Cognitive technologies for assessing skills

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Abstract

Solving any task involves thinking-to-gestures processes: unobservable mental superordinate goals to primitive hand movements acting on objects as trajectory data. The question is how to evaluate know-how taking into account both decision-making and dexterity. From the Cognitive Science literature and considering the collection of relevant data, we derive a functional definition of Know-How that can be useful for the conception of an automatic assessment system of Skills acquisition. This functional definition is also used to introduce a computational cognitive model that is based on the problem solving and task analysis literature. Discussion is about how much the model is of help for the building of a platform to implement the method as part of a MOOC.

Keywords: Model of Cognition, Task Analysis, Problem-solving, Complex Systems, eLearning, Cognitive technologies, Massive Online Open Courses

1 Introduction

Since 2007, a new trend in eLearning is the merge of free online classes, the Massive Online Open Courses (MOOC).

MOOCs that are about declarative knowledge can provide ways to evaluate how much students increase their knowledge about facts and concepts. Optimizing learning can be done through adapting swarm intelligence systems into what was called the man-hill optimization paradigm [1][2][3]. This means that finding optimal paths through the graphs of educational contents, valued by the preceding students’ successes and failures helps evaluating a particular student’ path till now as well as advising about the next steps of the learning processes.

Automatic assessment of knowledge can also be done using evidential Multiple choice questions, - which is easy-, but also through assessment of free texts provided by students. Generic tools are Latent Semantic Analysis (LSA) and SUMMA-LSA, two models that maps meaning into a semantic space that can be used to compute the semantic distances between words, sentences, and whole texts [2][3].

For automatic assessment of free texts provided by students, beyond LSA, SUMMA-LSA, there are Topics Model [7] that use a hidden-Markov model to learn sequential dependencies to be combined with the semantic information from the topics representation [8]. The Topics Model allows computing how much a given free response is close to the one provided by the question provider, either a teacher or another tutor student.

The content of eLearning classes are about verbal, written, graphical information, named here declarative knowledge, but also about Know-how with demonstration of the “how-to-it”, named here procedural knowledge.

The question under investigation is how we can model Know-how for eLearning. As a difference with declarative knowledge, Know-how can difficultly be captured with talks (typing): the procedural knowledge of Know-How is related to the behavior of an agent that uses objects, mainly in the context of learning for professional purposes.

The topic of the paper is about how to model distant Know-How in order to be captured for assessment.

2 What is Know-How

2.1 Know-How as Goal States

Know-how is the skill of an agent to perform tasks. Performing a task is to achieve a goal state
To do so: move medium and small disk to middle place

The sub-goals structure is as follows.

1. Move large disk to left place
To do so: move medium and small disk to middle place
   1.1. Move medium disk to middle place

To do so: move small disk to left place
   1.1.1. Move small disk to left place
   1.2. Move small disk to middle place
2. Move medium disc to left place
To do so: move small disk to right place
   2.1. Move small disc to right place
3. Move small disc to left place

Note that the tree-like sub-goals structure provides the semantic of the procedure: the how by the top-down path (e.g., how to move the medium disk to the middle place: 1.1? By moving first the small disk to the left: 1.1.1) and the why by the bottom-up path (e.g., why do you move the medium disk to the middle: 1.1? To move the large disk to the left: 1, after having also moved the small disk to the middle place: 1.2).

Traditionally tasks are modeled using such a tree-like sub-goals structure [10], [11] with logical (IF, OR, XOR...) and temporal (No order, Same time, Until...) operators (or constructors) that indicate time relationships between sub-goals. The set of sub-goals has a hierarchical structure: high levels sub-goals are found at the top of the tree while the observable action units (primitive) are at the leaf nodes.

**Definition 2** – Know-How is about how to perform any particular sub-goal as well as being able to explain why this sub-goal is to be performed.

### 2.3 Know-How as a set of conditions, prerequisites, constraints and post-requisites

Know-how is not solely being able to know what to do (goal), how to do it (procedure as sequences of actions on objects) and why (sub-goal structures). Know-how is also the taking into account of external constraints (Do I get sufficient time for performing that task? Is it the priority among tasks?) as well as internal constraints (I have to stay in that room).

More crucial are conditions (things that need to be true otherwise the task cannot be performed: e.g., the necessity of having a specific tool), prerequisites (to be done before starting running the task) and post-requisites (to be done after the task is achieved).

Consider the following list of ordered actions, provided as professional procedure, to perform a medical test on patients for checking lack of insulin.
Example 3:
- Wash hands before and after treatment. It is a non-sterile treatment.
- Explain to the patient the course and purpose of the treatment.
- Have the patient urinate directly into the goblet to the extent possible, otherwise use a urinal or basin.
- Put non-sterile gloves.
- Dip the strip into the urine.
- Wait the recommended time for reading the test strip (usually a few tens of seconds).
- Compare the resulting color with the color scale on the vial.
- Record the result of the care record and send it to the nurse.
- Dispose of waste, cleaning and disinfecting equipment.

Precautions
- Check the expiry date of the test strip vial.
- Do not touch the test part of the strip.
- Observe the reading time.

The understanding of this task requires differentiating
- CONDITIONS: having gloves, test strips with correct expiry date, a goblet, urinal or basin,
- PREREQUISITES: explain to the patient, have the patient urinate, Wash hands, Put sterile gloves,
- INTERNAL CONSTRAINTS: do not touch the test part of the strip, observe the reading time,
- POST-REQUISITES: Dispose of waste, cleaning and disinfecting equipment, wash hands.

The GOAL is “having the recorded result sent to the nurse” and the sub-goals are: 1 - dip the strip into the urine, 2 - wait the recommended time for reading the test strip, 2.1 - compare the resulting color with the color scale, 2.2 - record the result of the care record, 3 - send record to the nurse.

Definition 3 – Know-How is about the context of the task that allows performing it.

2.4 Know-How as a causal agent-to-patient objects chain

We have seen that the goal of a task is to have object(s) transformed. These goal objects are patient target objects that must be transformed for the purpose of the task: eg "the letter must be mailed", "the three pieces of the tower of Hanoi to be right", "the result of the test is to be sent to the nurse". This patient target object is transformed because of action made by functional objects.

Although the hand is usually the main functional object to act on patient objects, - the simplest case is its direct action on the patient target object: "to take a knife"-, the procedure of a task (structured goals) is to act on patient objects with functional objects as tools, or means that are used to obtain the final goal state. These functional objects (F) operate on patient objects (P) in a causal chain, where each object is in turn patient then functional [12], as follows:

Example 4:
F: HAND -> P: KNIFE (handle)
F: KNIFE (Blade) -> P: BREAD (outside)
F: BREAD (container) -> P: CHEESE (content) => SANDWICH

All along the running task, objects are used for their function to operate on other patient objects. First, there are relations between functional and patient objects: a knife is used to cut the meat because the meat is sufficiently soft to be cut. Thus, performing a task is to construct a causal chain involving patient objects that are transformed to be used as functional objects: e.g., the hand (F) takes the knife (P) in order to use the knife (F) to cut the meat (P).

Second, an object can be used in turn as patient then functional object because it has both patient and functional parts (Fig. 2).
Figure 2. The whole-part decomposition of Tasks objects: parts are either patient (the handle of the knife) or functional (the blade of the Knife).

Definition 4 – Know-How is the knowledge of the causal chain involving patient and functional parts of each object as well as the relation between the functional part of a F object and the patient parts of a P object on which the former is operating.

2.5 Know-How as a causal agent-to-patient objects chain

As a matter of fact, the know-how about the preceding task medical test example is not delivered alone. It is delivered with some knowledge as follows:

Example 3 - completed:
“When the food shortage, the body will draw on its reserves (in the liver and muscles). After exhaustion of these reserves, there will be use of fats and proteins, whose degradation produces ketones. For diabetic patients with a lack of insulin (which allows the passage of glucose into the cells), the cells of the body, lacking of glucose, will use the fat reserves of where the production of ketones. These are hazardous waste for the body that urine eliminates”. The professional who is performing the medical test and has this knowledge should be able to link know-how with this knowledge, being able to know what the test trip is measuring.

Definition 5 – Know-How is the competency to link the procedure with the domain knowledge of the task.

3 Know-how data for eLearning Assessment

A proper way for a teacher to evaluate a student know-how acquisition is to observe her realizing tasks and to ask questions about the understanding of how and why. Distant teaching of many students does not make it possible as well as the making of videos by students that may not have the required tools.

Although incomplete, because virtual objects do not have all of the properties of physical ones, Serious Games (SG) can be used, in addition to eLearning classes, for practicing, acquiring and assessing Know-How.

The specific question under investigation is how we can model the behavior of students for Know-how acquisition through for eLearning. The behavior of distant students is a number of dependent variables that we record for the Know-how Digital Campus (KHDC) project.

3.1 Know-How data as Human-Machine interaction

Learners have to display to themselves eLearning contents using motor commands (touching, clicking…).

We developed SiouXtrack with a traces recording module that allows the observation of all user actions. This module takes the form of an extension to the web browser installed on the client device. All interactions between the user and the browser are recordable in the form of user actions and subsequent responses of the system with more or less detail. Any action on the interface of the viewed website can be compared with the system events triggered and the specific consequences that follow for the user. Usual widgets like buttons, lists, tables and menus, text inputs and multimedia items like sounds, images and videos are taken into account. Context switches like opening and closing of documents, changes and manipulations of windows and tabs are also recorded.
Any information needed for offline simulation of the user experience can be recorded and stored into the SiouXtrack database. An interface for the observer-researcher accessed from the browser preference pane allows entering of parameters to fine tune the way traces are to be collected: list of events to consider, sharpness of recordings, properties of the web page elements to be stored and more.

Viewed URLs filtering can be turned on, using regular expressions, to define precisely the set of URLs for which user behavior is to be recorded. The collected traces are transmitted to a server and stored in the SiouXtrack database. This database can then be queried to provide aggregated statistical analyzes and summaries of types of user paths as well as analysis in terms of individual protocols.

### 3.2 Know-How data as Eye-movements

Once contents are displayed, learners have to read and watch. We also developed eye-tracking technology from the webcam. What was read, seen, inspected and for how long is under the scope of the subsequent online analysis that can be done from eye movements recording [13]. Eye-tracking method [see 14 for a large review] is the eye-movement recording when a task.

Generally, a key task activity is visual search.

Eye-tracking analysis allow exploring visual search of a particular information through exploration and the processing of the objects on the interface. The exploration corresponds to the transition between different areas of the page of the site, such as navigation menu, text, www links, picture, video...

Thus, eye-tracking allows to identify the areas seeing by subjects, the areas never explored by them, the area first explored, etc. [15]. The processing of eLearning-objects leads to search for particular information to decide if related to the main goal or to the current sub-goal.

With this method, the scan path, - that is the fixation-saccade succession, with progressive (towards unexplored area) or regressive (towards an area previously fixated) saccades -, allows knowing where the student looks and for how long. Thus, the completeness of the collection of information, but also the order in which the information is collected can be evaluated regarding the procedure of the running task to be watched or assessed.

### 3.3 Know-How data as body movement and hand gestures

Know-how is also the primitive real actions that have to be performed. The correct sequence, velocity, time delays, precision are variables of the body movements and of hand gestures. For this Human behavior recognition, we use 3D Zernike Moments approach [16, Fig. 3].

Once the body or hands movements in videos are recognized, correctness, velocity (speed and acceleration), time delays and precision can me measured by comparing the path in 3D space with the one of the expert of the task.

This can be done if the students are wearing Inertial Measurement Units (IMUs), - a device that combines accelerometers and gyroscopes -, that transmit velocity as well as orientation in 3D space (fig. 4).

![Figure 3. Classification of body and of hands movements, using a 3D Zernike Moments approach (Bouziane, Chahir, Molina & Jouen, 2012).](image)

![Figure 4. IMUs located on the body, harms and hands to record the spatial paths of gestures.](image)
Thus, the spatial path done by students, when practicing, or for assessment, can be matched with the spatial path done by the professional of the task (fig. 5).

Figure 5. The recording of absolute 3D spatial trajectories done by a professional (on left) and done by a student (on right: three successive trials).

Measurement of similarity among different 3D spatial trajectories can be simply achieved by defining a spatiotemporal corridor and by deciding if a given trajectory is mainly within the corridor, and if late or in advance [17].

A more sophisticated technique is, contrary to [18] clustering method: (i) the segmentation of the pathway of the trajectory in basic predefined segment units. A pathway can then be defined as the ordered segment units set that composes it; each segment having a duration; (2) the use of Support Vector for calculate similarity; a trajectory being a vector whose dimension is the number of distinct segment units in it.

Thus, advising a student how to acquire the right gesture when acting is to check if her trajectory is in the expert corridor and, for precision, how much similar is the trajectory to the expert one.

4 Modeling Know-How for assessment

According to the definitions of what "Know-How" is (section 2 above) and the dependent variables that we can record (section 3 above), the remaining question is how to assess the Know-How that was acquired by an individual? The model we propose for its automatic assessment is hierarchical and modular.

First module is [Goal Knowledge]: the properties that the target task object must have in order for the task has been done. This module is independent because you can have a correct representation of content without knowing how to do to get it. This property of the task goal makes possible to evaluate if the task has been done, to use different procedures and materials, to make it done by another agent, etc. This module is also conditioning the evaluation of Know-How: why someone would be tested about a task if s/he does not know for what? This task goal level is known as being independent of procedure and of devices [19] [20].

Second module is the [set of independent sub-goals] (or subtasks). Tasks are made of sub-tasks that can be separately known without knowing how to link them to perform the task. For instance, the Tower of Hanoi problem is not about how to move each disk but in what order. This is an economical property for MOOCs (made of separate bricks of content) and for assessment of Know-How.

Third module is the knowledge [task objects], in terms of their patient and functional properties [12]. One might know how each device tool is functioning and how to use each device separately of others without knowing how to apply each tool to others.

Fourth module is the cognitive and goal-oriented Know-How module that is the built-in [mental model] of the task, made of the sub-goals structure, linking sub-goals to objects (not the reverse according to the object primacy [21]). This mental model, of a schema form, entails heuristics, inferences and planning by both top-down (the task goal) and bottom-up processes (perception of task objects) by simultaneously establishing the causal links between objects and the sub-goals structure.

Fifth module is [perception], visual, auditory, tactile, proprioception as inputs for capturing object information as well as feedback of how the running task is transforming objects.

Sixth module is [body movements and gesture], directed to objects, as first level output. Second output level is the state transformation of objects.

Last but not least, the seventh module is the [metacognitive control of behavior] dealing with external constraints, conditions, pre-requisites and post-requisites, according to the task specific goal, but also to more super-ordinate goals.
Figure 6 shows how these modules interact. Finally, for a given task, each combination of modules content can be matched with the domain knowledge in Long Term Memory (not displayed in the model depicted in Fig. 6, that concerns Working Memory).

Although the model is a learning model, it prefigures the automaticity of the task with experience for which [Perception] and [Body Movements and Gesture] are more and more associated in such a way they are less and less associated to the other modules. The model also prefigures affordances, when the perception of an object indicates directly which of the sub-goals is to be used, avoiding decision-making in the mental model module.

5 Discussion and conclusion: Assessing Know-How

The modular model of Know-How provides the method for automatic assessment of the acquisition of running tasks. First, before assessing a particular task, check if the task objects and the independent sub-goals are known. It happens that they are learnt while practicing the whole task. It is of interest to assess their learning per se. The assessment process is the same than for the whole task (next steps).

Second, verify the Goal Knowledge is known in order to avoid misunderstanding of what is to be done. Because you cannot pursue the assessment, decide between providing the correct task goal or learning more.

Third, if the Goal task is known, question the How and why of the sub-goal structure. This can be done by questionnaire with multiple choices or by asking production of free texts.

Fourth, ask to perform the task in the virtual world of a serious game while recording eye movements [Perception] and actimetry [body movement and gesture]. Categorize the trajectories and evaluate how much their relative values fit the professional ones, either by the corridor technique or by computing vector similarity.

Fifth, correlate perception (eye tracking) and primitive-actions results (body movements and gesture) with the how and why of cognitive questions, looking for discrepancies.

Sixth, consider meta-cognitive control of behavior as individual parameters that rely either on personality or on the involvement in the task (motivation, emotion).

Is learning professional skills under the scope of eLearning and of MOOCs? Contrary to declarative knowledge that is mediated by symbolic external representation (words, graphs, diagrams, pictograms, images), Know-How is the action on physical objects, among them humans.

Because a science of simulation is still missing, the one that develops theories able to provide criteria about how much a simulation of X is a sufficient substitute of X, eLearning skills, obtained by using virtual objects in serious games, cannot ascertain the professional skills in the physical world. However, it may help facilitating the acquisition of Know-How for next real practices.

The Know-how Digital Campus (KHDC), which is a MOOC that we are putting in place for learning many kinds of skills, needs assessment techniques.

By considering what Know-How is and the collection of relevant data, we provided a model issued from the problem-solving and task-analysis literature. It is of help for implementing the whole assessment method in the next platform we are building.

References


