Incorporating psychomotor skills training into GIFT tutors: "outside the box" authoring support

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INTRODUCTION

The Generalized Instructional Framework for Tutoring (GIFT) is enabling training developers to create diverse and effective Intelligent Tutoring Systems (ITS) in support of a broad array of U.S. Army training needs. GIFT-enabled technology initiatives are developing new tools and methods for streamlining ITS development along numerous fronts. However, a general category of performance that is under-represented in ITS is skills falling within the psychomotor domain. Paradoxically, psychomotor skills are foundational to many of the competencies that compose the U.S. Army's vision for 21st Century Soldier Competencies as expressed in the Army Learning Model (ALM).

Although there has been steady improvement in GIFT tools, libraries and methods, development of tutors for skills falling within the psychomotor domain remains a challenge that designers must address with little support from GIFT or its contemporary authoring tools. Despite these challenge, a few examples have illustrated the promise of using ITS for psychomotor skills training in domains including marksmanship and tactical combat casualty care. The success of such demonstrations though has relied on significant investments of time by highly specialized training development and technology experts. In order to scale the production of training that incorporates psychomotor skills, ITS frameworks such as GIFT must support an author not only in creating the conventional elements of an ITS but also in interpreting information arriving from external sensors in a way that productively advances learning objectives.

The Psychomotor Skills Training Agent-based Authoring Tool (PSTAAT) is an agent-assisted ITS authoring tool for the GIFT framework. In this paper we present our approach to helping an author link psychomotor measures from external sensors with performance thresholds and with corresponding instructional feedback. We discuss the use of guided examples and the agent's encapsulated knowledge of psychomotor ITS authoring. We also introduce a new machine learning-based approach that analyzes sensor data to recommend performance ranges. We conclude with an example authoring interaction.

PSYCHOMOTOR SKILLS: INSTRUCTIONAL CHALLENGES

Psychomotor skills have properties that are distinctive from skills training in other domains (cognitive and affective, Bloom, et al., 1956). Psychomotor skills involve movement and coordination but generally de-emphasize verbal processes. Tasks like fast-roping, applying a tourniquet, flying a CH-47, aiming a weapon, or traversing a chasm illustrate the prevalence and military relevance of psychomotor skills.

Psychomotor skills typically include physical movement, coordination, and use of gross, fine, or combined motor-skills. Learning these skills (like all learning) requires practice. Tutoring systems to train psychomotor skills would thus emphasize practice of some kind, opportunities for skill performance with coaching and feedback, and assessed skill demonstration. However, tutoring systems in this domain of learning must accommodate the distinctive metrics for assessing performance of psychomotor skills (e.g., speed, force, precision, distance, technique).

Another differentiating property of psychomotor skills is the process involved in mastery – i.e., the stages of skill acquisition. Adopting a process model is important to authoring because it helps structure the authoring dialogue. Our model draws from multiple researchers who generally follow Bloom's basic tenets. From theories advanced by Dave (1970), Simpson (1972), Harrow (1972), and Romiszowski (1999), we adopted a simplified synthesis of psychomotor skill learning suitable for organizing the PSTAAT authoring process (Brown, Bell & Goldberg, 2017), summarized in Table 1.

Table 1. Psychomotor skill model synthesized by comparing multiple research models.

Level	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	Trying a specific physical activity over and over.	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 the physical activity in order to perfect it.	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.

The authoring interactions in PSTAAT thus support creating activities for a learner progressing through observing, imitating, practicing and adapting. This analysis established a foundation for developing an agent to support the authoring of simulation-based ITS focused on psychomotor skills as discussed next.

PSYCHOMOTOR SKILLS: AUTHORING CHALLENGES

While successful development efforts have demonstrated that ITS are an effective approach to training psychomotor skills, developing these systems remains a costly and time-consuming enterprise. ITS authoring tools are limited in scope, capability, and generalizability, so the time, expertise and resources needed to create ITS persist. In contrast to general-purpose authoring tools, however, tools that address the development of a specific kind of ITS can be more powerful because they embody (and help authors adhere to) a set of assumptions about what the authored product will look like and how it will behave. PSTAAT is representative of a more specific tool, supporting authoring with an agent that encapsulates knowledge useful in guiding the authoring process, to include pedagogical knowledge tailored to instruction in, and assessment of psychomotor skills.

Psychomotor skills can be distinguished from cognitive skills because they involve movement and coordination, typically composed of physical movement, coordination, and use of gross, fine, or combined motor-skills. Because psychomotor skills are not inherently suited to be trained in conventional computer-mediated learning environments, developing ITS that incorporate psychomotor skills training presents several distinctive challenges. Motor skill elements of a psychomotor skill must be practiced using a physical device, such as rudder pedals, a firearm, or a tourniquet. Physical devices that capture and digitize motions and actions have demonstrated the ability to replicate, to varying levels of fidelity, user effects in a simulated environment in domains including flying, driving, performing medical procedures, and firefighting.

Training, however (in contrast to simulation), requires the additional capability to interpret performance from the stream of digital data flowing from the physical device. The ITS author must therefore be able to construct ways for the tutor to make sense of the data captured by a sensor. This presents specific challenges to the author, who must: (1) identify which among the specific data points sampled by the physical device should be attended to as indicators of expert versus novice performance; (2) calibrate each data source, in order to associate numerical data with performance markers; (3) define assessment and feedback associated with specific performance tiers; and (4) accommodate variable performance thresholds in cases where context can alter assessment thresholds.

For training psychomotor skills, the primary factor for mastery is practice. Psychomotor skills tutoring should thus emphasize opportunities to practice physical skills with coaching, feedback, and assessment. The author must also consider the nature of performance metrics for psychomotor skills; measures such as speed, precision, distance, or technique might have to be monitored. The ITS author is thus faced with the complex task of correlating data from physical devices with multiple and composite performance metrics.

PSYCHOMOTOR SKILLS: ASSESSMENT CHALLENGES

To help an author apply the appropriate performance ranges associated with the use of a physical device, we introduce a new machine learning (ML) approach that analyzes and classifies sensor data. The ML algorithms automate the detection of sensor thresholds (e.g., detecting the difference between Expert and Novice performance) based on expert feedback. The ML algorithm processes raw sensor data using sensor-appropriate scripts and integration with appropriate machine learning libraries through a Spark instance. Leveraging RapidMiner integrations with GIFT, it is also possible to bypass or adjust automated sensor threshold detection through direct adjustment of ML models. The ML algorithm applies a range of possible models to the test data generated in the performance modeling phase (or provided directly by the author), and attempts to determine the 'best-fit' model for a given combination of sensors and a given performance metric outcome or expertise level.

The ML model uses the data imported from cases to learn one or more reward functions that characterize and explain expert behavior, using Inverse Reinforcement Learning (IRL); and to learn to distinguish expert behavior from novice behavior (i.e., clustering). Once the training data set has produced an ML model, we use it to auto-generate the logic model. The logic model then evaluates performance during task execution. If desired, the ML model can also be an additional source of feedback on how to improve performance (e.g., "reduce breathing rate during the latter half of task performance"). Figure **1** illustrates the steps in the creation and use of the ML model.

EXTENDING GIFT WITH PSYCHOMOTOR AUTHORING

PSTAAT is designed to work within the Army Research Laboratory (ARL) Generalized Instructional Framework for Tutoring (GIFT) (e.g., Sottilare, 2012; Sottilare, Goldberg, Brawner & Holden, 2012). PSTAAT is thus an extension to GIFT that supports the authoring of psychomotor skills specifically, and that leaves to the broader GIFT environment support for authoring skills in the cognitive domain.

PSTAAT uses an exemplar ITS to provide relevant illustrations for authoring and to inform the design of the authoring tool itself. This exemplar, the Adaptive Marksmanship Trainer (AMT), was created in the GIFT to enhance an existing Engagement Skills Trainer (EST) that uses instrumented emulators of several types of firearms. AMT enhances this system by incorporating adaptive tutoring and automated performance measures (Goldberg, Amburn, Brawner & Westphal, 2014).

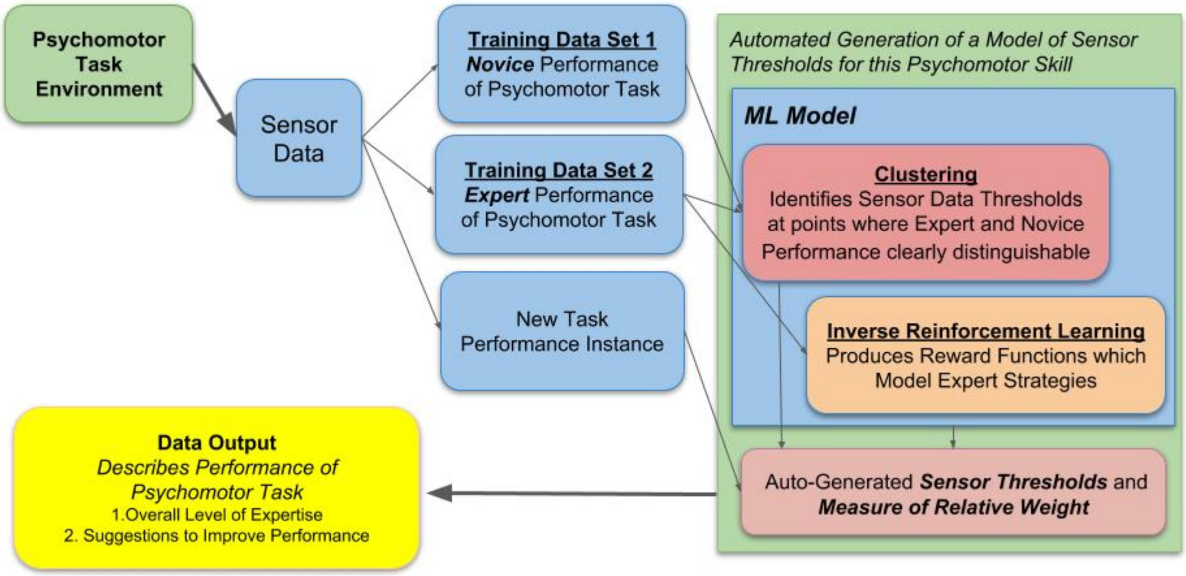

Figure 1. Steps in creation and application of machine learning model.

An initial step of the authoring dialogue is to instantiate the instructional model (recall Table 1). The author may incorporate some or all of the phases of the model for the psychomotor instruction being developed. Within each phase the author specifies the psychomotor activities to be performed by linking to a corresponding training application (e.g., a Unity application incorporating a backhoe emulator).

To help the author conceptualize the mapping from device outputs (e.g., a trigger squeeze, an aim point) to performance assessment for any given activity (external simulation), we adapt from AMT a layered mapping to associate sensor outputs with skill metrics, mediated by a middle layer that encapsulates the mechanisms for analyzing input data to determine a performance threshold. Figure 2 shows the layers using the exemplar ITS sensors and skills. This abstraction helps an author focus on mapping sensor data (top layer) to skill performance (bottom layer). The processing of those inputs (done by performance profiles, middle layer) is defined by the author and guided by PSTAAT to create adaptive, contextual feedback specific to the learner's detected performance (currently, above, at, or below expectation).

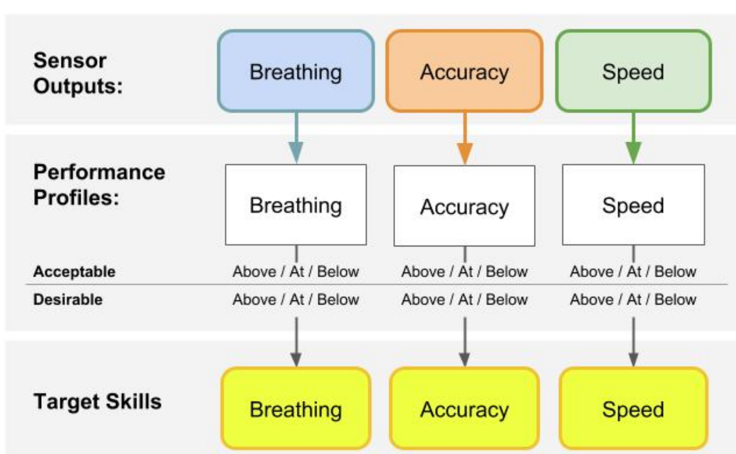

Figure 2. Example of layered mapping of sensors to skills, mediated by performance profiles.

GIFT IMPLEMENTATION

To provide psychomotor domain-specific authoring support, PSTAAT introduces a Psychomotor Activity Course Object to the GIFT Course Creator. A course object is an element that can be selected from a panel of supported types and added via a drag-and-drop authoring interface to a course flow sequence being created in the Course Creator. Each type of course object represents a different method of presentation and/or interaction with the learner and can be combined in any order in a course sequence. The PSTAAT extension, called the Psychomotor Activity Course Object, is depicted in Figure 3.

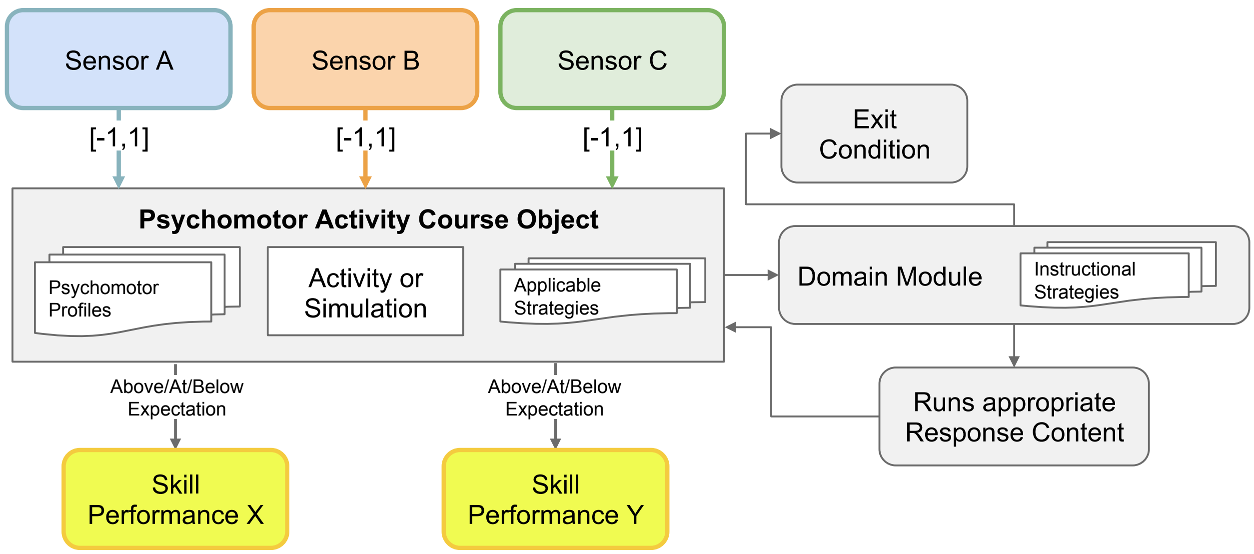

Figure 3. Schematic diagram of PSTAAT course object for mapping sensors to target skills

When a Psychomotor Course Object is added to the Course Creator, PSTAAT auto-generates a GIFT-compliant template, organized by the phases of the psychomotor domain (Observe, Imitate, Practice, Adapt). For each phase, the author selects a performance profile (that related sensor outputs to skill performance). At this point, the author can choose an existing profile, modifying it if desired, or create a new profile, a process discussed later. Once each phase is configured with a selected psychomotor profile, the PSTAAT agent auto-populates the psychomotor activity with placeholder learner states and guides the author through development of instructional strategies to complete the tutor.

To define a psychomotor activity, an author selects configured sensors as inputs and defines adaptive content delivery for the configured target skills. This adaptive behavior is defined by associating tailored feedback with corresponding performance levels calculated by a Psychomotor Profile (Figure 4). A Psychomotor Profile processes data from active sensor feeds to derive measures of performance (using an above/at/below expectation scale). The algorithms driving this assessment are informed by cases – previously generated data captured from subjects performing a task and tagged with performance outcomes. During data capture, data is tagged in one of two ways; either by an objective measure of task performance (e.g., a score generated automatically by the task environment) or by a subjective, human labeling of task performance (e.g., an expert observer determining that a given instance of the task performance was “above” expectation).

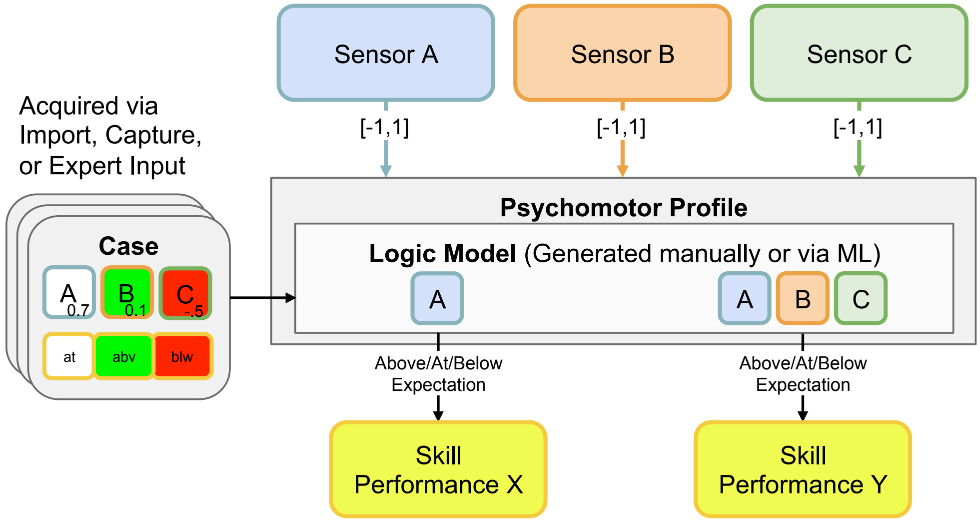

Figure 4. Schematic showing detail of the Psychomotor Profile.

PSTAAT thus manages the authoring dialogue in three segments: skills profiling, sensor mapping, and course object definition (i.e., activities, sequencing). The PSTAAT authoring agent provides contextual authoring support for each of these general-purpose task areas, and recommends the use of psychomotor domain instructional approaches and adaptive feedback strategies in the form of templates and examples.

EXAMPLE INTERACTION

A brief example illustrates an authoring interaction. For brevity we omit preceding steps typical in the GIFT Course Creator unrelated to PSTAAT. The author first chooses a preferred instructional model, skips the Observing phase, and selects an existing performance profile for the Imitating phase (Figure 5).

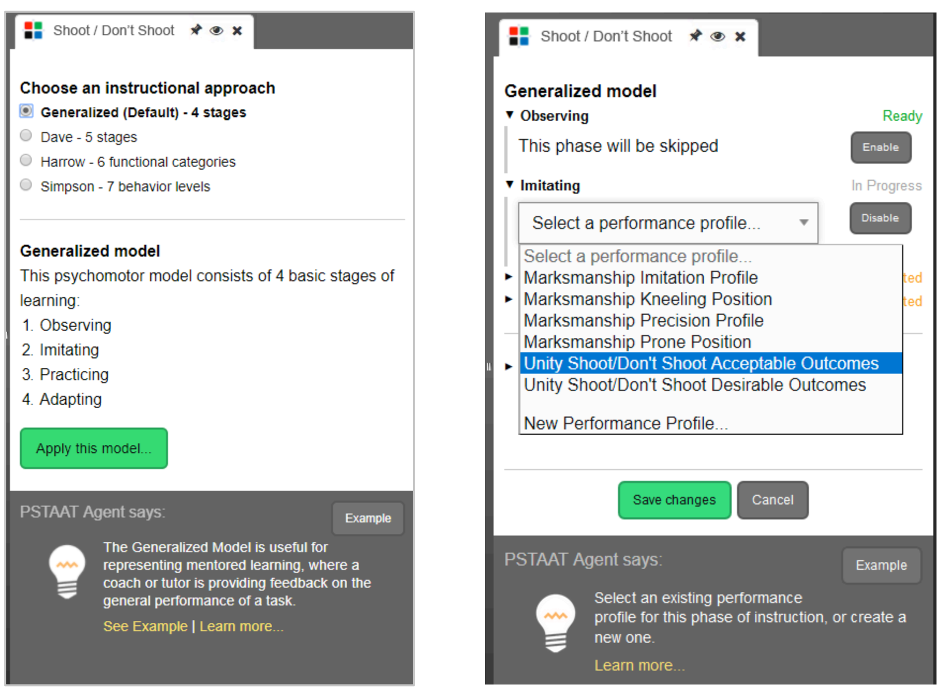

Figure 5. Selecting an instructional model and assigning performance profiles to each phase.

The author then adds instructional feedback and remediation for the selected performance profile (Figure 6). At any time, the author may edit the threshold values internal to a performance profile. Figure 7 illustrates threshold values for different performance tiers for a given device displayed. From this editor, the author can modify this configuration, add sensors, and link this profile with an external application.

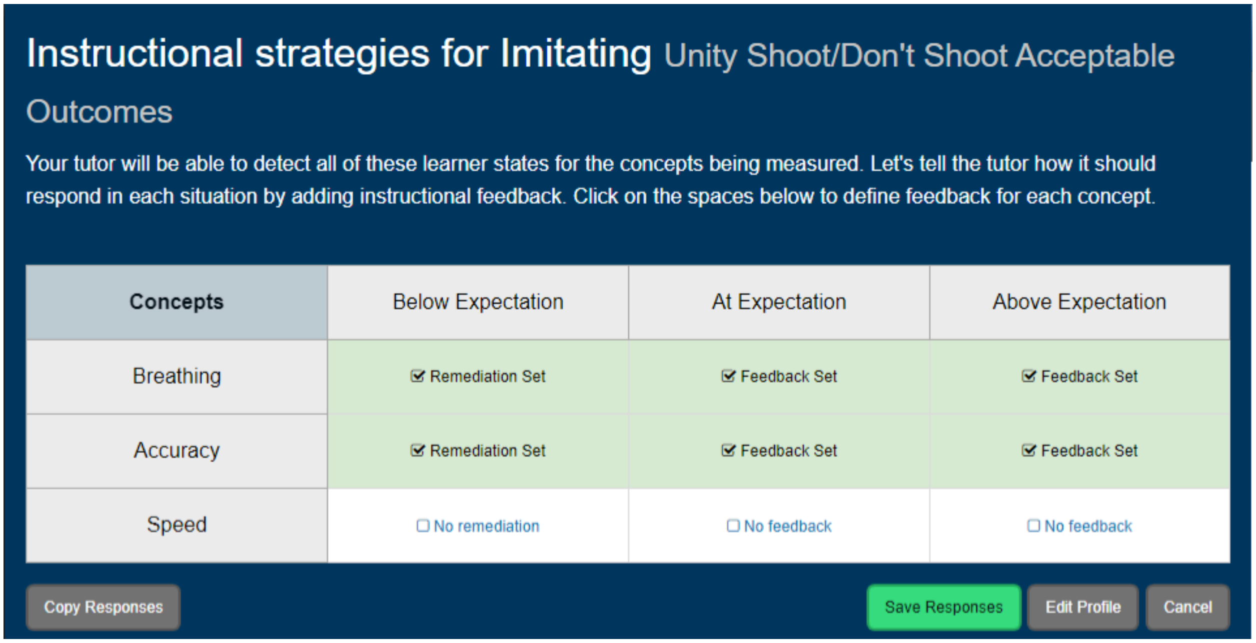

Figure 6. Assigning feedback and remediation for a selected performance profile.

CONCLUSIONS AND FUTURE RESEARCH

Streamlining ITS authoring remains an elusive goal, but steady progress in tools and frameworks such as GIFT are bridging this gap. For ITS that train psychomotor skills, authors face additional challenges. To support the integration of external training simulations and corresponding physical devices with a tutoring system, PSTAAT demonstrates an agent-driven system that employs templates, editors, and sensor data processing via machine learning-derived assessments. When fully integrated, PSTAAT will expand the reach of ITS authors by enabling them to incorporate psychomotor skills training along with cognitive skills training, cultivating a richer diversity of training applications emerging from the GIFT community.

PSTAAT demonstrates 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.

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.

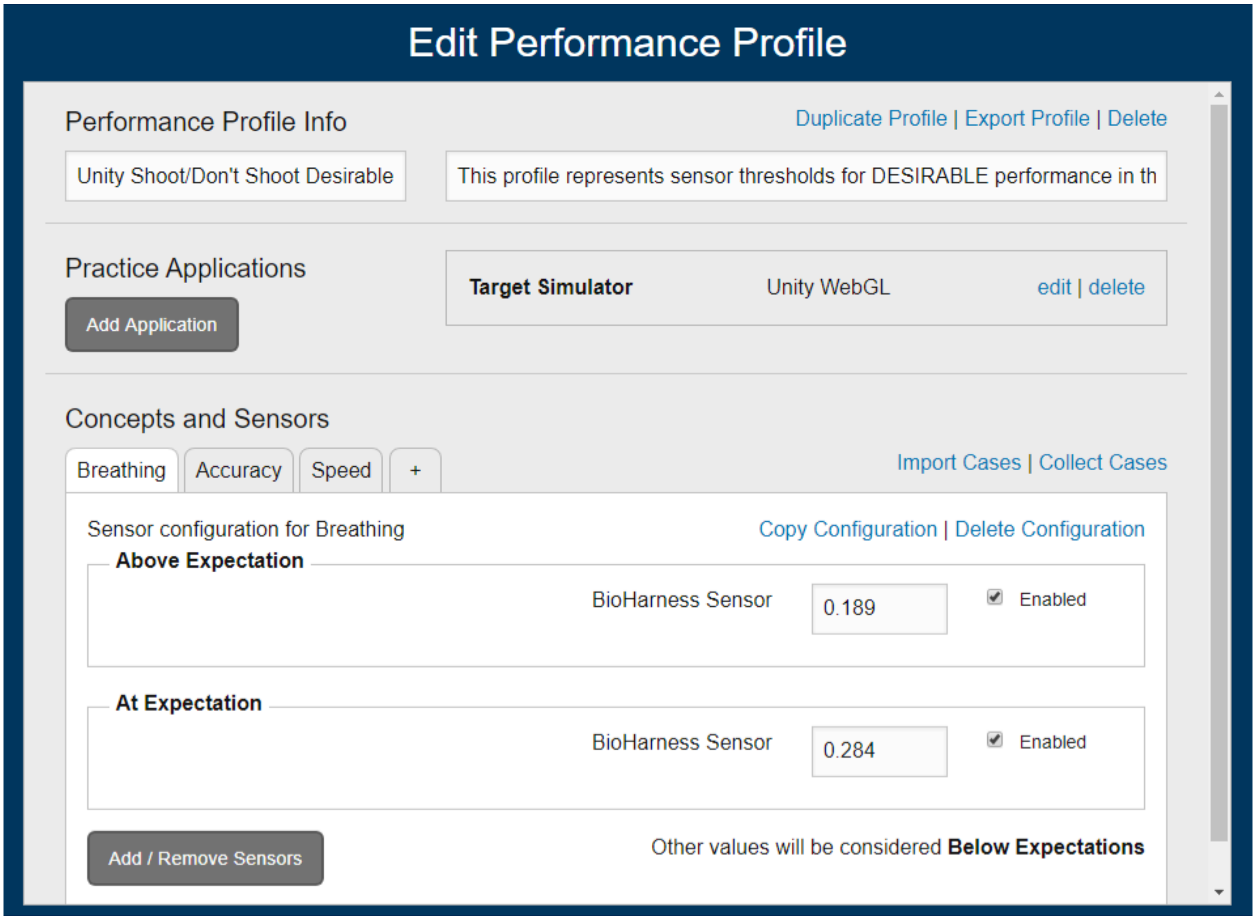

Figure 7. Performance Profile editor for viewing/modifying performance thresholds and adding sensors.

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