Architecting E-Coaching Systems: A First Step for Dealing with Their Intrinsic Design Complexity

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E-coaching systems are a highly valuable asset for promoting healthier lifestyles. However, the design of these systems is intrinsically complex. This article proposes a loosely coupled architecture to support the modeling of e-coaching solutions, reducing design complexity and enhancing the flexibility required for the e-coaching process.

E-coaching is a plan conducted by a system to lead a person from an initial stage to a target goal—for example, to make sure that a sedentary person walks for 30 minutes every day. The plan typically includes a set of milestones (interim goals) and several potential paths (coaching actions) that can be used to reach milestones. However, the suitability of each path depends on a particular coaching context (for example, personal characteristics and behavioral attitudes), the coaching goal to be reached, and the user's current progress. Therefore, the paths in the coaching process must be defined dynamically (considering the set of available alternatives) and be based on the current context and past experiences of the user.

The widespread use of smartphones and commercial wearable devices—such as Fitbit, Nike+ FuelBand, and Jawbone UP—has created several opportunities to develop e-coaching systems for health prevention.[1] Bart Kamphorst defines an e-coaching system as "a set of computerized components that constitutes an artificial entity that can observe, reason about, learn from, and predict a user's behaviors, in context and over time, and that engages proactively in an ongoing collaborative conversation with the user in order to aid planning and promote effective goal striving through the use of persuasive techniques."[2] Although these systems are typically autonomous, they can also be used to support blended coaching strategies in scenarios where humans

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(for example, health specialists) play an active role. Typically, the complexity of these systems increases with their required level of autonomy.

Designing e-coaching systems, particularly those addressing healthcare scenarios, is intrinsically complex. It requires knowledge from several domains (psychology, health, persuasive computing, human–computer interaction, data science, and software engineering[3,4]), and the design must be context-aware. In this sense, the system design must consider not only the sensing and representation of the e-coaching context, but also contextualized reasoning and learning based on the impact of past coaching actions.[2,5] Moreover, making these systems effective requires dealing with the complexity of identifying suitable persuasion mechanisms, using artificial intelligence techniques, and implementing system personalization (using self-adaptive mechanisms based on user models and context).[5]

In addition, there are almost no structural design guidelines (such as reference architectures or patterns) to help deal with such complexity. Therefore, software designers and researchers must conceive and model these systems using their intuition instead of reusing designs that have proven to be useful in the past.

To reduce the complexity of designing these systems, we present a loosely coupled architecture for e-coaching systems (LAES), which addresses the main design concerns of these systems and decouples the system structure from its behavior. This strategy allows for addressing the design of these systems in an incremental way to obtain a flexible solution that can self-adapt its behavior during the coaching process. The proposed architecture also provides a guide for conceiving e-coaching systems and exploring the particular design concerns (persuasion, self-adaptation, personalization, reasoning, and diagnosing). This represents a first step toward a personal informatics theory that organizes, understands, and contextualizes the knowledge in this study domain, helping to address the study and modeling of these systems in a more affordable way.

E-COACHING SYSTEM DESIGN

Kamphorst[2] proposes a set of minimal features that e-coaching systems must include: social ability, credibility, context-awareness, personalization (user tailoring), learning of user behavior (including behavior change), proactiveness, and guidance (coaching planning). These requirements can be used as a checklist to determine the potential coaching capabilities under development or in already implemented systems or designs. However, the relations among these requirements are not explicit, so it is not clear how to use them for constructing a system model.

It is important to note that the design of these systems involves two major concerns: the system structure and its e-coaching mechanisms. The system structure determines the capabilities potentially required by the system to conduct a coaching process, such as context awareness, decision making, and self-adaptation. This structural design must be independent of any coaching task and represents only the underlying infrastructure of the intelligent system. Typically, this design is quite conceptual and generic; therefore, it can be reused to conceive or adjust other e-coaching solutions.

The second design concern (e-coaching mechanisms) is focused on determining how to properly use the available resources to conduct the e-coaching process in an effective way. This design stage includes the definition of the particular e-coaching process and work context to be considered in the application domain. This also includes characterizing the target person (such as gender, age, attitude, coaching goal, progress, and past experiences). Suitable results of this second design stage are more difficult to reuse because they are context-dependent. Therefore, they are recommended to be used only in the same or similar application contexts. Both design concerns are mandatory and equally challenging for designers. However, addressing the latter makes sense only if the former has been properly identified. Software engineering has shown that reusing this type of solution (design and architectural patterns for a particular application domain) reduces the design complexity of systems.

Although related literature reports that many e-coaching systems support healthcare scenarios,[1,3,6] in most cases the reusability of these designs tends to be low or null for several reasons. For instance, many proposals present their system designs as the fusion of structural and specific coaching components.[7–9] Given their specialization, they are potentially reusable only when designing systems that follow the same coaching purposes and are therefore used in the same application context. In many other cases, the designs are presented as articulated collections of software and hardware components, representing the system infrastructure. These designs are usually addressed in certain types

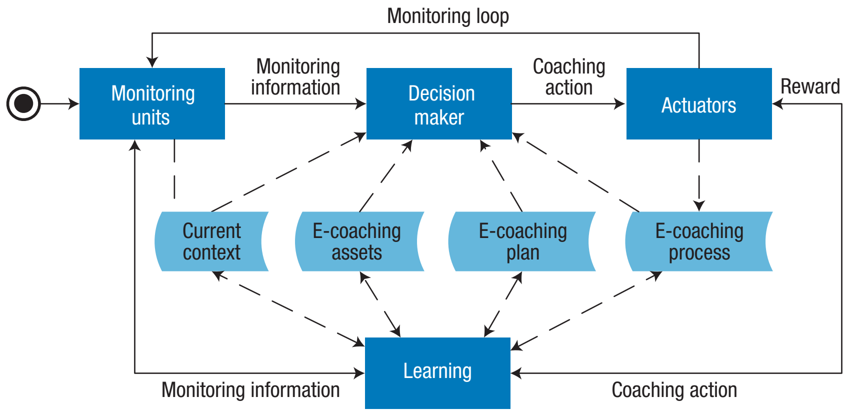

FIGURE 1. Conceptual model of an e-coaching system.

of systems, such as socially assistive robotics[10] and Internet of Things–based health-supporting systems.[11] The reusability of these designs is also limited, not only because specialized and general structures should be reused together, but also because of the high complexity of these supporting technologies, which makes these proposals obsolete in the short term.

The literature also reports some conceptual models that can be used to support the structural design of e-coaching systems and thus help deal with their inherent design complexity. Some of the most well-known models are Computerized Behavior Intervention,[12] PHG (personalized health guide),[13] the transtheoretical model of behavior,[14] and several flavors of cognitive architectures.[15] These models are highly useful and reusable, but they represent the system structure in terms of psychological and cognitive concepts. They do not propose a conceptual representation from a software engineering point of view. Therefore, developers—although being able to reuse these models—still have to bridge the gap between what the models propose and what needs to be designed for the operative structure of the e-coaching system.

A CONCEPTUAL MODEL

The structural design identifies the main components of the system, as well as the way in which the components interact to provide contextualized e-coaching services (see Figure 1). This structure organizes the system in terms of functional components and supporting data, and it recognizes the four major activities of the e-coaching processes: monitoring, decision making, persuasion/awareness provision, and diagnosing/learning.[2,4]

The first component monitors particular context variables and events, and accordingly informs both the e-coaching decision maker and the learning unit.[3] It also includes the notification of relevant changes in the e-coaching context. The decision maker uses this input to determine whether an e-coaching action is required. If it does, that component determines when and how to intervene in the user space, as well as what action is required to be triggered to persuade the user to do something or to make the user aware of a situation.[4] The actuator conducts the coaching actions, which can be persuasive or reflective.[3] Persuasive actions motivate behavior change using explicit actions, whereas reflective actions provide awareness information that can be accessed on demand by the user.[16]

The impact of each coaching action should be evaluated to determine not only its usefulness in the future, but also to assess the need to trigger a new action if the former action was not effective. A learning unit is in charge of this activity, which also delivers intrinsic or extrinsic rewards to keep the user engaged with the e-coaching process.[16] As shown in Figure 1, the first three components run the monitoring loop, and the last component improves the knowledge available for performing more effective coaching actions in the future.

The e-coaching process should also count on supporting information to properly perform the activity. As depicted in Figure 1, this information includes the current context, the e-coaching assets, the e-coaching plan, and the e-coaching process. The current context characterizes the ongoing coaching situation, which includes the user model, the status of the context variables being monitored, and the sequence of events sensed by the monitoring units.[3,5] The e-coaching assets include the contextualized and prioritized rules and actions that can be used to instantiate and adjust the coaching plan. The plan establishes the interim and final goals, but the details about how to reach these goals should be built on demand by the learning unit according to previous experiences and using the available e-coaching assets. It is important to note that the findings

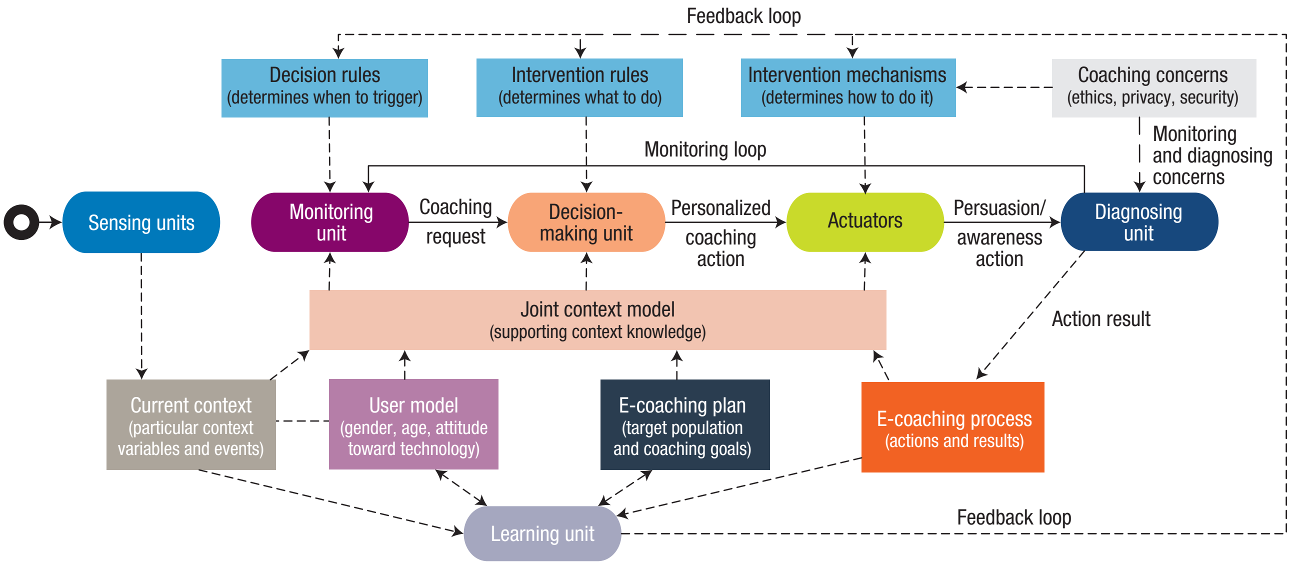

FIGURE 2. Loosely coupled architecture of an e-coaching system.

reported in e-coaching studies can be represented as contextualized assets and thus become reusable for developers and researchers.

Finally, the e-coaching process establishes the sequence of actions and rewards delivered to the user, trying to move the user's behavior from the current status to a target status. Given that these actions temporarily affect the user behavior, the feedback obtained from each action is recorded in the e-coaching process and then used to adjust the coaching plan, the context status, and the priority of the available assets.

In this conceptual model, the behavior of the e-coaching system is mainly specified through data representations. Therefore, it can be tailored, personalized, and extended on the fly (for example, through unattended remote updates) without changing the system source code. This design strategy makes these systems more flexible, adaptable, and better prepared to address medium-to-long coaching processes. According to Thomas Fritz and his colleagues,[3] most systems reported in the literature only evaluate their effectiveness in the short term, probably because their behavior adaptation requires changing source code. In this sense, LAES makes it easier for the system to self-adapt and can even improve the system behavior according to the current e-coaching context and process evolution.

LAES: LOOSELY-COUPLED ARCHITECTURE FOR E-COACHING SYSTEMS

Figure 2 shows the LAES architecture, which was derived from the model shown in Figure 1 but includes many more design details. For instance, the component initially identified as "e-coaching assets" was divided into four pieces of knowledge: the decision rules that determine when a coaching action is potentially required; the intervention rules that establish what action to take according to the coaching context; the intervention mechanisms that indicate how the coaching action must be conducted; and the coaching concerns that establish the ethics and privacy and security issues to be considered during the e-coaching process. This definition of e-coaching assets is aligned with the steps identified by Heleen Rutjes and her colleagues[4] to conduct an e-coaching action. These pieces of knowledge are contextualized because the suitability of their components is typically expressed through predicates that involve context variables and values assumed by them. Therefore, the findings of the studies reported in the literature can be specified as rules, intervention mechanisms (to persuade or provide awareness), and constraints to the e-coaching actions.

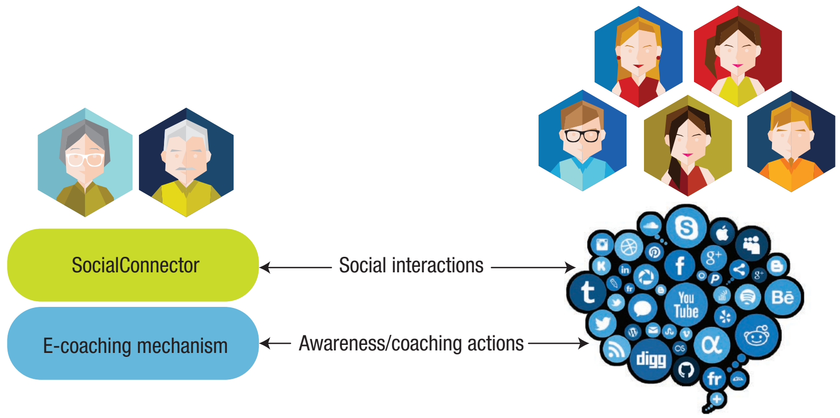

FIGURE 3. E-coaching scenario of the SocialConnector system.

The previous monitoring units component is now decoupled into sensing and monitoring units. Sensing units are in charge of keeping the value of the context variables updated, and monitoring units identify context changes and determine whether they eventually require a coaching action. This structure adheres to a regular self-monitoring process, like the one described by Michael Klein and his colleagues.[12] Therefore, it represents an input for the decision-making process.

The previous decision maker and actuators were not specified in detail because their design will depend on the particular coaching activity they are supporting. Therefore, their design will not be reusable in another context. The previous learning unit was decoupled into two loosely coupled components: the diagnosing unit and the learning unit. The diagnosing unit infers the potential impact of any coaching action and records such information in the coaching process component to support learning from previous experiences. The learning unit consumes information from the joint context and produces knowledge that refines, extends, or updates the coaching assets. Many researchers propose the use of machine-learning techniques to generate this new knowledge, which is quite favorable in systems adhering to the LAES architecture, given that they contextualize and centralize the coaching information of the users.[4] The learning unit also uses such knowledge to adjust the user model and instantiate the e-coaching plan.

Figure 2 also shows the use of a joint context model, which is the aggregation of the current context, user model, and the e-coaching plan and process. Although the e-coaching literature recognizes the relevance of considering the coaching context and user modeling, there are almost no reports indicating the structure of these components. For instance, Klein and his colleagues suggest several context variables that can be used to support e-coaching for therapy adherence.[12] Although useful, such a proposal is specific for that application domain and is therefore not easy to reuse in other coaching purposes. In that respect, the structure of context presented in this model also represents a contribution to the state of the art, recognizing that each particular e-coaching system must derive specific context models from this structure during the design process.

Deriving an e-coaching system

We used the LAES architecture to model an e-coaching mechanism that is embedded into the SocialConnector application[17] to promote the social health of older adults. This e-coaching system encourages adult children and grandchildren to interact with older family members using social media (see Figure 3). This helps the elderly improve their emotional status, and helps the rest of the family feel that they are complying with their implicit filial obligations.

The main design goal of this system was to encourage people to respect the social interaction rhythm agreed upon between the elderly and each family member.[19] Figure 4 shows the design of this e-coaching system, where the color of components and assets maps to the components defined in the LAES architecture (see Figure 2).

To derive an e-coaching system from the LAES architecture, the designer should determine what components of the architecture are required to support the new coaching process and how to instantiate them to reach the coaching goals. For instance, in this case, the user model component (see Figure 2) was decomposed into four components given the nature of the participants in this scenario: family, member, relationship, and user preference (see Figure 4). Similarly, the role of the sensing unit (see Figure 2) is played by the interaction sensor (see Figure 4), which senses and records both the social interactions involving

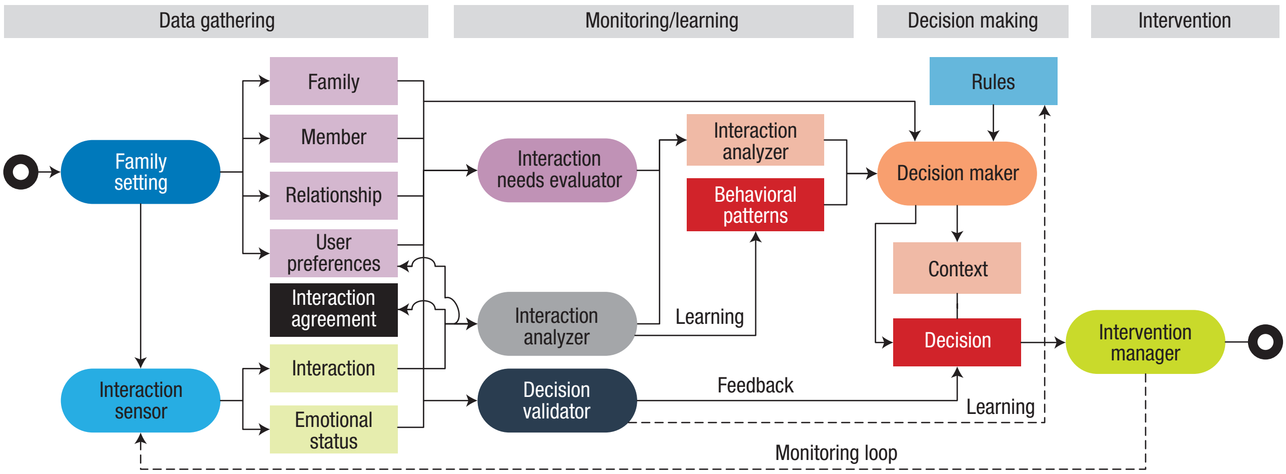

FIGURE 4. Structure of the SocialConnector e-coaching system.[19]

older adults and the emotional status of the elderly (in other words, it records the current context).

The most complex instantiation is always the definition of the rules and mechanisms to conduct the coaching process according to the current context (see Figure 2). This complexity is given by the uncertainty about the suitability of each potential alternative to be used in the process. In this sense, findings of coaching studies can be used to instantiate these assets. Similar to other models, the LAES architecture does not ensure the proper instantiation of these components. However, it represents such an instantiation in the form of data abstractions that allows human designers or coaches to add and adjust the e-coaching rules remotely, quickly, and with low effort. Given that these update processes are not visible to the end users, designers can tune the e-coaching strategy whenever they want, as many times as required. This capability is the result of the decoupling of components proposed by the LAES architecture.

This e-coaching system was used during nine weeks by nine family networks (64 people), involving two changes of the coaching strategy (at the end of weeks three and six). The obtained results show that the system was useful for reaching the coaching goal, and that its structure allowed users to tailor the coaching strategy on the fly and remotely, without requiring a physical access to the device used by the participants.[18] This shows in practice the self-adaptation capabilities that can be expected from systems derived from the LAES architecture.

The minimal requirements for e-coaching systems

Considering the list of minimal requirements stated by Kamphorst[2] for e-coaching systems, we conducted an inspection of LAES using an approach inspired by the Architecture Tradeoff Analysis Method (ATAM).[20] The inspection lasted for almost three hours and involved three external software architects with more than 10 years of experience designing collaborative systems. After reviewing the core of these requirements, we presented the LAES architecture and the reviewers evaluated the capabilities of the architecture to address the stated requirements, asking for design justifications when required. Following are the evaluation results.

- Social ability. The social ability of an e-coaching system allows it to engage with users in an ongoing interaction. The monitoring unit (see Figure 2) helps reach such a goal, as it regulates the interaction with the user considering three criteria: taking action when the user requires support, triggering coaching actions when the process requires it, and keeping the social link with users without overwhelming them.
- Credibility. The coaching actions triggered by the system must make sense to the users and be perceived as being trustworthy. Otherwise, they

will be ignored, jeopardizing the e-coaching process. In LAES, the use of contextualized assets and a joint context model both support e-coaching contextual decision making. Therefore, if the e-coaching actions were properly defined, it is expected that users will perceive the system as credible.

- Context-awareness. The context-awareness capability of the system is required not only for recommending tailored coaching actions (what to do), but also to determine when and how these actions should be performed. In this respect, all functional components of the architecture are context-aware and use contextual data representations to determine their behavior in real time, thus making the system behavior self-adaptable.
- Personalization (user tailoring). The user model component is utilized to personalize the e-coaching activities. However, its representation was not defined in the architecture given that the relevance of the contextual attributes (such as gender, age, or attitude toward technology) depends on each particular application domain.
- Learning of user behavior (including behavior change). It is expected that user behavior will change over time; therefore, the system must identify these changes and learn from them. The learning unit uses the context information and the coaching plan and process as input to identify the behavior changes. The generated knowledge (the learning) is represented through decision and intervention rules, and in the usage priority of the intervention mechanisms.
- Proactiveness. This requirement is addressed mainly by the monitoring unit, which is in charge of keeping a permanent social link with the user and taking action when required. This component uses the record of past experiences and the coaching plan to allow the system to react properly by itself, considering the context situation.
- Guidance (coaching planning). Given that the user behavior usually changes over time, it only makes sense to define detailed coaching actions in the plan for the short term. The coaching plan records the interim and final goals, and the learning unit periodically defines coaching actions required to reach the next goal, according to the plan and using the available assets.

The reviewers agreed that LAES addresses and supports the functional and quality requirements defined by Kamphorst.[2] They also acknowledged that the proposed functional decoupling allows e-coaching systems to self-adapt their behavior just by changing the supporting data. This represents a low-cost adaptation capability that is highly demanded by most e-coaching systems.

The proposed LAES architecture, which decouples the e-coaching system structure from its behavior, allows for the incremental design of e-coaching systems and strategies. It can also be used to guide the design of an e-coaching system as a collaborative activity in which software architects, coaching specialists, and end users participate, leading to more effective systems. Given that the structure of LAES-based systems is decoupled from its behavior, which is also based on data (mainly context-aware rules), it is expected that these systems have a high self-adaptation capability involving low effort. Moreover, such supporting information can be extended or tuned on demand using the results of past experiences or findings of studies reported in the literature, increasing the coaching capabilities of the system. This capability is not present in the models discussed in this article, so our work represents a contribution to the state of the art in this study domain. ▣

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