor is applied to and which exact position it is placed on; the dynamics of the related motion, i.e. the accelerations and angular velocities to which the segment is subjected. These data are measured at run-time, and all information can be stored with their timestamps, for successive analysis and tests.

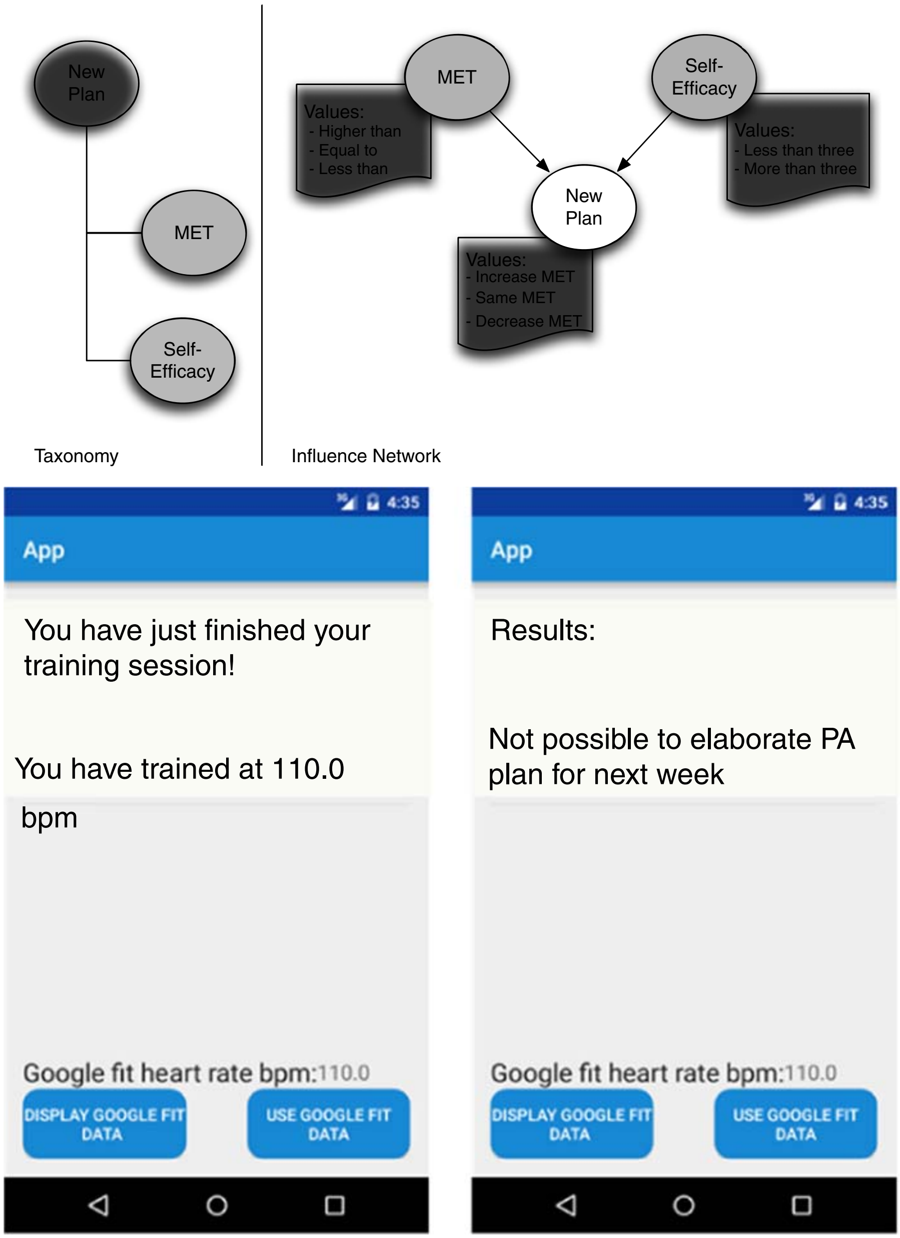
The knowledge seeker plays a crucial role not only in using the knowledge artifact produced by contributors, but also in criticizing it, being involved in its possible modifications. This is made possible by providing him/her with tools for detecting values from the KA application field. In our case study, the adoption of wearable sensors permits to continuously check for user HBR, feeding the knowledge model described above. The user can evaluate the knowledge artifact suggestions, identifying possible errors as well as ways to improve the model.

The KAFKA framework offers different ways of interacting with the knowledge artifact, depending on the level of involvement a KA-User wishes to reach.

The simplest way is acting as a lurker: the KA-User exploits the knowledge artifact to solve his/her problem as is, providing the necessary input values. In case of values not included in the model, the framework will fail in producing an output and the KA-Developer will be notified to extend it properly. In the PA case study, this situation can occur when the person HBR is out of the considered range for moderate or intense activity.

Figure 6 shows how the problem is depicted in KAFKA. The left part of the figure shows the results of a PA session conducted at 110 bpm, with the consequence that is impossible to calculate METs on the basis of Equation (2) and define a new training plan. The KA-Developer is then informed about the knowledge artifact failure and can modify the knowledge model including new values and rules to take care of them. This modality implies the adoption of influence networks as the procedural knowledge representation artifact (Sartori and Melen, 2016), as presented on the top of the figure.

The second possibility is acting as a knowledge contributor: the KA-User exploits the knowledge artifact not only to solve his/her problem, but also to suggest modification to the underlying knowledge model. KAFKA provides this kind of users with an opportune interface to update the domain ontology. The user can add nodes as well as relationships with other nodes: the framework automatically generates rules to take care of modifications in the domain ontology, thanks to the procedural knowledge management by means of Bayesian networks (Melen *et al.*, 2015).




**Note:** Procedural knowledge involved is modeled as an influence network

**Figure 6.**
KAFKA notification of problems in knowledge artifact modeling

Figure 7 shows the interface to describe the ontology and the Bayesian network in KAFKA. The sample is related to the decisional process in Figure 5, where the suggestion to increase, decrease or maintain the PA plan for the next week depends on the current week self-efficacy and MET value. New plan is the output of the system, depending on

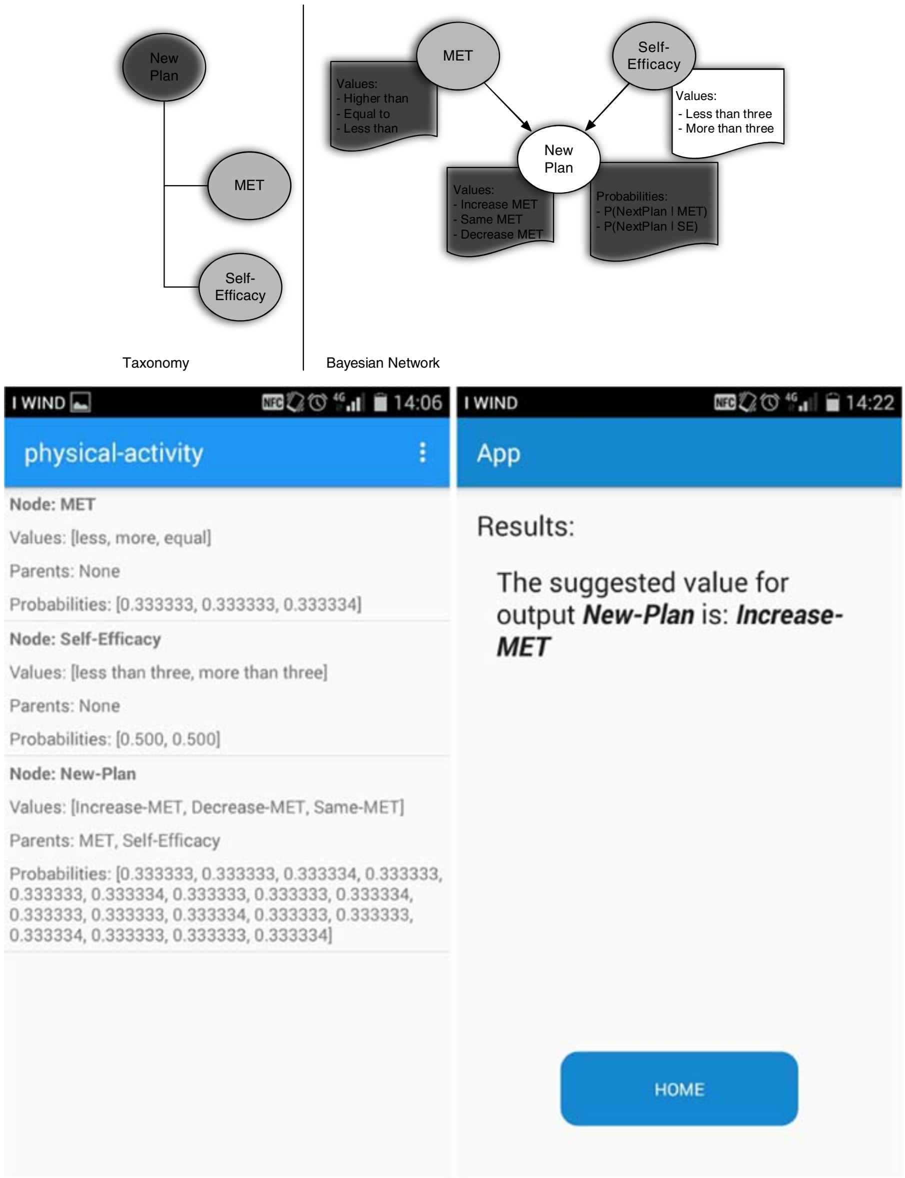



**Figure 7.**
KAFKA graphical use interface for the KA-developer

self-efficacy and MET, that are the inputs. The KAFKA framework automatically creates a Bayesian network (sketched on the top of the figure) where self-efficacy and MET are the evidences and the new plan is the outcome. CPTs for each node are calculated and the Bayesian network is used to automatically generate a rule-based system where the evidences are the left hand side and the outcome is the right hand side of each rule.

Figure 8 shows a possible modification on the situation depicted in Figure 7, where the self-efficacy node depends on the waistline input; the self-efficacy value will be higher if

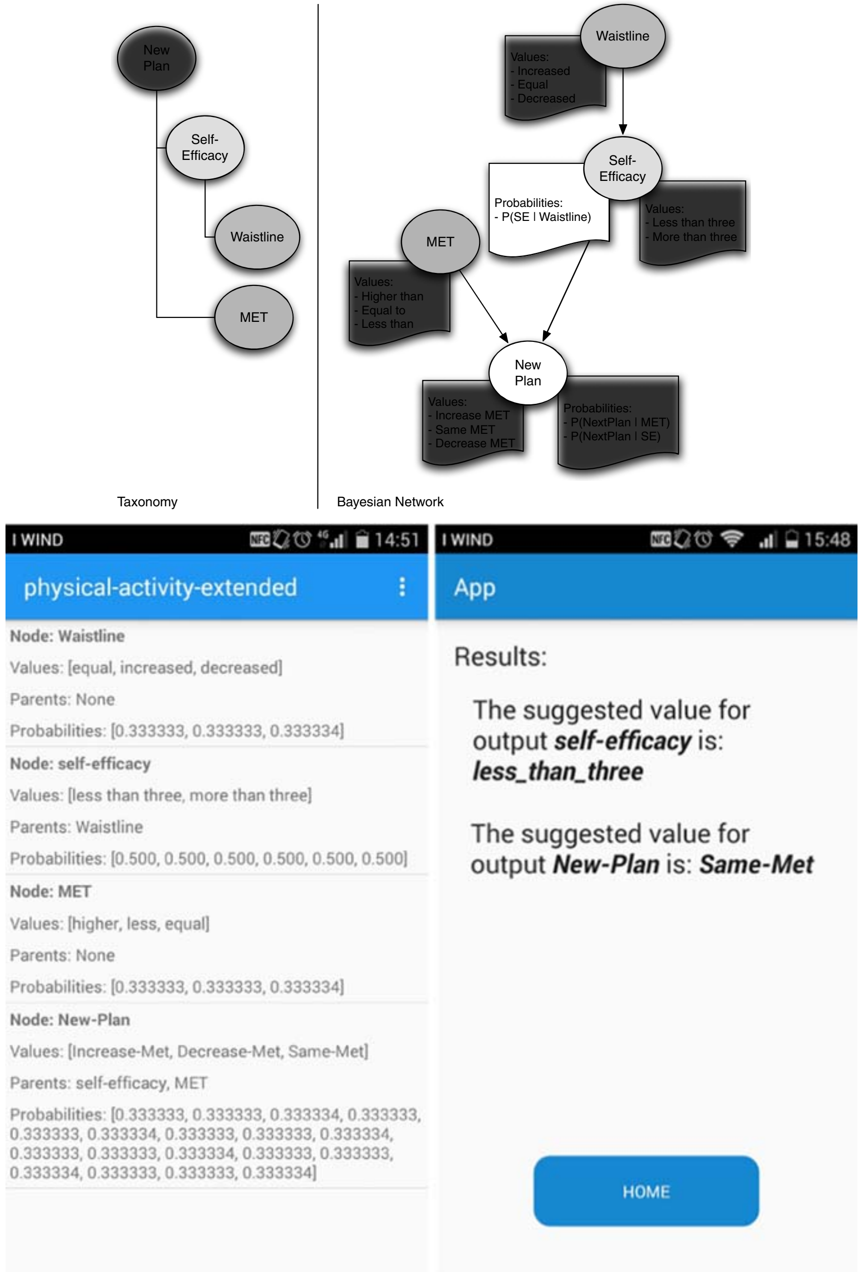



**Figure 8.**
Modifying the knowledge artifact: self-efficacy becomes a partial output depending on waistline input

the waistline decreases thanks to the training. The addition of the waistline node and the relationship with the self-efficacy one can be made by the KA-User itself: the KA-Developer will be notified about the change in the knowledge artifact structure, in order to eventually modify the rules automatically produced by the Bayesian network.

### 4.4 *The Muoviti! app prototype*

The knowledge artifact modeled in KAFKA has been exploited to design and implement a first prototype of application to support physical activities, namely, the Muoviti! app. The app is developed under Android 5.1 OS and is conceived to support KA-Users of the community to plan their training on instantaneous, daily and weekly timing scale.

Different from most applications available on the market, the main goal of Muoviti! is to provide suggestions customized on the physical and psychological well-being state of the user, represented by quantitative (e.g. HBR and age) and qualitative (e.g. self-efficacy) variables. These variables can be inserted manually by the user or derived automatically by the wearable technologies adopted by the app.

Figure 9 shows the schematic architecture of the application and the frontend graphical user interface. The KA-User is implemented on a smartphone running Android OS 5.1 or higher and equipped with Bluetooth 4.0 or higher and one or more wearable devices to record the HBR. The application can be interfaced both with Android Wear and with other kinds of devices. The user registers himself/herself specifying the birthdate and the name. The birthdate is used to calculate the subject maximum heart beat rate (MHBR). When the user logs in for the first time, the system proposes to him/her the initial PA program, corresponding to 120 MET per week split into three sessions. The sessions are automatically arranged by the application on the calendar: the user can modify their allocation according to his/her duties.

When a session should start, the user can launch the app selecting the wearable device to use for HBR monitoring and activating it. This means that the app does not always monitor the user activity, since he/she should be educated to make exercises according to a plan. Every kind of PA is registered (also swimming, if the adopted wearable device is water-proof): it is mandatory that such activity is made at given HBR frequencies (between $0.6 \times$ MHBR and $0.8 \times$ MHBR), that are registered as a CSV file on the smartphone, each with the related time-stamp. The user can pause the detection or definitely stop it: in the first case, new data will not be registered till resumption, in the second case the session will be closed and the MET and self-efficacy computation will be accomplished.

These data are then sent to the server, where the knowledge artifact designed and implemented by the KA-Developer is placed. At the end of the week, the server executes the rule-based system introduced above to determine the new plan for the next week.

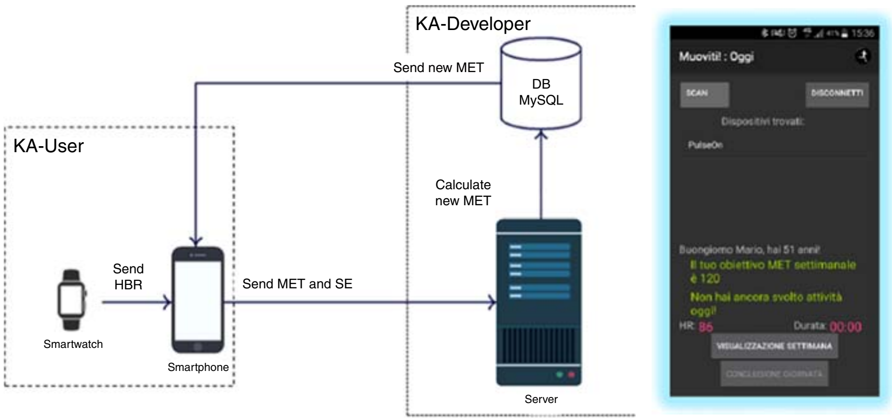



**Figure 9.**
The architecture and interface of the Muoviti! app

## 5. Results and discussion

Measuring how technology influences the evolution of communities of practice is not trivial, being necessary to evaluate quantitatively the concept of SOVC. Virtual communities face a different environment than traditional, "offline" communities. For example, they are characterized by anonymity, and the possibility to transgress social boundaries in case no sanction occurs (Schroeder and Axelsson, 2006).

Thus, many doubts arise about the application of traditional SOC measures to SOVC: while SOC is quantitatively measured by means of the well-known sense of community index (SCI) (Chavis *et al.*, 1986), some works have pointed out the difficulties for this index to evaluated SOVC (Blanchard, 2007). Abfalter *et al.* (2012) proposed recently to adopt a refined version of SCI, namely, SCI2 (Chavis *et al.*, 2008): this index consists of 24 closed-ended items measured on Likert-like scale (not at all = 0, somewhat = 1, mostly = 2, and completely = 3).

The items are grouped into four dimensions: reinforcement of needs (RON), membership (MEM), influence (INF) and shared emotional connection (SEC). By definition, the total sense of community index ($\mathrm{TSOC}^I$) is:

$$\mathrm{TSOC}^I = \sum_{i=1}^{24} Q_i \tag{4}$$

where $Q_i$ is the value in the range [0-3] given by the user to the $i$th question. Subscales values can be obtained through the following equations:

$$\mathrm{RON} = \sum_{j=1}^{6} Q_j \tag{5}$$

$$\mathrm{MEM} = \sum_{k=7}^{12} Q_k \tag{6}$$

$$\mathrm{INF} = \sum_{l=13}^{18} Q_l \tag{7}$$

$$\mathrm{SEC} = \sum_{m=19}^{24} Q_m \tag{8}$$

In our study, we have exploited $\mathrm{TSOC}^I$ to measure the impact that frameworks like KAFKA potentially have on the creation and maintenance of communities of practice in domains similar to the case study. In particular, we are interested in evaluating if knowledge management systems based on the knowledge artifact notion can support communities of practice to evolve. To this aim, we introduce the notions of lurking, seeking or contributing communities on the basis of their $\mathrm{TSOC}^I$ value.

A community of practice is said lurking if its total SCI $\mathrm{TSOC}^I_L$ is less than the product of total number of participants and the number of items in the questionnaire:

$$0 \leqslant \mathrm{TSOC}^I_L = \sum_{j=1}^{n} \sum_{i=1}^{m} Q_i \leqslant n \times m \tag{9}$$

where $1 < m \leqslant 24$ is the number of items; and $n$ the number of people involved in compiling them. A CoP is lurking if all its members answer, on average, not at all or somewhat to each question.

A community of practice is said seeking if its total SCI $\mathrm{TSOC}_S^I$ is greater than $\mathrm{TSOC}_L^I$ and the product of total number of participants and the number of items multiplied 2 in the questionnaire:

$$\mathrm{TSOC}_L^I < \mathrm{TSOC}_S^I = \sum_{j=1}^{n} \sum_{i=1}^{m} Q_i \leqslant 2 \times n \times m \tag{10}$$

where $1 < m \leqslant 24$ is the number of items and $n$ is the number of people involved in compiling them. A CoP is seeking if all its members answer, on average, somewhat or mostly to each question.

Finally, a community of practice is said contributing if its total SCI $\mathrm{TSOC}_L^I$ is greater than $\mathrm{TSOC}_S^I$ and less than the product of total number of participants and the number of items multiplied 3 in the questionnaire:

$$\mathrm{TSOC}_S^I < \mathrm{TSOC}_C^I = \sum_{j=1}^{n} \sum_{i=1}^{m} Q_i \leqslant 3 \times n \times m \tag{11}$$

where $1 < m \leqslant 24$ is the number of items and $n$ is the number of people involved in compiling it. A CoP is contributing if all its members answer, on average, mostly or completely to each question.

### *5.1 Participants*

We have involved in the research 25 people as KA-Users. They have been asked to answer the same questionnaire before and after KAFKA usage. The Muoviti! app has been used to make them able to understand the benefits of tools like KAFKA in their day-by-day lives. The people were initially informed about the importance of PA and methods to improve it. This step was crucial to make them able to share the same goals and the knowledge model of the case study. In particular, the concepts of MET and self-efficacy have been introduced, as well as the method to integrate them into the PA suggested plan.

Then, they were asked to compile the questionnaire for $TSOC^I$ calculus.

### *5.2 Measures*

Although the guidelines for $TSOC^I$ calculus recommend the set of 24 questions is completely considered, we have cut off it as suggested by previous researches (Abfalter *et al.*, 2012): 13 of them were selected.

The questionnaire was submitted to the group at the beginning of the analysis and after one month of use of KAFKA and Muoviti!, to calculate the possible variations in the global SOVC due to the adoption of KAKFA.

In this preliminary analysis, we have focused on the whole community rather than on single participants. Table I reports the total SCI and its subscales. The choice has been to maintain the basic structure of the questionnaire, as suggested by guidelines, contextualizing the question with respect to the case study. The possible values of items have been classified as lurking if equal to not at all or somewhat, contribution otherwise. In this way, it could be possible to understand if KA-Users involved in the study are active members of the community, or not; in the second case, it is also possible to understand if and how a lurker can change his/her status to knowledge contributor, trying to deduce if

| Dimensions items | $Value_1$ | $Value_2$ | $\delta$ |
|---|---|---|---|
| *Reinforcement of needs* | 88 | 190 | +102 |
| Q1: I get important needs of mine met because I am part of this community | 8 | 50 | +42 |
| Q2: Community members and I value the same things | 44 | 66 | +22 |
| Q3 This community has been successful in getting the needs of its members met | 0 | 43 | +43 |
| Q6: People in this community have similar needs, priorities and goals | 36 | 31 | −5 |
| *Membership* | 37 | 102 | +65 |
| Q9: Most community members know me | 37 | 37 | 0 |
| Q10: This community has symbols and expressions of membership … that people can recognize | 0 | 22 | +22 |
| Q11: I put a lot of time and effort in being part of this community | 0 | 43 | +43 |
| *Influence* | 114 | 148 | +34 |
| Q13: Fitting into this community is important to me | 43 | 29 | −14 |
| Q15: I care about what other community members think of me | 48 | 61 | +13 |
| Q18: This community has good leaders | 23 | 58 | +35 |
| *Shared emotional connection* | 71 | 136 | +65 |
| Q19: It is very important to me to be a part of this community | 29 | 56 | +27 |
| Q20: I am with other community members a lot and enjoy being with them | 21 | 57 | +36 |
| Q22: Members of this community have shared important events together | 21 | 23 | +2 |
| Total sense of community index | 310 | 576 | +266 |

**Table I.**
Items to calculate SOVC and their evaluation before ($V_1$) and after ($V_2$) the usage of KAKFA

the sharing of knowledge about the domain is modified thanks to the introduction of knowledge artifacts.

The table clearly shows a positive trend in the sense of community evolution: the community moves from the initial lurking state to the final seeking one. The questionnaire has been repeated after four weeks of usage of the Muoviti! app: each week five members of the community were provided with the necessary equipment: a wearable device, namely, a PulseOn wristband for the detection of HBR and the app for the planning of PA. Doing so, only one of the five initial groups has not been provided with the application. The answers given by the members of this group were substantially similar to the initial ones, while the adoption of the knowledge artifact described positively influences the involvement of other groups. While the very significant improvement of RON subscale was favored by the really low level of initial evaluation, increasing of MEM and SEC dimensions are really impressive.

From the MEM point of view, the variation of item Q11 is the most interesting, being motivate by the effort of participants in extending the knowledge model, for example, the relationship between waistline input and self-efficacy, introduced above, was proposed by the users. Other important suggestions were the inclusion of more traditional parameters like calories burned during PA, distance run and the monitoring of weight variations.

From the SEC perspective, it is important to highlight how the usage of the Muoviti! app has allowed to the group members to synchronize their PA agendas, promoting the accomplishment of collective training sessions rather than individual ones. This aspect suggested us future developments of the app in the social network direction.

To validate these findings, we followed the approach envisioned in Cabitza and Locoro (2017) and classified the community by statistical hypothesis testing at a confidence level of 95% and significance level of 0.05. Since the SOCV questionnaire encompasses items defined on a four-level ordinal scale (0-3) we associated a binomial testing procedure with the three possible categories mentioned above by assuming the null hypothesis proportion of 0.50 (see column test probability in Table II). In general, if the procedure is not able to detect a statistical significant difference between the number of either 0 or 1 responses (cf. Group 1 in Table II) and the number of either 2 and 3 responses (cf. Group 2 in Table II), then the community is denoted as a "seeking" one. Otherwise, if a statistical significant difference is detected, the community is denoted as either "lurking" or "contributing" according to whether the cardinality of Group 1 is greater than the cardinality of Group 2 or not, respectively.

In particular, Table II shows the results of the test procedure for our case study produced by IBM SPSS (v. 22). From these results it is clear that we could associate the community at hand with an extreme category (i.e., either lurking or contributing) in both experimental conditions, since the observed significance level (or $p$-value, or Exact Sig. in Table II) was found to be lower than 0.05 (in fact it is lower than 0.001).

Comparing this conclusion with Equations (9)-(11), further considerations can be made. The lurking condition of the community before using KAKFA was correctly predicted by the $TSOC_L^I = 310$ value. According to the $TSOC_S^I = 576$ value, the community after the KAKFA usage should be seeking rather than contributing. This issue seems to suggest that the indexes proposed in Equations (9)-(11) can be considered useful to approximate quickly the state of a virtual community, but they should be further investigated to analyze the boundaries between two consecutive conditions. Indeed, the $\mathrm{TSOC}_S^I = 576$ characterizes a seeking community that tends to become contributing, positioning it in a sort of intersection between the two regions. These results will be addressed by our future works.

## 6. Conclusions and future works

Communities of practice have been always conceived as important centers for knowledge sharing and creation inside organizations. Thus, disciplines like knowledge management are interested in developing tools to support their promotion and maintenance. The continuous improvement of mobile technologies, as well as their availability at relatively low costs offers new possibilities to support them.

In our opinion, the most important aspect to focus on is the possibility to exploit wearable technologies to involve knowledge seekers at knowledge contribution level, trying to reduce the lurking level of KMSs users. To this aim, we have proposed an innovative and still on-going research on KAFKA, a methodology for the development of decision support systems based on the knowledge artifact concept. The most interesting feature of KAKFA is the integration of wearable technologies and knowledge engineering implementation tools into a unique conceptual and computational framework. In this way, knowledge seekers can participate in the knowledge modeling tasks, suggesting new variables and relationships among them to consider. Knowledge seekers and contributors, although still considered as distinct roles in the knowledge artifact creation and maintenance, share some parts of the knowledge domain. Different levels of interaction with the underlying knowledge artifact have been thought, according to the level of involvement reached by the knowledge seeker.

| Group | Category | $n$ | Observed prob. | Test prob. | Exact Sig. (2-tailed) |
|---|---|---|---|---|---|
| *Value₁* | | | | | |
| Group 1 | $\leqslant 1$ | 231 | 0.71 | 0.50 | 0.000 |
| Group 2 | $> 1$ | 94 | 0.29 | | |
| Total | | 325 | 1.00 | | |
| *Value₂* | | | | | |
| Group 1 | $\leqslant 1$ | 119 | 0.37 | 0.50 | 0.000 |
| Group 2 | $> 1$ | 206 | 0.63 | | |
| Total | | 325 | 1.00 | | |

**Table II.** The results of the binomial test for the community of our case study

To show the applicability of KAFKA, the PA promotion domain has been presented. We have introduced how a knowledge artifact can be created and updated by knowledge contributors and seekers. Moreover, we have presented the Muoviti! app as a first prototype of application developed thanks to the active collaboration between knowledge seekers and contributors. The Muoviti! app has been designed and implemented to be used with different kinds of wearables, allowing every person to enter the community as he/she prefers. This approach is completely different from other similar applications, like PulseOn or FitBit, that are tailored on specific devices to work. Another important difference between the Muoviti! app and similar ones is its devotion to target users not considered before, that are adults with no particular physical diseases. Most similar applications, like King *et al.* (2013), are focused on elderly people. The scope of Muoviti! is different, being the target users involved in so many activities that is difficult for them planning time for improving their conditions. Moreover, the Muoviti! app is, at our knowledge, the first attempt to put into a unique conceptual and computational framework quantitative variables measured by wearables and qualitative, psychological indicators usually detected at hand by the specialist. The final aim of this approach is supporting user to improve his/her lifestyle, taking care of both his/her physical and psychological well-beings. The adoption of KAFKA allows to extend this model in the future, to consider new variables in the decision-making process.

We have also presented the preliminary results of experiments conducted on a small community of users: despite the small number of people involved in the study and the limited period of time it has been accomplished, results have demonstrated how the knowledge artifact approach can significantly increase the SCI in virtual communities of practice. This measure has been used to understand if the people involved in the analysis were able to act as a community rather than a simple set of users. For this reason, we have tried to evaluate both the lurking and contributing percentage of participation. The users have been provided with KAFKA to test their capacity to propose extensions to a given knowledge model and their overall involvement in the knowledge maintenance process. During the five weeks of experimentation, we have observed (most of) them to collaborate in the analysis of the app, its graphical user interface, its inputs and outputs. As introduced above, the waistline proposal of a quantitative variable to evaluate self-efficacy is one of the results obtained in this step, where knowledge seekers have become knowledge contributors. But many other points have been highlighted that we are considering in order to extend the app, like the modification of user interface to include maps, the inclusion of graphs to summarize results obtained, and so on.

From this point of view, we can state these preliminary results are encouraging.

From the theoretical point of view, future works are oriented to improve the integration among components of the HLKA; in particular, the relationships between ontology and Bayesian network should be further investigated to increase accuracy in the generation of rules.

From the practical point of view, wearable technologies could be exploited to provide prototypes and applications developed from KAKFA with new interesting functions to support virtual communities, like social network management, real-time notifications to participants, and so on. In the case study domain, we are interested in expanding the Muoviti! app with the possibility to share results obtained as well as training sessions. To develop the social component of Muoviti! the collaboration of target users is crucial; in fact, it is not clear at the moment if group activities have better impact on individual results and motivation. The results obtained in SOVC improvement encourage us to make deeper research in this direction.

## Notes

1. http://herzberg.ca.sandia.gov
2. www.un.org/esa/population/publications/WPA2009/WPA2009_WorkingPaper.pdf

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