Focused authoring for building GIFT tutors in specialized domains: a case study of psychomotor skills training

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INTRODUCTION

As expressed in the Army Learning Model (ALM), psychomotor skills are foundational to many of the competencies that compose the U.S. Army's vision for 21st Century Soldier Competencies. Training psychomotor skills is being addressed in part through the use of sophisticated intelligent tutoring systems (ITS) that tailor and adapt instruction during simulations, and promising ITS investments have been made in numerous domains including marksmanship and tactical combat casualty care. However, current ITS authoring tools tend to lack generalization and are limited in scope. The process to develop ITS thus remains time-consuming and costly. For the Army to successfully realize the ALM vision, creating ITS that target psychomotor skills must be an affordable, replicable, and reusable process.

The Generalized Instructional Framework for Tutoring (GIFT) is supporting ALM by developing new tools and methods for streamlining ITS development. In this paper we report on the development of the Psychomotor Skills Training Agent-based Authoring Tool (PSTAAT), an agent-assisted ITS authoring tool for the GIFT framework. Our approach uses guided examples and the agent's encapsulated knowledge of psychomotor ITS authoring. We present an integrated approach to GIFT ITS authoring that uses performance support and agent techniques to provide informative feedback and guidance to the author during the ITS development process. We discuss how psychomotor task performance models and sensor configurations can be abstracted into reusable psychomotor profiles that both simplify and streamline the design of psychomotor activities within GIFT. Finally, we present recommendations for further generalization, enhanced reusability and portability of course components and authoring support in GIFT.

BACKGROUND

GIFT is a modular instructional architecture that provides a framework for the automation of learner modeling, domain modeling, and ITS authoring, delivery, and evaluation (e.g., Sottilare, 2012; Sottilare, Goldberg, Brawner, & Holden, 2012). GIFT remains under development and is being used to capture best practices and theories and to demonstrate adaptive pedagogical approaches and learner-centric tutoring strategies based on real-time assessment. Recent capabilities such as conversational agents and online and mobile instruction have further expanded the impact of GIFT (Sottilare, 2016).

GIFT contains numerous tools and features that support authors. Significant improvements have been made since early GIFT releases, when authoring involved writing Extensible Markup Language (XML) and understanding specific behavioral and configuration controls. Basic client-side editing tools were developed to assist with XML authoring, but knowledge of the architecture and of ITS was still required. To offer tools that are more familiar, intuitive, and supportive, the GIFT team created its first browser-based authoring tool, called the Survey Authoring System (SAS), that offered a unified authoring and preview environment with features such as integrated tool tips, and searching, sorting, filtering, and managing question banks. The subsequent browser-based GIFT Authoring Tool (GAT) provided access to authoring components in the GIFT Cloud with additional advances in usability and functionality. The GAT also began to enforce an authoring workflow by requiring that elements such as concepts and surveys be defined prior to including them in courses (Ososky, 2016).

Based on a usability survey (Holden & Alexander, 2015), Ososky and Sottilare (2016) conducted a heuristic evaluation of GIFT authoring tools that yielded numerous recommendations for further improvement of interface consistency, user-centered design, and support materials. Many of these suggestions are being implemented in the latest version of GIFT Cloud. Now called the *Course Creator*, the primary authoring tool is accessible through the GIFT Open Virtual Campus web application (Figure 1).

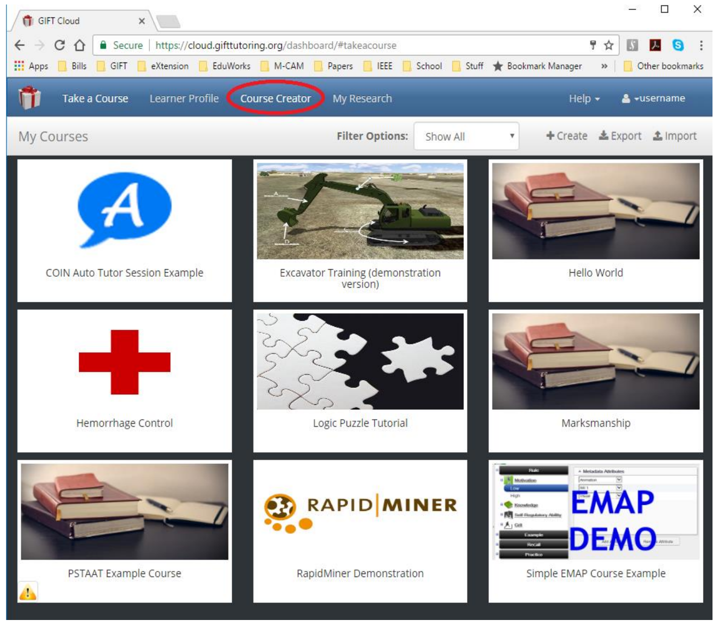

Figure 1. Course Creator Screen in GIFT

PSTAAT further extends GIFT authoring with an agent-supported tool that supports the authoring of psychomotor task training. In keeping with the direction of other improvements being made in GIFT authoring, PSTAAT provides integrated guidance informed by grounded instructional design principles and psychomotor methodologies while seeking to streamline the authoring process through workflow, templates, reuse, and semi-automation.

CHARACTERIZING PSYCHOMOTOR SKILL

Psychomotor skills can be distinguished from skills in the other domains of learning (cognitive and affective, after Bloom, Engelhart, Furst, Hill & Krathwohl, 1956). Psychomotor skills involve movement and coordination but generally de-emphasize verbal processes, and are prevalent in almost every tactical mission a Soldier might be tasked to accomplish. Tasks like fast-roping, assembling a Trident Pier, meal preparation, applying a tourniquet, flying a CH-47, aiming a weapon, or traversing a stream illustrate the prevalence and importance of psychomotor skills in performing the duties of a Soldier in today's Army.

Psychomotor skills typically include physical movement, coordination, and use of gross, fine, or combined motor-skills. The primary factor in mastering these skills is practice. Psychomotor skills tutoring should thus emphasize opportunities to practice physical skills with coaching, feedback, and assessment (Ericsson, 2006). Performance metrics for psychomotor skills are another differentiating property. Measures such as speed, precision, distance, or technique are examples of how psychomotor skill performance might be generally measured, which is a factor that tutoring systems in this domain of learning must accommodate (Goldberg, 2016).

We compared psychomotor domain models that follow the basic tenets proposed in (Bloom, Engelhart, Furst, Hill & Krathwohl, 1956) including theories advanced by Dave (1970), Simpson (1972), Harrow (1972), and Romiszowski (1999). A simplified synthesis of these psychomotor taxonomies that appears on several university websites (Table 1) is also suitable for designing in the PSTAAT authoring tool.[1]

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[1] This synthesis appears on several university websites without attribution to an original source, including Rowan University (http://users.rowan.edu/~cone/curriculum/psychomotor.htm) and Penn State University (http://archive.tlt.psu.edu/learningdesign/objectives/psychomotor.html).

Each of the models represents a pedagogical progression of phases for psychomotor task instruction and is based on slightly different principles of cognitive function or learning. Selection of an appropriate model would be dependent on the type of task and requirements of the tutor. Our summary analysis established a foundation of knowledge for developing an agent to support and guide the authoring of simulation-based ITS focused on psychomotor skills, as discussed in the next section.

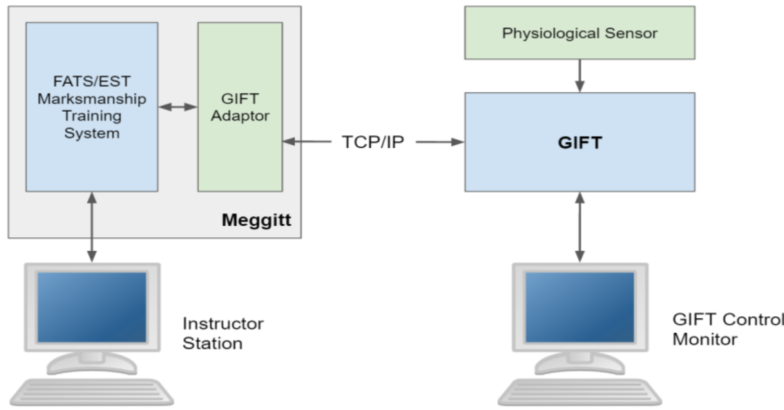

Figure 2. Overall architecture of the exemplar ITS

Table 1. Psychomotor skills domain model, synthesized from prevalent academic models.

Phase	Definition	Example
Observing	Active mental attending of a physical event.	The learner watches a more experienced person. Other mental activity, such as reading may be a part of the observation process.
Imitating	Attempted copying of a physical behavior.	The first steps in learning a skill. The learner is observed and given direction and feedback on performance. Movement is not automatic or smooth.
Practicing	Repeatedly trying a physical activity.	The skill is repeated over and over. The entire sequence is performed repeatedly. Movement is moving towards becoming automatic and smooth.
Adapting	Fine tuning. Making minor adjustments in to perfect activity.	The skill is perfected. A mentor or a coach is often needed to provide an outside perspective on how to improve or adjust as needed for the situation.

AUTHORING OF PSYCHOMOTOR SKILLS TUTORS

PSTAAT is intended to support authoring by encapsulating knowledge and assumptions about psychomotor skills training and assessment. PSTAAT uses an exemplar ITS to provide illustrations for authoring and to provide an example outcome. This approach uses an ITS built for a legacy framework and adapts it incrementally to instantiate a new ITS, a process we call *guided case adaptation* (Bell, 2003).

Exemplar Psychomotor Skills Tutor

The Adaptive Marksmanship Trainer (AMT), our exemplar ITS, was created in GIFT to enhance an existing Engagement Skills Trainer (EST) that uses instrumented emulators of several types of firearms. AMT (Figure 2) enhances this system by incorporating adaptive tutoring and automated performance measures (Goldberg, Amburn, Brawner & Westphal, 2014). The EST makes use of a Meggitt FATS® M100 Simulation Training System and a Zephyr BioHarness to support engagement skills training. AMT processes input from 5 different sensors (breathing, barrel movement, trigger squeeze, sight picture, and shot count) to observe the learner while performing marksmanship drills. AMT uses a layered concept organization (Figure 3) to provide adaptive, contextual feedback with remedial training specific to the learner’s detected performance levels for each reading (above, at, or below expectation).

Generalizing the Exemplar

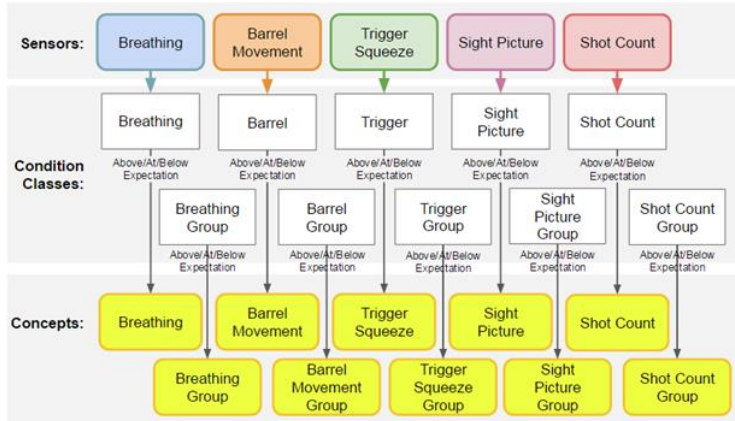

Figure 3. Basic sensor to concept mapping in the exemplar ITS

In creating a normative abstraction of the AMT authoring process, we identify steps in the workflow that can be used as the basis for a general-purpose development sequence in an authoring tool. Our workflow analysis excluded integration of hardware sensors (which is important but beyond the scope of the authoring tool). We identified three types of authoring tasks implicit in AMT: skills profiling, sensor mapping, and course object(s) definition (*i.e.*, activities and sequencing). PSTAAT provides contextual authoring support for each of these general purpose task areas, and emphasizes the use of psychomotor domain instructional approaches and adaptive feedback strategies in the form of templates and examples. The PSTAAT authoring agent is thus derived from analysis of the exemplar ITS combined with a review of ITS authoring techniques and psychomotor domain requirements. The agent initially addresses GIFT course structure and implementation; Psychomotor instructional design and strategies; Sensor model application and configuration; and Reusability and standards. Each of these is discussed below.

AUTHORING SUPPORT IN PSTAAT

PSTAAT capabilities are designed with authoring support components to be contextually incorporated into GIFT Cloud's Course Creator authoring workflow. They are envisioned as agent-driven interactions with feedback geared towards specific ITS design and development needs.

GIFT Course Structure and Implementation

To support psychomotor authoring within GIFT, PSTAAT introduces the construct of a psychomotor activity course object. A *psychomotor activity* uses configured sensors as assessment inputs and provides adaptive content delivery for associated concepts through a *psychomotor instructional approach* and the application of one or more *psychomotor profiles*. The psychomotor activity connects concept state transitions (identified by the logic model in a psychomotor profile) to instructional strategies and feedback that may be sequenced by the GIFT Domain Module (Figure 4).

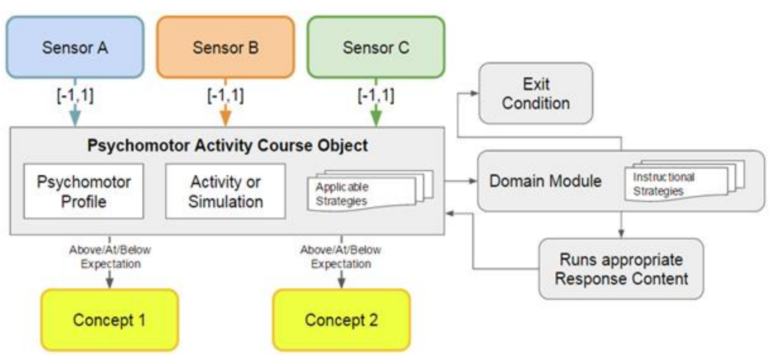

Figure 4. Example Psychomotor Course Object in PSTAAT

The authoring agent will assist during the adaptive psychomotor activity construction process by auto-generating a GIFT-compliant template for the ITS organized into phases by the selected psychomotor instructional approach and configured for the selected psychomotor profile(s) at each phase. Once the ITS template has been generated, the authoring agent will auto-populate the psychomotor activity with placeholders for all possible learner state transitions that could be detected by the configured sensors. To complete the tutor, the authoring agent will guide the author through development of instructional strategies for each placeholder state transition. For example, a particular learner state transition may reflect that the learner has performed *above* expectation in one sensor reading, but *below* in another. The authoring agent would advise that an appropriate instructional strategy for this state transition would include positive reinforcement for the skill performed above expectation along with remediation and guidance for the skill performed below expectation. PSTAAT will also assist with ITS testing by providing an activity preview feature. In preview mode, the author can step through a tutor manually selecting each possible instructional response to validate the situational appropriateness of content and feedback. When a psychomotor activity is executed in real-time, it will incorporate generalized user guidance that is appropriate for the learner's current state in the activity's pedagogical phases and instructional strategies. For example, when a learner begins adaptive remediation after performing a task, PSTAAT automatically injects appropriate messaging into the GIFT template to provide context for that transition to the learner.

Psychomotor Instructional Approach and Feedback Strategies

In the specialized case of psychomotor skills training, the tutor must have the ability to sense and observe the learner's task performance outcomes and readily adapt to any situation with appropriate instruction. In order to do this, the ITS must recognize "states" in the learner's skill performance data and respond with specific feedback and training material. Therefore, the content should be robust enough to support a wide range of previous knowledge and skill experience. For some psychomotor tasks, performance moderators such as visual acuity or physical conditioning can have significant impact on performance outcomes. In our current approach, it is possible that sensors or surveys could be leveraged to attempt to understand moderating factors and to tailor instructional feedback strategies accordingly. As part of the GIFT tutor instructional design process, the author must identify specific training concepts and associate each concept to one or more observable performance metrics provided by sensors.

Within the PSTAAT psychomotor activity, an author may choose from a set of psychomotor instructional approach templates to teach these concepts. An instructional approach template, based on a psychomotor domain model, represents a sequence of pedagogical phases that each contains appropriate activity components for all possible learner state transitions. Guidance from the authoring agent will support the author's selection of an appropriate psychomotor instructional approach for the tutor's intended behavior and outcomes. With guidance and examples from the authoring agent, the author provides response feedback strategies for all relevant learner states in each pedagogical phase by filling in activity design gaps with reinforcing or remedial content combined with contextual feedback. The instructional approach and feedback strategies are validated by the author through the use of the PSTAAT preview mode. Figure 5 depicts the authoring agent's interactions during psychomotor activity building.

Sensor Model Application and Configuration

As discussed in the previous section, a psychomotor domain ITS must have the ability to observe task performance and interpret the data collected to identify the learner's current state transition. The incorporation of sensors and the association of sensor data to performance thresholds is critical to this process. Although PSTAAT is designed to support this calibration process, it is distinct from the instructional design of the ITS. This sensor profiling is highly dependent upon the sensor hardware and the contextual authenticity in which the sensor will be used to measure psychomotor task performance.

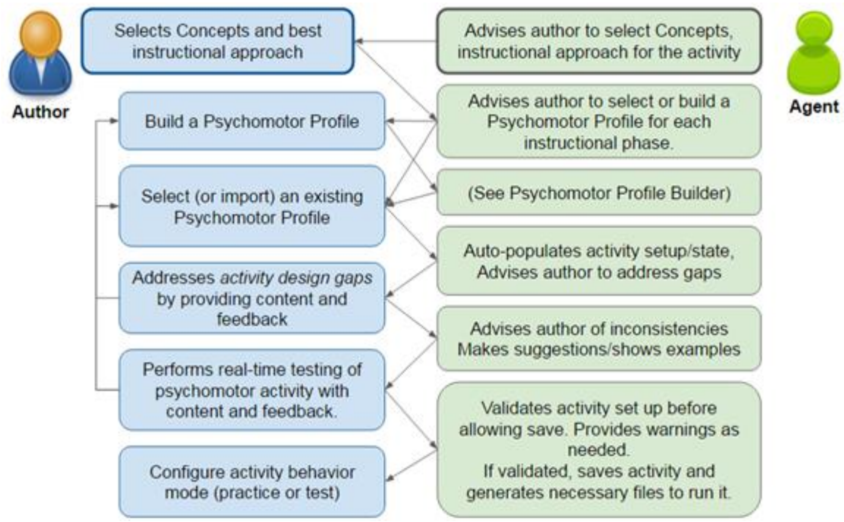

Figure 5. PSTAAT authoring agent dialog for psychomotor activity building

In PSTAAT, a *psychomotor profile* provides the logic to inform concepts based on sensor inputs. The resulting configuration of sensor inputs for each concept includes the settings for at, below, and above expected performance levels. A psychomotor profile may be selected from a set of existing profiles when designing a PSTAAT psychomotor activity. In order to encourage reuse and further streamline ITS development, psychomotor profiles may be imported, modified, exported, and reused within PSTAAT.

During psychomotor profile building, the authoring agent will implement a combination of performance support and machine learning techniques to both streamline and facilitate sensor modeling. To create the logic model for a profile, PSTAAT will require "case data" describing the sensor inputs gathered for a set of concepts at varying levels of performance. The user will have the option to import existing case data or use an integrated machine learning process to collect case data and allow the PSTAAT authoring agent to guide the modeling process. In instances when normative sensor input performance levels are known, the user will also be able to manually enter the values for the logic model (Figure 6).

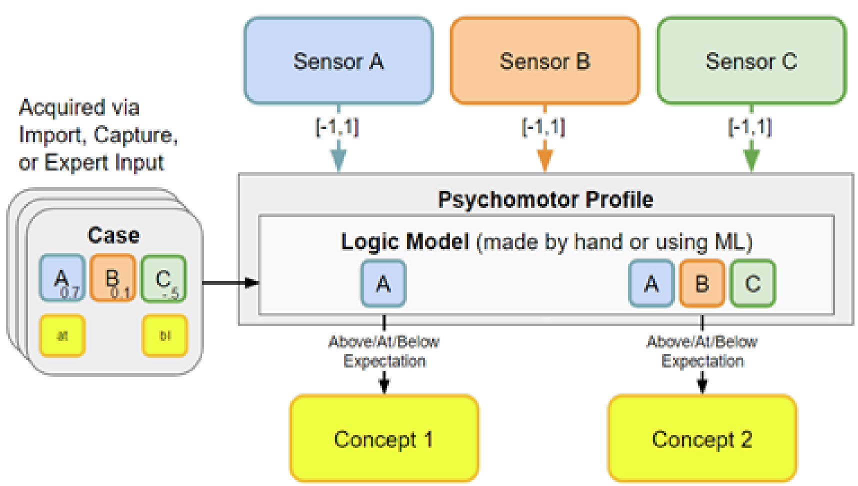

Figure 6. Example Psychomotor Profile in PSTAAT with 3 sensors and 2 concepts

PSTAAT's process for building a psychomotor profile using supervised machine learning will follow a two-step process, where the first step enables the algorithm to learn how to estimate the categorical results (i.e., below, at, or above expectation) and the second helps the author to set proper thresholds. During this process, the system will employ supervised training methods to construct one or more machine learning models that will be used to convert sensor data into concept performance levels. Throughout the sensor modeling process, the authoring agent acts as the expert coach and provides analytical feedback on the estimated model accuracy. A sample dialog with the authoring agent is depicted in Figure 7.

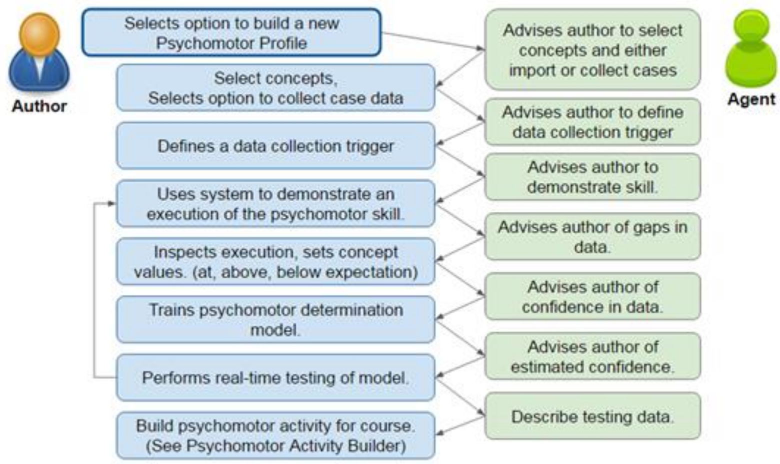

Figure 7. Authoring agent dialog to build a psychomotor profile using Machine Learning

Promoting Reusability

Several practices can improve the affordances for reuse. PSTAAT will leverage existing GIFT Cloud components and workflows, e.g., the "Adaptive Courseflow" course object in the Course Creator. PSTAAT will in addition offer reusable instructional approach templates, instructional feedback templates, and psychomotor profiles. The psychomotor activity course object provides template and profile management features for this purpose. PSTAAT will provide built-in templates, some extracted from the exemplar ITS. PSTAAT users will also have the ability to create new custom templates and profiles. Reuse is extended beyond a single course through export and import of templates and profiles.

The authoring agent can encourage the practice of reusing templates and course objects through properly sequenced guidance and the availability of convenient export/import options. The agent can provide examples and guidance on how to organize concepts to improve prospects for reuse. Similarly, when the authoring agent auto-generates portions of an ITS, the components will be assigned predictable, human-readable names that can be used to interpret pedagogical phase, concept, and sensor associations. Consistent naming conventions and the use of common web standards will ease the overhead associated with maintenance of the PSTAAT ITS as well as the interpretation of completed ITS course files.

INTEGRATION

PSTAAT will contribute to GIFT a new authoring component called a *psychomotor activity* course object, which can be dragged into a course flow like any other course object. This component will be designed to utilize existing Course Creator authoring elements and to provide a contextual authoring agent. This agent will guide the user through the creation of psychomotor activities and psychomotor profiles via a sequence of guided dialogues appearing in the Contextual Help panel (Figure 8).

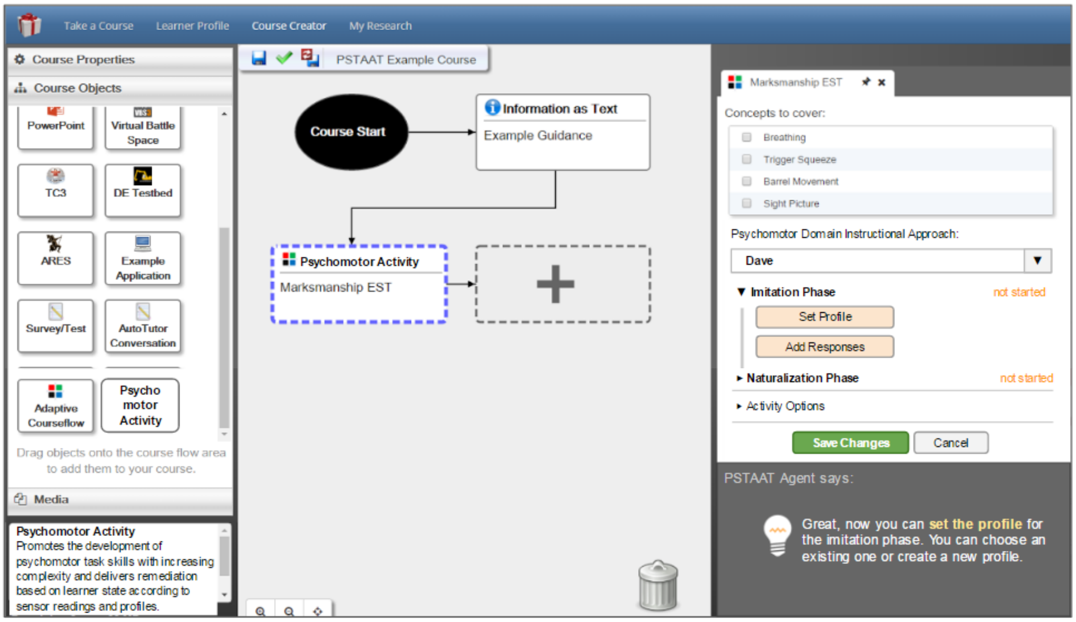

Figure 8: UI integration of the Psychomotor Activity Course Object

A psychomotor activity will be associated with a psychomotor instructional approach, one or more psychomotor profiles, and any content associated with instructional strategies to be used for remediation. Additional configuration steps may be necessary as the ITS design unfolds, as the author incorporates additional GIFT components (e.g., natural language dialogue) as part of an instructional strategy.

A psychomotor profile is composed of links to a set of sensors, a set of concepts, configuration settings related to the capture of a psychomotor event (e.g., "capture the last second when the trigger is pressed"), a psychomotor logic model that interprets captured sensor data and assigns values to concepts, and links to cases used in training the psychomotor logic model. The agent will be composed of a set of dialogue screens that, based on user input and the state of the ITS, will guide the user through the entire psychomotor activity creation process (Figure 9). The agent will be informed of the addition and use of sensors, concepts, the creation and training of a psychomotor profile, and the configuration of the psychomotor activity, including the inclusion of instructional strategies.

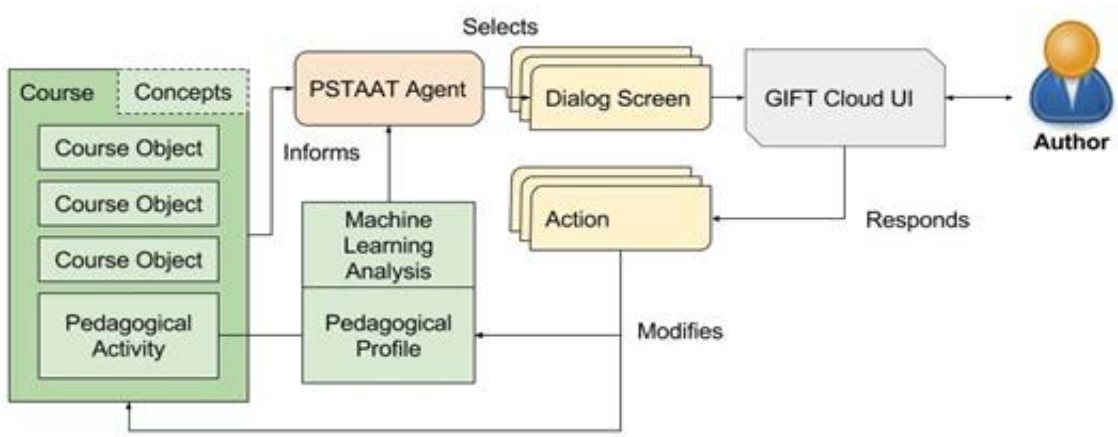

Figure 9: PSTAAT Agent Functional Block Diagram

CONCLUSIONS AND FUTURE RESEARCH

PSTAAT embodies a number of decisions made to reduce the cognitive complexities and costs associated with ITS development, to improve prospects of reuse, and to provide contextual knowledge and guidance relevant to psychomotor task instruction. Several features new to GIFT are being introduced in PSTAAT including: an activity preview feature, the abstraction of sensor configurations into reusable profiles; an agent-guided instructional design workflow; the use of templates to represent lower-level design components like psychomotor instruction and feedback; and lower-level design component management.

PSTAAT is currently addressing psychomotor skills that can be readily practiced through one or more simple sensors, or systems that can be reduced to simple sensors. Complex, sequential psychomotor skills will require more models, a wider set of sensors, and robust machine learning such as the use of Recurrent Neural Networks, Deep Learning, and other techniques that capture and interpret a wide range of input.

Currently, GIFT does not provide a generalized template management service that could be used across all of its interface objects and components. Such a service would potentially facilitate future expansion in object variety as well as user-customized objects. Similarly, since the authoring tool does not run in the the GIFT course delivery environment, native support for intelligent agents is not present while authoring. The PSTAAT team is exploring the use of a generalized performance support system. Performance support templates could encapsulate tool workflow and domain knowledge organized by user state and could be used to select appropriate feedback. Such an approach could provide a simple, common method of providing guidance that is not dependent on traditional, real-time intelligent agent architecture and services. The PSTAAT psychomotor activity course object will implemenet localized versions of these features, but it is our hope that the capabilities could be generalized across GIFT tools in the future.

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