Guidelines for Tree-based Learning Goal Structuring

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ABSTRACT
Educational technology needs a model of learning goals to support motivation, learning gain, tailoring of the learning process, and sharing of the personal goals between different types of users (i.e., learner and educator) and the system. This paper proposes a tree-based learning goal structuring to facilitate personal goal setting to shape and monitor the learning process. We developed a goal ontology and created a user interface representing this knowledge-base for the self-management education for children with Type 1 Diabetes Mellitus. Subsequently, a co-operative evaluation was conducted with healthcare professionals to refine and validate the ontology and its representation. Presentation of a concrete prototype proved to support professionals' contribution to the design process. The resulting tree-based goal structure enables three important tasks: ability assessment, goal setting and progress monitoring. Visualization should be clarified by icon placement and clustering of goals with the same difficulty and topic. Bloom's taxonomy for learning objectives should be applied to improve completeness and clarity of goal content.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation (e.g. HCI): User Interfaces; H.5.3 Information Interfaces and Presentation (e.g. HCI): Group and Organization Interfaces

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Diabetes; Healthcare; Education; Learning goal -setting -attainment; Personalization; Collaboration; Visualization; Knowledge-base.

INTRODUCTION
Advancements in media technologies provide new opportunities for education. For example, Intelligent Tutoring Systems (ITSs) provide immediate tailored instructions or feedback to a learner to facilitate effective learning while lessening the students dependency on a teacher. Also, consider eHealth applications that have been designed to increase a person's knowledge and control over health and well-being. Especially in self-regulated learning motivation is highly important to optimize adherence to the education program [18]. Research suggests that goal setting and feedback on goal attainment enhance motivation (e.g., [7, 10, 16]) and learning gain (e.g., [5, 9]). Moreover, personal goal setting allows for tailoring of the learning process, this is applicable to personalization of educational technology (e.g., [14]).

Incorporating personal learning goals in educational technologies requires knowledge of learning goals relevant to the domain, a mechanism to set personal learning goals and to share this information between different types of users (e.g., doctor and patient, teacher and student) and with the system, and means to monitor learning progress. Ability-trees are used in games to structure and visualize skills that allow the player to tailor character development and game-play. Gamification has been applied to educational technologies. For example, task completion is rewarded with points or achievements. Using an ability-tree for learning goals is an interesting approach to provide a solution for goal structuring, setting, and monitoring.

In this paper we propose guidelines for a tree-based learning goal model and user interface to support collaborative goal setting. In a case study, on self-management education for children with Type 1 Diabetes Mellitus, we explore requirements for a tool to set personal learning goals. We developed a knowledge-base (ontology) formalizing learning goals and tasks based on medical protocols. We created a user interface presenting these learning goals in a tree-based graph, and enabling personal goal setting. Based on a co-operative evaluation we formulated guidelines to improve the design.

BACKGROUND

Learning Goals
Effective learning requires commitment, adherence and motivation, which can be increased by learning goals [7, 9]. Goals enhance motivation independent of their source (i.e., assigned, self- or collaborative set), if relevance is provided [11]. However, performance is lower for unexplained, assigned goals than self- or collaboratively set goals [12]. Contrary, Kleinrahm et al. [10] found that cooperative goal setting and reflection increased motivation.

Black and Wiliam [5] concluded that awareness of goals and goal attainment improves learning gain. Similarly, goal-setting theorist believe that feedback results in setting higher goals [12]. Which in turn, leads to better performance [11]. This fits Vygotsky's [21] theory on the zone of proximal development (ZPD), predicting that experiences slightly advancing current abilities encourage and advance learning [17].

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In instructional classroom learning goals are often strategically chosen to align with institutional or national standards. However, in self-paced learning the education process can and should be tailored by the learner. Self-regulated learning (SRL) increases learning gain, but is more demanding in terms of effort and thus motivation [18]. SRL theorists believe that strategies such as goal setting, self-monitoring and self-evaluation are vital for effective learning [23]. Motivation comes from goal orientation, self-efficacy believes, task value, and outcome expectations [18, 15]. SRL benefits from a mastery goal orientation (i.e., focus on learning of the ability), while a performance orientation (i.e., focus on demonstration of abilities) declines performance [2, 22, 15].

Ability Trees

In graph theory a tree is defined as an undirected graph in which two nodes are connected by exactly one edge. In a directed graph edges have an associated direction, and in a rooted tree one node is designated as the root. In computer science a tree is a non-linear, hierarchical data structure represented by a root node and linked children or sub-trees [19]. The direction can be from (out-tree) or to (in-tree) the root [13]. In the remainder of this paper we use *tree* as data structure.

Graph theory based models are used in e-learning environments guiding the self-paced learning process, and enabling personalization thereof (e.g., [4, 20]). Learning object graphs formalize the structure of a course, representing mandatory and recommended learning objects—including objectives but mainly content—and relations between them. Through assessment and authoring, objectives are selected, constructing individual learning paths that align with the learner's profile.

Tree-based data structures are used in games allowing players to customize their game experience. For example, in the strategy game Civilization players can choose to develop skills in alphabet or mathematics, but only after having achieved the writing skill. In role-playing games such as Diablo (I and II), players develop their character using points to gain magical powers. These so called ability-trees are visual, hierarchical representation of possible sequences of developments. Abilities are displayed in branching paths and open up after completing required prerequisites. These structures, based on abilities opposed to levelling, allow players to excel in some areas while progressing more slowly, or not at all, in others. Expected is that ability-trees are familiar, and therefore understandable, to children.

CASE: DIABETES SELF-MANAGEMENT EDUCATION

Current Practises in Diabetes Education

Type 1 Diabetes Mellitus (T1DM), diagnosed by a growing number of children, is a high impact digestion disease which requires daily self-management. Thus, to improve well-being and avoid complications, long-term behaviour change is necessary [8]. Learning objectives are personal and change while ageing. Therefore, self-management education is highly personalized. It is directed by challenges faced in daily life and aimed at gradual development of attitudes, knowledge and skills needed for autonomous self-management.

In the Netherlands, formalization of learning goals is limited to (annual) check lists arranged by topic and age such as the *weet & doe-doelen* (knowledge & skill goals) composed by the Dutch organization for diabetes nurses EADV (http://www.eadv.nl). Hierarchical relations between goals are implied; a goal can be prerequisite for one or more others (e.g., injecting insulin requires knowledge of appropriate body parts). Further, goals become increasingly complex for older children. As a result, goals may cover multiple topics and thus precede or succeed goals on different topics. Moreover, specific goals are irrelevant to some children (e.g., pump users do not necessarily need to learn injecting themselves).

Active involvement of patients in the disease management and education process is essential [1]. Objectives should be defined collaboratively between patient and caregivers. This is in line with the Motivational Interviewing (MI) guiding style adopted in healthcare counselling. The principle of MI [16] is to explore and resolve a patient's ambivalent feelings towards change, opposed to coercing or persuading. MI is believed to increase the patients commitment to developing self-management abilities.

Diabetes Education Framework

The PAL project[1] develops mHealth technology providing educational support to children with T1DM. The aim is to gradually increase children's self-management abilities and responsibilities. The envisioned system includes an embodied conversational agent (robot and avatar), extra-curricular educational child-agent activities, and an authoring tool.

Authoring Tool

The authoring tool is a web-based application for healthcare professionals (HCPs) designed to support goal setting, progress monitoring, and attainment registration. The current state is a functional, but minimal, prototype presenting diabetes self-management learning goals, and providing an interface to set personal goals or register attainment together with a child.

Diabetes Learning Goal Structure

We formalized the learning goals, as proposed by the EAVD, in an ontology (Figure 1). Learning goals are classified by type (i.e., knowledge or skill) and values are given for difficulty and topic. Additionally, restrictions are added for prerequisite goals. (The progress and state properties are specific to a child and values are given at a later time.) Further, achievements are added for each topic and difficulty combination, and tasks (e.g., 'win a quiz on insulin') are linked to learning goals (e.g., 'know locations for insulin injection'). The restrictions and relations allow the system to provide personalized content, and calculate and update goal progress automatically.

We created a tree-based visualization of the goals and achievements (Figure 2) because the merging structure of an in-tree fits the diabetes learning goals; from leafs with a single focus topics (e.g., 'Nutrition'or 'Insulin') to multilevel topics (e.g., 'Nutrition in social context') and ultimately the root node 'Self-management'. Further, tree presentations have been applied successfully to structure abilities in games.

[1]Personal Assistant for a healthy Lifestyle: http://www.pal4u.eu/

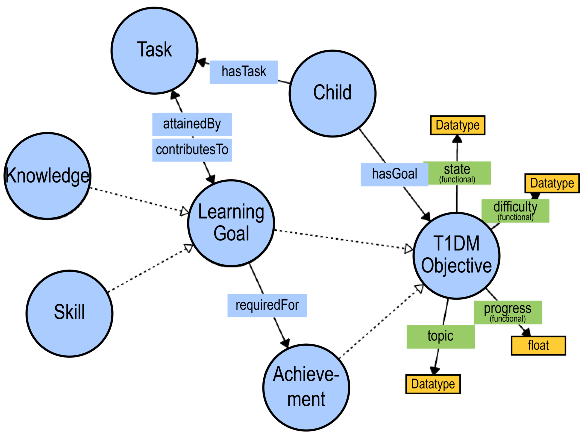

Figure 1. The Diabetes Education ontology. Nodes depict the objective types (classes). Arrows depict object or data properties, dotted arrows depict subtype relations. Self-management learning goals are instantiated in the knowledge or skill class.

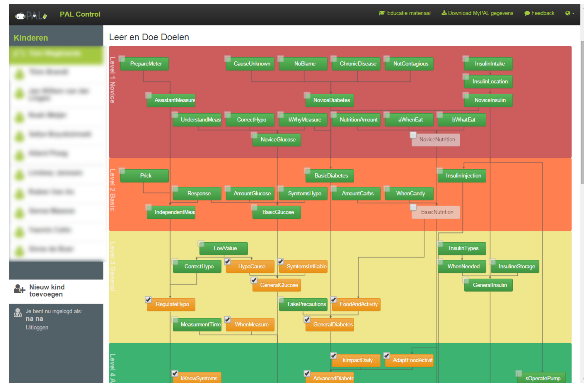

Figure 2. The authoring tool (PAL Control), displaying the diabetes learning goals (i.e., knowledge and skills to attain to progress towards self-management) and achievements with current progress for a 10 year old boy. Attained objectives are green, yellow ones are active. Coloured horizontal bars depict difficulty levels. Topics are arranged vertically.

Nodes represent a learning goal (i.e., knowledge or skill) or achievement. Edges depict connections to prerequisite nodes. Attaining all learning goals on one topic at one difficulty grants the achievement and unlocks the possibility to advance on this topic. For example, a child who attained all difficulty 1 goals on glucose (i.e., knows why measurement is needed, how to correct a hypo, and understands the measurement value) is granted the achievement 'Novice Glucose', and may advance to the next level. Edges connecting a node to multiple, represent nodes prerequisite to more than one others. For example, knowledge of the correct response to a glycemic value is required for both 'Basic Glucose' and 'Independent Measurer'. The proposed model facilitates tailoring to a child's situation and development by selection of personal learning goals, while enforcing to have obtained prerequisite abilities.

Collaborative Goal Setting Interface

A minimal graphical interface was created to support goal setting and progress monitoring (Figure 2). It displays the goal-tree and provides mechanisms to switch between goal states (active, inactive and attained). Active goals, pursued in the near future, are yellow. Attained goals are green. Inactive goals are greyed-out but visible to raise awareness, allowing children to ask about them. The goal state is changed by clicking the node (register attainment) or the selection box at the top-left corner (activate). Upon activation, all prerequisite goals activate automatically, the user can inactivate (irrelevant) goals clicking the selection box. The goal-tree is presented top-down, first displaying goals for new learners, to avoid frequent scrolling.

METHODOLOGY

To gain insight about diabetes education protocols and elicit user requirements, interviews were conducted with HCPs at an early stage. Implicit knowledge and experience appeared fundamental to forming of the, highly personalized, educational process. Besides, HCPs are not used to thinking from a technological design perspective. Hence, development of a goal ontology and user interface were no trivial tasks. Therefore, we selected a co-operative, formative evaluation method providing a minimal example and collaboratively composing guidelines for further development.

Evaluations were conducted with 7 HCPs (6 Dutch nurses, 1 Italian doctor), and 35 children (aged 7-12 M/F) and their parents, in 3 hospital (2 Dutch, 1 Italian) in May-June 2016. Each child visited the hospital two times, once at the start and end of a three week period. In between children played educational activities at home. The first consultation covered personal goal setting using the authoring tool. In the second meeting progress was discussed. An observer was present and audio, keystrokes, and clicks were recorded during at least each nurse's earliest consultation. Additionally, in the Netherlands, training sessions of approximate half an hour were carried out prior to consultations using a think-out-loud protocol whilst preparing goals for the first child. Semi-structured interviews were conducted posterior with all professionals.

RESULTS AND DISCUSSION

A total of 11 goal setting consultations have been observed and analysed. A typical consultation was attended by a paediatric diabetes nurse, child, and one parent and lasted for about 10 minutes. All meetings included assessment of the child's current abilities, goal suggestions by the professional, conformation by the child and/or parent, and registration of goal state (active, inactive or attained) in the authoring tool. These steps were repeated for individual goals by a top-down walk through of the goal-tree.

Assessment of the child's current abilities was mostly straight forward: the nurse asked whether or not the child knows or can do x, where x is a specified goal. In six sessions answers were given by the child and parent in collaboration or turn, in three sessions the child responded alone, in two sessions only the parent was involved (both cases a 7-year old child). In four occasions assessment was done more implicitly by 'small-talk' (e.g., "Your horseback riding right? Do you have any difficulties with your diabetes then?"). If agreed on goal attainment, it was registered as such. A goal was set active if no agreement was reached. Assessment was suspended for a topic if goals were set active.

Although the selection mechanism was easily understood and goal setting was done effectively, the *topic clusters* were not clear. For example, Nurse 1 was looking at glucose goals in search for a goal on nutrition. Further, the *achievement concept* was hard to grasp. For example, instead of activating goals and achievement, Nurse 1 explained that she did not select the achievement because the related goals were not yet attained, and Nurse 3 marked achievements attained while related goals were still active. In addition, *handling irrelevant goals* was troublesome for two nurses. For example, Nurse 4 registered 'Insulin Injection' attained because the child, as a pump user, did not need to learn how to inject insulin by pen (opposed to leaving it inactive). Moreover, questions were raised about the *intent or meaning for specific goals*. For example, Nurse 3 doubted whether to activate 'Insulin-type Needed', because the child did know the facts but was not yet able to apply this knowledge in daily situations. Further, nurses were unable to select goals they had in mind for a child because they were not present in the goal-tree. For all but one, this were attitude goals such as feeling more secure. In posterior interviews with HCPs, the following five issues on the goal ontology and user interface were discussed.

First, the *complexity of the goal-tree* was too high. For the nurses, the meaning of 'achievement' (i.e., *not* concerning new knowledge or skill) was not clear. Furthermore, the user interface was not clear: Icons to clarify the topic were proposed, and all HCPs suggested or favoured visualization of achievements by displaying related goals in nested nodes. One nurse suggested showing only the active difficulty level, hiding others. To support tailored learning goals, this must be done per topic or a collapse-on-select mechanism could be considered: when selecting an achievement it unfolds and enables (de)activating containing goals.

Second, the *clarity and completeness of the goal content* showed shortcomings. The ontology did not include attitude goals and lacked distinction between factual knowledge and the ability to apply this knowledge. Application of Bloom's Taxonomy [6] for educational objectives and gradual development of more complex skills might solve these shortcomings, distinguishing cognitive (knowledge), psycho-motor (skill) and affective (attitude) processes. The cognitive dimension includes multiple levels such as remembering, understanding and applying [3]. Explicitly formulating goals on these levels bridges knowledge development, practice and assessment.

Third, *feedback on goal attainment for progress monitoring* was missing (i.e., whether a goal was registered attained manually or by the system). When the start and end meeting were attended by different nurses, they were unsure about newly attained goals. So, information about goal-state changes should be provided for nurse shiftes and time periods (i.e., simple visualization of goals attained since the last meeting by placement of an icon).

Fourth, *goal setting and assessment of current abilities* were partly supported. Although goals can be selected at any difficulty, while the recursive mechanism ensures that prerequisites are activated, nurses started at the top of the tree and worked their way down assessing each goal. As a result, an overview of current abilities was created, and for each topic unattained goals were set active. This is different from the current practise where a single focus is chosen based on the child's experiences. Nurses had different preferences, either favouring several goals allowing the child varied experiences in the learning framework or favouring a mechanism selecting a focus topic from active goals. Nurses agreed that the top-down goal assessment provided a valuable overview of the current state of abilities of a child. It was time consuming, but nonetheless considered more usable than current check-lists. Three nurses suggested to let the child play a game (e.g., with the robot) to assess abilities and serve as input for goal setting.

Fifth, *collaboration with the child during goal setting* was partly supported. According to the nurses, the authoring tool eased interaction between them and the child. However, goal setting was less collaborative than desired. Children's involvement was limited to (dis)agreement; they did not proactively discuss specific goals, while active involvement is key to motivation for behaviour change [16]. Children's involvement can be improved by allowing them to select their personal focus from active goals. Moreover, HCPs may benefit from training in collaborating with a child using the authoring tool. Nonetheless, goal setting was believed helpful making the education process more interesting and transparent to the children.

The present study has some limitations such as a lack of quantitative data proposed by the number of participants and method. We do not report on usability statistics because they do not provide novel information for research and development of intelligent user interfaces. We plan to expand our user base and methods to evaluate alternative interfaces and investigate the effect of goal setting on learning outcomes. Although, other structures might be feasible as well, we have chosen a tree-structure because this fits our domain. Further research, presenting alternative structures, is needed to make any conclusions on structure preferences. Suggestions provided in this paper are applicable to tree-based structures.

CONCLUDING GUIDELINES

The main challenges addressed in the present work are the development of an ontology for diabetes self-management education and an interface to support collaborative personal goal setting and monitoring. An authoring tool was created for this purpose and co-evaluated with healthcare professionals.

Guideline 1: The authoring tool should provide *clear, visual feedback* on goal *structure*, and *active state and progress*. For example, by usage of icons depicting topic and state changes.

Guideline 2: The *different concepts* of the model (e.g., goal and achievement) should consistently have a *different representation* (e.g., shape) in the user interface .

Guideline 3: The domain should be fully covered in goal content. In our case *differentiation* between *affective and cognitive*, and *factual and application* objectives should be embedded (e.g., Bloom's taxonomy).

Guideline 4: The authoring tool should support, next to goal setting, progress monitoring and attainment registration, *assessment of current abilities*.

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